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EVALUATING THE ENERGY SECURITY IMPACTS OF ENERGY POLICIES

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Introduction

For policymakers, the term “energy security” refers mostly to assured access to oil, coal, and gas. This conventional energy security concept, however, has become less useful to policy formation due to increasingly global, diverse energy markets combined with emerging, energy-related transnational problems (such as acid rain). Moreover, a policy-oriented rationale for “energy security” must also encompass global issues such as climate change and many other economic, technological, and international security considerations. As a consequence, a more comprehensive operating definition of “energy security” is needed, along with a workable framework for analysis of which future energy paths or scenarios are likely to yield greater energy security in a broader, more comprehensive sense.¹

Defining energy security

Many of the existing definitions of energy security begin, and usually end, with a focus on maintaining energy supplies – and particularly supplies of oil.² This supply-based focus has as its cornerstones reducing vulnerability to foreign threats or pressure, preventing a supply crisis (including either or both of restrictions in physical supply or an abrupt and significant increase in energy prices) from occurring, and minimizing the economic and military impact of a supply crisis once it has occurred. Current national and international energy policies, however, have been facing many new challenges, and as such need to have their effectiveness judged by additional criteria. This broader array of criteria needs to be considered as a key component of new energy security concepts.

Why has oil been the primary focus of energy security policy? There are good reasons behind this particular focus. First, oil is still the dominant fuel (~35 percent) in global primary energy supply (as of 2008³). Second, the Middle East, where the largest oil reserves exist, is still one of the most unstable areas in the world. Third, and related to the second reason, oil supply and prices are often influenced by political decisions of oil suppliers and buyers. Fourth, world economic conditions, as aptly demonstrated in the last several years, are still vulnerable to oil price volatility, since there are certain key sectors that are heavily dependent on oil (such as transportation,

petrochemicals, agriculture, and others), with limited short-term alternatives for substitution. Fifth, the key words here are “volatility” and “instability.” Although globalization has improved the transparency of the oil market, oil prices remain to some extent at the mercy of speculators, as well as being affected by fluctuations in currency values, subject to manipulation by oil suppliers and, of course, sensitive to the forces of market supply and demand (for a discussion of the impact of speculation on the oil market, see Harris⁴). This has been dramatically shown recently, with oil prices roughly doubling between mid-2007 and mid-2008, followed by a 75 percent decline in price by early 2009, followed by a return to Fall 2007 price levels by early 2010.⁵

Few works have made a serious attempt to clarify the concept of energy security. One attempt at a clear definition of energy security was that by the Working Group on Asian Energy and Security at the Massachusetts Institute of Technology’s (MIT) Center for International Studies. The MIT Working Group defined three distinct goals of energy security:⁶

1. reducing vulnerability to foreign threats or pressure;
2. preventing a supply crisis from occurring; and
3. minimizing the economic and military impact of a supply crisis once it has occurred.

These goals implicitly assume that an “oil supply crisis” is the central focus of energy security policy. In essence, the central tenets of conventional energy security policy are: (1) reduction of threats to oil supply, and (2) operating in a mode of crisis management. These tenets constitute a shared view among key energy policymakers in both the East and the West.

Differences in energy security policies

If the above characterization of conventional energy security thinking is shared by the major energy consuming/importing countries, does this mean that there are no critical differences in energy security policy among them? No. Although many countries share the above broad characteristics, it is also true that there are significant differences. What are the differences and why do they exist? One important factor is, of course, natural and geopolitical conditions. One country might have abundant natural resources and another might not. Some consumer countries are located close to energy-producing countries, while some are distant and thus need transportation of fuel over long distances. Those conditional differences can lead to basic differences in energy security perceptions.

In sum, there are three major attributes that define the differences in energy security thinking between countries: (1) the degree to which a country is energy resource-rich or energy resource-poor, (2) the degree to which market forces are allowed to operate as compared with the use of government intervention to set prices, and (3) the degree to which long-term versus short-term planning is employed.⁷ Despite these differences in thinking, however, energy policies in both resource-poor countries and resource-rich countries are arguably converging, as both types of countries recognize the need to face a new paradigm in energy policy.

Emerging paradigm: toward comprehensive energy security

National energy policies in the new century are facing challenges on multiple fronts. The substance of these challenges needs to be incorporated into a new concept of energy security. It is important to note here that energy security policies in various countries are now showing trends of “convergence” rather than “divergence,” despite the basic differences in concepts of energy security as discussed above. This convergence does not eliminate regional and national differences, of course, but it is an encouraging sign with regard to minimizing the potential conflict that may

come from differences in energy security concepts, as reflected in the different energy security policies that countries adopt.

The following is a quick review of the major challenges that will help to bring about a new energy security concept.

Environment

Perhaps the most serious challenge to traditional (supply–security-oriented) energy policy thinking is the need to protect the environment. If environmental problems are to be solved, energy policies will have to be reformulated. International environmental problems present the greatest impetus for change. Two international environmental problems inherently linked with energy consumption, in particular fossil fuel consumption, are acid rain and global climate change.⁸ Transboundary air pollution (acid rain) has been an international issue in Europe and North America, is a developing issue in East Asia, and even has trans-Pacific elements.⁹

Global climate change poses an even broader and more complex challenge to energy policy than transboundary air pollution. Although there are relatively straightforward (though often not cheap) technical solutions – including flue gas desulfurization devices – to reduce the emissions of acid rain precursors, greenhouse gas emissions cannot so easily be abated by “end-of-pipe” methods. A comprehensive approach toward greenhouse gas emissions is necessary. The climate change issue also brings in a much longer time perspective than business and governments are used to dealing with. Other environmental issues, such as radioactive waste management, also require long-term perspectives. In sum, environmental issues must be incorporated into the energy security concept.¹⁰

Technology

Risks associated with development and deployment of advanced technologies challenge current energy policy thinking. Conventional thinking understates such risks and tends to see them as short term, not long term. Risks include nuclear accidents such as those at Three Mile Island in the United States (1979) and Chernobyl in the former Soviet Union (1986), natural disasters with impacts on energy infrastructure (such as Hurricane Katrina’s impacts on oil and gas production in the Gulf of Mexico, and the impact of the July 2007 earthquake near Niigata, Japan on the seven-unit Kashiwazaki-Kariwa nuclear plant), and the failure of R&D efforts (such as the synthetic fuel, fast breeder reactor, and solar thermal programs in the US during the 1970s and 1980s) to perform as expected. Technological risks can be transnational; the accident at Chernobyl is a good example of an incident with decidedly cross-boundary implications. Also, markets for advanced technologies are becoming global and, as a result, technological risks can be exported. Nuclear technology, for example, is being exported to a number of developing countries, most notably China and India, but also potentially including Vietnam, Indonesia, Thailand, Pakistan, and Malaysia,¹¹ as well as Middle Eastern nations including the United Arab Emirates.¹² As the world moves rapidly toward a “technology intensive” energy society, a new energy security concept must address the various domestic and international risks associated with advanced technologies.

Demand-side management

Another challenge to energy policy thinking is the need to address energy demand itself. Conventional energy policy seeks to assure supply while assuming that demand is a given. This notion has been changing since the mid-1980s, when the concept of demand-side management

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(DSM) was first incorporated into energy planning. Now, management of energy demand is almost on an equal footing with management of supply – new technologies such as distributed generation and “smart grids,” in fact, blur the distinction between demand and supply – and is recognized as a key tool in the achievement of climate change mitigation and other environmental goals. DSM does not, however, eliminate uncertainties that are inherent in energy policy planning. Unexpected demand surges and drops occur depending on, for instance, changes in weather patterns and economic conditions.

There are risks associated with energy demand just as with supply. Conventional energy policy thinking has tended to underestimate demand-side risks. Risks stem from, for example, demand surges (periods of peak demand in response to extreme conditions). These are a serious concern for utility management, but managing peak demand is not easy, particularly given uncertainties in consumer behavior. Long recessions are another major concern for energy industry managers, since recession means large supply capacity surpluses. Uncertainty (risk) in the demand-side of the total energy picture is therefore a key component of a new concept of energy security.

Social-cultural factors

“Not in my backyard” (NIMBY) and environmental justice concerns are becoming global phenomena, making it increasingly difficult, time-consuming, and costly to site “nuisance facilities” such as large power plants, waste treatment and disposal facilities, oil refineries, or liquefied natural gas terminals (for example). Although people may recognize the need for such facilities, many communities prefer not to have the actual plants in their neighborhood. Opposition to plant siting has elevated the importance of local politics in energy policy planning. Who has the right to decide where to locate such facilities? Who has the right to refuse? Can any rational policymaking process satisfy all stakeholders? These questions pose not only a challenge to energy security policy, but also to democratic institutions themselves. NIMBY epitomizes the “social and cultural” risks that need to be recognized in policymaking agendas. Various social-cultural factors present a challenge to current energy policy thinking.

There are “enviro-economic” concerns as well. It is often the case that the party who bears the risk should get economic compensation. But how much compensation is reasonable, and who should be qualified to receive such compensation? These issues are often difficult to decide.

Public confidence is also a social factor influencing energy policy; once lost, it is hard to recover. “Public confidence” should be distinguished from “public acceptance,” which is commonly used in traditional energy policy thinking. Promoting public acceptance is often the object of public relations campaigns. Promoting public confidence involves more than public relations. Examples of efforts to increase public confidence in energy decisions include, for example, efforts by the US Department of Energy (DOE) to increase information disclosure, as well as the effort by the Japanese government to make the nuclear policymaking process more transparent (for instance, by holding roundtable discussions). Accounting for social-cultural factors and increasing public confidence in energy choices are therefore central components of a new concept of energy security.

International relations – military

New dimensions in international relations and new military risks are challenging traditional energy policymaking. The end of the Cold War has brought in its wake a new level of uncertainty in international politics. Although the risk of a world war has been drastically reduced, the threat of regional clashes has increased, as demonstrated by ongoing conflicts in the Middle East, the Balkans, and the former Soviet states of the Caucasus, to name just a few. The international

politics of plutonium fuel-cycle development, with its associated risks of nuclear terrorism and proliferation, remains an area where energy security and military security issues meet. The brave new world of post-Cold War international relations must be accounted for in a new concept of energy security.

Comprehensive concept of energy security

The above five key components – environment, technology, demand-side management, social and cultural factors, and post-Cold War international relations – are central additions to the traditional supply-side point of view in a new comprehensive energy security concept.

A nation state is energy secure to the degree that fuel and energy services are available to ensure: (a) survival of the nation, (b) protection of national welfare, and (c) minimization of risks associated with supply and use of fuel and energy services. The five dimensions of energy security include energy supply, economic, technological, environmental, social and cultural, and military/security dimensions. Energy policies must address the domestic and international (regional and global) implications of each of these dimensions.

What distinguishes this energy security definition is its emphasis on the imperative to consider extra-territorial implications of the provision of energy and energy services, while recognizing the complexity of implementing national energy security policies and measuring national energy security. The definition is also designed to include emerging concepts of environmental security, which include the effects of the state of the environment on human security and military security, and the effects of security institutions on the environment and on prospects for international environmental cooperation.¹³

Sustainability and sustainable development

As environmental and other considerations, apart from energy supply, play increasing roles in the development of energy policies, in both industrialized and developing nations, the concepts of sustainability and sustainable development are becoming intimately entwined with the goals of energy policy. An understanding of what these concepts mean, and what they may mean for energy security, is therefore helpful.

Sustainability

A strict definition of sustainability is as follows:¹⁴ “A sustainable process or condition is one that can be maintained indefinitely without progressive diminution of valued qualities inside or outside the system in which the process operates or the condition prevails.” Further, from a biophysical perspective, sustainability means “maintaining or improving the life support systems of earth.” Due to recent “intense and pervasive” human activity, “biophysical sustainability must, therefore, mean the sustainability of the biosphere minus humanity. Humanity’s role has to be considered separately as economic or social sustainability. Likewise, sustainable development should mean both sustainability of the biophysical medium or environment and sustainability of human development, with the latter sustaining the former.”

Sustainable development

As defined in the report of the 1987 World Commission on Environment and Development, sustainable development is “development that meets the needs of the present without

compromising the ability of future generations to meet their own needs.”¹⁵ Other recent definitions of this concept have spanned the range from “corporate sustainability,” meaning “responsible environmental and labor management practices” in business, to a definition of sustainable development that includes “a vast, diverse set of goals, such as poverty elimination and fair and transparent governance.”¹⁶

Like ensuring energy security, pursuing sustainable development includes addressing numerous, often conflicting issues, including¹⁷ human poverty, impoverishment of the environment, the possibility of wars on all different spatial scales, oppression of human rights, and wastage of human potential. The forces driving these issues – which are also forces affecting energy security – include excessive population growth, poor distribution of consumption and investment, misuse of technology, corruption and mismanagement, and lack of knowledge/power on the part of victims.

Though sustainable development, arguably, will never have a single, clear definition, as “sustainability” depends on what is being sustained and “development” depends on the desired outcomes, it is clear that achieving sustainable development, like enhancing energy security, depends on addressing a variety of economic, social, and environmental goals – and these goals are often in conflict.

There are sustainable development/energy security challenges related to actually accomplishing the goals of sustainable development policies. For example, Smil¹⁸ underlines some of the formidable challenges involved in replacing fossil fuels with renewable fuels to move toward sustainable development, including the scale of the shift in fuel use required, the relative energy and power densities of fossil versus renewable fuels and power systems, the intermittency of many renewable fuels, and the geographical distribution of renewable resources relative to where fossil fuels are currently used. These challenges may ultimately mean that a truly sustainable economy must actually produce less in the way of goods and services than our global economy does today, rather than using alternative resources to sustain or expand the existing level of output.

The International Atomic Energy Agency (IAEA), in cooperation with other agencies, has assembled a list of indicators for sustainable energy development.¹⁹ The IAEA list starts with a consideration of the economic, environmental, social, and institutional dimensions of sustainable development, and develops 30 different indicators, most with several subcomponents. Many of these indicators touch upon the issues and perspectives noted above, and many are reflected in the discussion of methods and parameters for evaluating energy security that are presented in the next section of this chapter.

No matter how it is defined and measured, sustainable development will require increasing understanding of the interlinked nature of environmental, social, and economic problems – as addressing single problems without consideration of linkages to other problems may be risky. Sustainable development – and addressing energy security – will also require increasing transparency in planning and decision-making of all types, particularly for large projects, and building human capacity (and societal support for such education) to ensure that the capabilities exist in all “stakeholder” groups (those affected by decisions) in order to address multifaceted problems and participate in planning processes.

Evaluating and measuring energy security

Given the multiple dimensions of energy security identified above, and the linkages/overlaps between energy security dimensions and the dimensions of sustainability and sustainable development, a framework for evaluating and measuring – or at least comparing – the relative attributes of different approaches to energy sector development is needed. Such a framework should be

designed to help to identify the relative costs and benefits of different “energy futures” – essentially, future scenarios driven by suites of energy (and other social) policies. Below we identify some of the policy issues associated with the dimensions of energy policy presented earlier, and present a framework for evaluating energy security, as broadly defined.

An energy policy conceptual framework

A listing of each dimension of energy security – broadly defined as above – is provided in Table 3.1, which also offers a sampling of the policy issues with which each dimension of energy security is associated. The two right-hand columns of Table 3.1 provide examples, many drawn from the energy security approaches described above, that might be used to address the types of “routine” and “radical” risk and uncertainty that are faced in the planning, construction, and operation of energy systems. It should be noted that while Table 3.1 provides what is intended to be a broad, but by no means complete, list of policy issues, even the categories shown are often not necessarily independent. Certain energy technologies will be affected by climate change (hydroelectric power and inland nuclear power plants, for example, may be affected by changes in water availability), and there are many other examples of interdependence that need to be carefully thought through in a full consideration of the energy security impacts of candidate energy policies.

Testing the energy security impacts of different energy scenarios

Given the broad definition of energy security provided above, how should a framework for evaluation of energy security impacts of different policy approaches be organized? Some of the challenges in setting up such a framework include deciding on manageable but useful level of detail, incorporation of uncertainty, risk considerations, comparison of tangible and intangible costs/benefits, comparing impacts across different spatial levels and timescales, and balancing analytical comprehensiveness and transparency. To meet these challenges, a framework was devised based on a variety of tools, including the elaboration and evaluation of alternative energy/environmental “paths” or “scenarios” for a nation and/or region (for example, with the LEAP²⁰ software tool used in the Asian Energy Security project), diversity indices, and multiple-attribute (tradeoff) analyses, as described below. Central to the application of the framework is its application to search for “robust” solutions – a set of policies that meet multiple energy security and other objectives at the same time.

The framework for the analysis of energy security (broadly defined) includes the following steps:

1. Define objective and subjective measures of energy (and environmental) security to be evaluated. Within the overall categories presented in Table 3.1, these measures could vary significantly between different analyses.
2. Collect data, and develop candidate energy paths/scenarios that yield roughly consistent energy services, but use assumptions different enough to illuminate the policy approaches being explored.
3. Test the relative performance of paths/scenarios for each energy security measure included in the analysis.
4. Incorporate elements of risk.
5. Compare path and scenario results.
6. Eliminate paths that lead to clearly suboptimal or unacceptable results, and iterate the analysis as necessary to reach clear conclusions.

Table 3.1 Energy security conceptual framework

Dimension/Criterion of Risk and Uncertainty Associated with Energy Security	Energy Security Strategies/Measures	Identification and Management of Radical Uncertainty
	Reduction and Management of Routine Risk	
1. Energy Supply	<ul style="list-style-type: none"> • Domestic/imported • Absolute scarcity • Technology/fuel intensive? • Incremental, market-friendly, fast, cheap, sustainable? • Cost-benefit analysis • Risk-benefit analysis • Social opportunity cost of supply disruption • Local manufacturing of equipment • Labor • Financing aspects • No regrets 	<ul style="list-style-type: none"> • Substitute technology for energy • Efficiency first • Technological breakthroughs • Exploration and new reserves
2. Economic	<ul style="list-style-type: none"> • Compare costs/benefits of insurance strategies to reduce loss-of-supply disruption • Investment to create supplier-consumer inter-dependence • Insurance by fuel (U, oil, gas, coal) stockpiling, global (IEA) or regional quotas (energy charters) 	<ul style="list-style-type: none"> • Export energy-intensive industries • Focus on information-intensive industries • Export energy or energy technology

Table 3.1 (continued)

<i>Dimension/Criterion of Risk and Uncertainty Associated with Energy Security</i>	<i>Energy Security Policy Issues</i>	<i>Energy Security Strategies/Measures</i>	<i>Identification and Management of Radical Uncertainty</i>
		<i>Reduction and Management of Routine Risk</i>	
3.	Technological	<ul style="list-style-type: none"> • R&D failure • Technological monoculture vs. diversification • New materials dependency in technological substitution strategies • Catastrophic failure • Adoption/diffusion or commercialization failure 	<ul style="list-style-type: none"> • Invest in renewables • Mixed oxide fuels recycling • Plutonium /fast breeder reactors • Uranium from seawater • Spent fuel management issues
4.	Environmental	<ul style="list-style-type: none"> • Local externalities • Regional externalities, both atmospheric and maritime • Global externalities • Precautionary principle 	<ul style="list-style-type: none"> • Ultimate nuclear waste storage • Risk-benefit analysis and local pollution control • Treaties • Mitigation • Technology transfer • Thresholds and radical shifts of state such as sea level rise and polar ice melt rate

- 5. Social–Cultural
 - Consensus/conflict in domestic or foreign policymaking coalitions
 - Institutional capacities
 - Siting and downwind distributional impacts
 - Populist revulsion or rejection of technocratic strategies
 - Perceptions and historical lessons
 - 6. Military–Security
 - International management of plutonium
 - Proliferation potential
 - Sea lanes and energy shipping
 - Geopolitics of oil/gas supplies
-
- Transparency
 - Participation
 - Accountability
 - Side payments and compensation
 - Education
 - Training
-
- Non-Proliferation Treaty regime
 - Terrorism and energy facilities
 - Status
 - Security alliances
 - Naval power projection
 - Transparency and confidence building
 - Terrorism
-
- Disposition and disposal of excess nuclear warhead fissile materials
 - Military options for resolving energy-related conflicts, securing infrastructure
-

Some of the possible dimensions of energy security, and potential measures and attributes of those dimensions, are summarized in Table 3.2. The table also includes, in its right-hand column, a listing of possible “interpretations” – that is, a listing of what direction in a given measure would typically indicate greater energy security. It should be noted that many of these dimensions and measures can and do interact – and a solution to one problem may exacerbate another. Formal or informal application of analytical methods such as “systems thinking” can be used

Table 3.2 Dimensions and measures/attributes of energy security

<i>Dimension of Energy Security</i>	<i>Measures/Attributes</i>	<i>Interpretation</i>
Energy Supply	Total primary energy	Higher = indicator of other impacts
	Fraction of primary energy as imports	Lower = preferred
	Diversification index (by fuel type, primary energy)	Lower index value (indicating greater diversity)
	Diversification index (by supplier, key fuel types)	Lower index value preferred (see above)
	Stocks as a fraction of imports (key fuels)	Higher = greater resilience to supply interruption
Economic	Total energy system internal costs	Lower = preferred
	Total fuel costs	Lower = preferred
	Import fuel costs	Lower = preferred
	Economic impact of fuel price increase (as fraction of GNP)	Lower = preferred
Technological	Diversification indices for key industries (such as power generation) by technology type	Lower = preferred
	Diversity of R&D spending	Qualitative–Higher preferred
	Reliance on proven technologies	Qualitative–Higher preferred
	Technological adaptability	Qualitative–Higher preferred
Environmental	GHG emissions (tonnes CO ₂ , CH ₄)	Lower = preferred
	Acid gas emissions (tonnes SO _x , NO _x)	Lower = preferred
	Local air pollutants (tonnes particulates, hydrocarbons, others)	Lower = preferred
	Other air and water pollutants (including marine oil pollution)	Lower = preferred
	Solid wastes (tonnes bottom ash, fly ash, scrubber sludge)	Lower = preferred (or at worst neutral, with safe re-use)
	Nuclear waste (tonnes or Curies, by type)	Lower = preferred, but qualitative component for waste isolation scheme
	Ecosystem and aesthetic impacts	Largely Qualitative–Lower preferred
Social and Cultural	Exposure to environmental risk	Qualitative–Lower preferred
	Exposure to risk of social or cultural conflict over energy systems	Qualitative–Lower preferred
Military/Security	Exposure to military/security risks	Qualitative–Lower preferred
	Relative level of spending on energy-related security arrangements	Lower = preferred

to assist in carrying out steps 4 and 5, above. These methods allow the interaction of the different elements of complex processes, and the way that those elements affect and feed back on each other, to be seen more clearly than if a pair of systems interactions are viewed independently.²¹

There is often a temptation, in step 5, to attempt to put the attributes of energy security into a common metric, for example an index of relative energy security calculated through a ranking and weighting system. We would recommend avoiding this temptation, as such systems almost invariably involve procedures that amplify small differences between paths/scenarios, play down large differences, and give an illusion of objectivity to weighting choices that are by their nature quite subjective. Instead, as described below, we recommend laying out the energy security attributes of each path/scenario side by side, which allows reviewers, stakeholders, and decision-makers to see the differences and similarities between different energy futures for themselves, and to apply their own perspectives and knowledge, in consultation with each other, to determine what is most important in making energy policy choices. Also not explicitly included in steps 5 or 6 are mathematical tools for optimizing energy security results over a set of paths or scenarios. Optimization can be attractive, as it appears to identify one “best” path for moving forward. Optimization models can in some cases offer useful insights, provided that the underlying assumptions and algorithms in the analysis are well understood by the users of the results. Optimization, however, like weighting and ranking, involves subjective choices made to appear objective, especially when applied across a range of different energy security attributes, and as such should be employed only with caution and with a thorough understanding of its limitations in a given application.

Development of paths/scenarios to test and evaluate future energy security impacts

An energy path or scenario describes the evolution – or potential evolution – of a country’s energy sector assuming that a specific set of energy policies are (or are not) put in place. The level of detail with which an energy path/scenario is described will be a function of the degree of realism required to make the path analysis plausible to an audience of policymakers, as well as the analytical resources (person–time) and data available to do the analysis. “Bottom-up” quantitative descriptions of energy paths offer the possibility to specify fuels and technologies used, as well as energy system costs and key environmental emissions, in some detail, but can require a considerable amount of work. Simpler econometric models (or models that combine econometric and end-use elements) can also be used, providing that model outputs can include measures of energy security like those presented above. A major criterion to keep in mind, when developing energy paths/scenarios, is that the paths chosen should be both reasonably plausible, yet different enough from each other to yield, when their attributes are compared, significant insight into the ramifications of the energy policy choices that the paths describe.

Some of the data requirements in defining an energy path/scenario can include:

- data on **current demand for and supply of fuels**, by sector, in the area (state, country, or region, for example) under study;
- existing **projections and scenarios** for the evolution of the **energy system** (over the next 15 to 30 years, for example) in the area;
- costs, applicability, availability, inputs, and efficiencies of the **technologies**, energy-efficiency measures, and fuels to be used in scenarios;
- information on **environmental impacts** expected (or derivation of impact estimates) from discrete levels of pollutant emissions (local, regional, and global);

- estimates of the **environmental costs of major accidents**, such as nuclear reactor meltdowns or major oil tanker accidents;
- existing methods for **ascribing costs to environmental impacts**;
- existing estimates of **climate change impacts** and their ramifications;
- existing scenarios and analysis of the likely **security impacts of proliferation** of nuclear power in the region;
- costs of **security arrangements**, including military hardware, armed forces readiness.

Of course, not all of the above information may be applicable to (or available for) a particular energy security analysis. Once the energy paths are specified, the next step is to evaluate the objective and subjective measures listed in Table 3.2 (or a similar set as defined by the researcher), or as large a subset of those measures as is practicable and desirable. In many cases, the use of economic models (or adaptation of existing results of such models) or other computational tools will be in order to perform measures evaluations.

Energy policy goals and problems to address in preparation of energy paths/scenarios

A key goal of energy policy is to improve energy security – whether broadly or narrowly defined – and thus to reduce existing (or looming) “energy insecurity.” Development (and modeling) of energy policies that accomplish this goal, at the global, national, or sub-national scales, begins with a review of the problems to be addressed, the attributes and inertias in the current energy system, and the likely determinants of the energy future that policies will hope to address. For example, problems to be addressed range from global climate change to local/regional/global air pollution, land and water resource stresses, war and other conflicts, nuclear weapons proliferation, and stresses on national and international financial systems, along with a daunting host of other issues. Inertias that must be reflected in energy paths include consideration of population growth, existing stocks of energy-using equipment and energy supply infrastructure, current patterns of energy consumption, and other existing trends among a host of factors contributing to the “momentum” of future energy supply and demand. Determinants of future energy use include those that are more predictable (but still, often, potentially addressed by policies), such as changes in demographics, changes in the need for energy goods and services, and changes in the intensity with which energy is used to produce goods and services. Less predictable determinants are those influences on energy supply and demand that are hard to predict with any degree of confidence at present, or that come as complete surprises, such as changes in resource scarcity, dramatic evidence of climate change (and/or abrupt changes in responses to climate change), conflict flare-ups in key energy supplier nations, acts of terrorism against energy systems, and major technological breakthroughs. These considerations shape future paths/scenarios for analysis.²²

Tools and methods

As noted above, Nautilus Institute’s ongoing Asian Energy Security and East Asia Science and Security projects continue to use the LEAP energy/environment planning software system as an organizing/calculation tool for the elaboration of future energy paths (“scenarios” in LEAP) and for the evaluation of some (but by no means all) of the energy security attributes of different paths. The energy security analysis approach above, however, can accommodate a range of tools or approaches for developing and evaluating energy paths, from simple spreadsheet tools to more complex models. Whatever tool is used, the key is to develop energy paths so as to provide

comprehensive accounting of how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions with regard to population, economic development, technology, fuel prices, costs of energy-consuming and energy conversion equipment, and other factors. Energy paths/scenarios should be self-consistent storylines of how an energy system might evolve over time in a particular socio-economic setting and under a particular set of policy conditions. Paths/scenarios can be built and then compared, using the energy security analysis framework above, to assess parameters such as energy requirements, social costs and benefits, and environmental impacts.

Application of paths outputs for energy security analysis

The outputs of energy paths analysis prepared using LEAP and/or other tools can be used directly for some of the measures of energy security described above. Typically, results from two or more different energy paths within a country or region are compared to indicate which path is preferable with regard to different direct measures of energy security, such as cost, physical energy output, fuels imports and exports, or environmental emissions. Depending on the energy security measure, a combination of direct use of model outputs, “off-line” quantitative analysis based on model output and other parameters, and the use of qualitative techniques based on the consideration of energy paths, together provide a powerful suite of tools for the evaluation of the impacts of different policies on energy security.

Other tools and methods for energy security analysis

One set of analyses critical to the comprehensive evaluation of energy security, but not directly performed by LEAP or similar tools, is the evaluation of the energy security impacts of risk for different energy paths. The incorporation of the elements of risk in energy security analysis can involve more qualitative but systematic **consideration of different potential futures** to “arrive at policy decisions that remain valid under a large set of plausible scenarios”; **sensitivity analysis** – where variations in one or more plans (or paths) are studied when key uncertain parameters are varied; **probabilistic analysis** – in which “probabilities are assigned to different values of uncertain variables, and outcomes are obtained through probabilistic simulations”; **stochastic optimization** – in which a probability distribution for each uncertain variable is assigned during an optimization exercise, **incorporating uncertainty** in the discount rate used in an economic analysis; and **search for a robust solution** – which Hossein Razavi describes as using “the technique of trade-off analysis to eliminate uncertainties that do not matter and to concentrate on the ranges of uncertainty which are most relevant to corresponding objective attributes.”²³

Although any or all of these six techniques could be applied within the energy security analysis framework that we suggest, probably the most broadly applicable and transparent of the techniques above are scenario analysis, sensitivity analysis, and “search for a robust solution”. In the PARES analysis of the energy security implications of two different medium-term energy paths for Japan for example, a combination of paths analyses and sensitivity analyses was used to test the response of the different energy paths to extreme changes in key variables.

Diversification indices

In a paper prepared for the PARES project, Thomas Neff borrows from the economics and financial analysis communities and other disciplines to create a set of tools, based on diversity indices,²⁴ that can help to provide a metric for the energy security implications of different energy supply strategies.

Neff starts with a simple diversification index, the Herfindahl index, written in mathematical terms as:

$$H = \sum_i x_i^2$$

where x_i is the fraction of total supply from source “i.” This index can measure the diversity of, for example, the types of fuels used in an economy (where x_i would then be the fraction of primary energy or final demand by fuel type). Alternatively, within a single type of fuel (such as oil), the index can be applied to the pattern of imports of a particular country by supplier nation. The index has a maximum value of 1 (when there is only one supplier or fuel type), and goes down with increasing diversity of number of suppliers or fuel types, so that a lower value of the index indicates more diverse, and (perhaps) more robust, supply conditions.

Consideration of risk in specific fuel import patterns can be worked into the above index, Neff argues, through consideration of the variance in the behavior of each supplier, and by application of correlation coefficients that describe how variance in the behavior of pairs of suppliers (for example, oil exporters Saudi Arabia and Indonesia) are or might be related. The correlation might be positive, for countries that tend to raise and lower their exports together, or negative, as when supplier “A” would tend to increase production to compensate for decreased production by supplier “B.”

Neff also addresses the topic of market, or systematic risk, that is, the risk associated with the whole market – be it a market for stocks, oil, or uranium – changing at once. Applying parameters that describe the degree to which individual suppliers are likely to change their output when the market as a whole shifts (the contribution of the variance of an individual supplier to overall market variance), allows the calculation of the variance of a given energy supply pattern. Hence, calculation of “portfolio variance,” for example, provides a measure of the relative risk inherent in any given fuel supplier pattern versus any other.

Multiple-attribute analysis and matrices

Deciding upon a single set of energy policies (or a few top options) from a wide range of choices is a complex process, necessarily with both qualitative and quantitative aspects, and should be approached systematically if the result of the choice is to be credible. There are many different methods, with many gradations, for deciding which set of policies or which energy path is the most desirable. These range from simply listing each attribute of each policy set or path in a large matrix (for example, on a chalkboard in a conference room) and methodically eliminating candidate paths (noting why each is eliminated), to more quantitative approaches involving “multiple-attribute analysis.”

In one type of application of multiple-attribute analysis, each criterion (attribute) used to evaluate energy policies or paths is assigned a numerical value. For objective criteria, the values of the attributes are used directly (present value costs are an example), while subjective criteria can be assigned a value based (for example) on a scale of 1 to 10. Once each attribute has a value, a weight is assigned to each attribute. These weights should reflect a consensus as to which attributes are the most important in planning. Multiplying the values of the attribute by the weights assigned, then summing over the attributes, yields “scores” for each individual policy set or path that can be compared. Although this process may seem like an attractive way to organize and make more objective a complicated decision/evaluation process, great care must be taken to apply the analysis so that (1) all subjective decisions – for example, the decisions that go into defining the system of weights used – are carefully and fully documented, and (2) the system used avoids magnifying small differences (or minimizing large differences) between policy or path alternatives.

Evaluating energy security impacts

Whatever tool or technique is used to decide between policy sets or paths, it is ultimately the policymakers and their constituencies who will decide which policies are to be implemented, or which energy path is worth pursuing. As a consequence, one of the most important rules of the application of multiple-attribute analysis to an evaluation of policies is to present the analytical process in an open, clear, and complete manner, so that others who wish to review the decisions and assumptions made along the way can do so.

The most straightforward approach to comparing paths is to simply line up the attributes values for each path side by side, and review the differences between paths, focusing on differences that are truly significant. For example, if the difference in net present value (NPV) cost of plan “A” is one billion dollars greater than that of plan “B,” it may seem, at first glance, like a lot of money, but the difference must be examined relative to the overall cost of the energy system, or to the cost of the economy as a whole. To an energy system that has, say, one trillion (10^{12}) dollars in capital, operating and maintenance, and fuel costs over 20 years, a difference between plans of one billion (10^9) dollars is not only trivial, it is dwarfed by the uncertainties in even the most certain elements of the analysis. The key, then, is to search for differences between the attributes of the plans – taking care to include both qualitative and quantitative attributes – that are truly meaningful.

One straightforward way to visualize the similarities and differences between paths, both quantitative and qualitative, is the use of a comparison matrix (or a set of matrices). These tables show, for example, the different attributes and measures of each path (cost, environmental emissions, military security, and others) as rows, while the results for each scenario/path form a column in the table. Table 3.3 shows an example of a comparison of two energy paths for Japan (done for the PARES project in the late 1990s) laid out in a “matrix” format. The “BAU” path

Table 3.3 Energy security comparison for Japan: BAU versus alternative path

<i>Dimension of Energy Security</i>	<i>Attributes</i>	<i>BAU Path Result</i>	<i>Alternative Path Result</i>
Energy Supply	Total primary energy	2010: 26.2 EJ; 2020: 28.7 EJ	2010: 22.0 EJ; 2020: 28.7 PJ
	Fraction primary energy as imports	2020: 96% of fuel use	2020: 85% of fuel use
	Diversification index (by fuel type, primary energy)	2010: 0.254 2020: 0.240	2010: 0.262; 2020: 0.230, 0.213 and 0.175 (separate accounting for pipeline gas, energy efficiency)
	Diversification index (by supplier, key fuel types)		Not quantified, but probably lower
	Stocks as a fraction of imports (key fuels)	Oil: 150 days' stocks in 1995 lasts for 110 days in 2020	Oil: 150 days' stocks in 1995 lasts for 187 days in 2020
Economic	Total energy system internal costs		27 trillion Yen (net present value) less than BAU path over 1990 to 2020
	Total fuel costs		32 trillion Yen (net present value) less than BAU path over 1990 to 2020
	Import fuel costs		About the same as total fuel costs

Table 3.3 (continued)

<i>Dimension of Energy Security</i>	<i>Attributes</i>	<i>BAU Path Result</i>	<i>Alternative Path Result</i>
	Economic impact of fuel price increase (as fraction of GNP)	In 2015, energy resource costs about 1% of GDP <i>more</i> than in alternative path	Impact of 2010 oil price rise to 4,725 Yen per bbl about 27 trillion Yen NPV <i>less</i> than BAU path, 1990 to 2020.
Technological	Diversification indices for key industries by technology type	For electricity generation: 2010: 0.166 2010: 0.166	For electricity generation: 2010: 0.153 2020: 0.105
	Diversity of R&D spending		Probably higher
	Reliance on proven technologies	Higher	
	Technological adaptability		Probably higher
Environmental	GHG emissions	In 2020: 1,600 Mte CO ₂ , 300 kte CH ₄ , 120 kte N ₂ O	In 2020: 1,000 Mte CO ₂ , 310 kte CH ₄ , 82 kte N ₂ O
	Acid gas emissions	In 2020: 2.0 Mte SO _x , 5.2 Mte NO _x	In 2020: 1.1 Mte SO _x , 3.2 Mte NO _x
	Local air pollutants	In 2020: 3.8 Mte CO, 1.1 Mte hydrocarbons, 0.94 Mte particulates	In 2020: 2.8 Mte CO, 0.55 Mte hydrocarbons, 0.54 Mte particulates
	Other air and water pollutants (including marine oil pollution)		Somewhat lower to substantially lower, depending on pollutant and pollutant source
	Solid wastes (tonnes bottom ash, fly ash, scrubber sludge)		Likely somewhat lower (depends on fuel sulfur, ash contents, degree of scrubbing)
	Nuclear waste (tonnes or curies, by type)		Somewhat (~5–10 percent over 1990 to 2020) lower; on-site spent fuel isolation means less waste transport
	Ecosystem and esthetic impacts	More large-infrastructure-related impacts	More indigenous energy-related esthetic impacts; less ecosystem impacts due to pollutants
	Exposure to environmental risk		Lower
Social and Cultural	Exposure to risk of social or cultural conflict over energy systems		Likely lower overall, but may require more social and cultural adjustment

Table 3.3 (continued)

<i>Dimension of Energy Security</i>	<i>Attributes</i>	<i>BAU Path Result</i>	<i>Alternative Path Result</i>
Military/ Security	Exposure to Military/ Security risks		Likely somewhat lower
	Relative level of spending on energy-related security arrangements		Likely somewhat lower

Notes: One exajoule, or EJ, is equal to one billion gigajoules, or 10^{18} joules.
mte = million tons equivalent. Kte = thousand tons equivalent.

roughly echoed Japanese government plans at the time, while the “Alternative” path featured an emphasis on aggressive application of energy efficiency and renewable energy in end-use demand and electricity (and heat) supply.²⁵ The matrix format allows, in theory, the comparison of a large number of different attributes for a large number of different paths, but in practice the more that the number of attributes can be reduced to the most significant few, and the more that the number of paths can be reduced to those that show clear differences relative to each other, the more easily comprehended and useful the comparison matrix will be. The matrix format is also compatible with the use of other tools and methods for evaluating aspects of energy security, including, but by no means limited to, the sampling of tools and methods presented above.

The side-by-side comparison of candidate paths/scenarios should, if the original set of paths considered was sufficiently broad, allow the elimination of paths that are clearly worse, in several (or key) attribute dimensions, than other candidates. The process of elimination of paths should, however, be approached in a systematic, transparent, and well-documented way.

Qualitative analysis

One advantage of the “matrix” method of paths comparison shown above is that it allows input on both quantitative and qualitative attributes and measures of energy security. In some cases, comparing attributes quantitatively across paths is theoretically possible (for example, employment impacts or spending on security arrangements), but not feasible from a practical perspective, at least for the study at hand. In other cases (exposure to social and cultural risk, for example), quantitative measures may simply not exist. In these types of cases, the only option for measuring the relative attributes of different paths may be qualitative analysis. There is no one correct way to accomplish a qualitative analysis, but such an analysis should attempt to address the issue from different points of view (for example, cultural impacts on different segments of society), should clearly define operating assumptions, and should clearly show a thinking-through of the relationship between cause (differences between energy paths) and effect (differences in attribute outcome). Qualitative analysis is by definition subjective, but is a necessary part of the overall analysis of different energy paths, which otherwise runs the risk of confusing the attributes that are **countable** with the issues that **count**.

Methods yet to be developed

The consideration of different energy paths and their outcomes is an inexact science, as noted above, with both objective and subjective components. Possible areas of research into methods of evaluating energy paths results include:

- developing better ways to summarize and visualize multiple energy security dimensions and attributes, including tabular, statistical, and graphical methods;
- developing statistical data on correlations between fuel exporter behavior for supply diversification analyses (for example, on correlations between the pricing and supply behavior of different groups of oil exporters);
- improving the analysis of economic interactions (for example, the impacts of using different energy sources – renewable fuels versus fossil fuels as a case in point – on employment and on other sectors of the economy) within candidate energy paths;
- identifying more effective ways of evaluating energy security impacts of risks of different types;
- exploring analytical methods for evaluating military security impacts and costs, including case studies of past energy choices with military security linkages;
- exploring the analytical use of the types of “scenario-building” processes to help to evaluate the differences between energy paths.

Conclusion

Energy security, if defined more comprehensively, has many overlaps with the concept of sustainability. As a consequence, many policies that seek to enhance future energy security, be it at the global, regional, national, or sub-national levels, also have the effect of enhancing (or moving toward) sustainability. In order to determine – to the extent possible with any forward-looking activity – whether future national, regional, and global energy policies will lead to improved energy security and sustainability, a systematic approach to evaluating the performance of different energy paths/scenarios with regard to the many dimensions of comprehensive energy security is needed. The analytical tools and methods described above (and summarized in

Table 3.4 Tools and methodologies for energy security analysis

<i>Tool or Method</i>	<i>Description</i>	<i>Advantages</i>	<i>Disadvantages</i>
Optimization Modeling	Mathematical modeling to determine the optimal solution (for example, by minimizing costs or pollutant emissions) from among a range of options that meet certain criteria (for example, for the development of electricity generation capacity)	Provides a single, “optimal” result that is easy to understand	Result depends very strongly on inputs and modeling parameters, which are often not easy for the users of the results to review
Energy Paths Analysis	Allows comparison of selected results related to energy security across different “paths” for the evolution of an energy system that (ideally) provides the same energy services to society	Flexible enough to allow a range of different policy options to be modeled, and to incorporate non-quantitative considerations in the design of “paths”	Requires care in design of paths so as to yield a result that is relevant to energy security policy, and is at an appropriate level of detail

Evaluating energy security impacts

Table 3.4 (continued)

<i>Tool or Method</i>	<i>Description</i>	<i>Advantages</i>	<i>Disadvantages</i>
Diversification Indicies	Mathematical formulae that allow the degree of diversification in a system – for example diversification among energy sources, or suppliers of imported energy – to be expressed as an index value	Relatively easy to use to compare the evolution of diversification over time in key parameters across energy paths driven by alternative policies	Provides only part of the energy security picture. Also must be applied with care, as some types of diversification – for example among suppliers feeding gas into the same pipeline – may yield similar results, but provide less real energy security than others
Multiple-Attribute Analysis with Factor Ranking and/or Weighting	Applies ranking and/or weighting procedures to potentially diverse attributes of a system to provide a set of overall numerical scores for use in ranking energy policy plans/paths/scenarios	Provides a single comprehensive metric that is easy to use in presenting options to policymakers or stakeholders	Rankings can unreasonably exaggerate small differences between choices, and/or downplay large difference; also can mask what are inherently subjective choices (weightings) as objective
“Matrix” Approach to Paths Comparison	Compare the results of energy paths that yield (roughly) the same benefits in a table that displays results for each path considered across a broad and representative range of energy security attributes	Allows the review of both quantitative and qualitative measures in the same table, without (or with limited) hidden judgments as to the importance of specific attributes	Depends on the user of the results to judge which attributes in the comparison are most important, and on the analyst to evaluate a representative set of attributes

Table 3.4), applied to evaluate and take into account both quantitative and qualitative factors and measures in multiple-attribute, side-by-side analyses of different candidate energy paths, provide at least the beginnings of such an approach. Together with other tools, this approach can be used to help to guide energy policy by placing the different dimensions of energy decisions before policymakers in a clear and transparent fashion.

Notes

- 1 This chapter draws from previous work done as part of the Nautilus Institute’s “Pacific Asia Regional Energy Security” project, including a summary of the PARES energy security analysis approach published earlier, and developed in related articles, as well as articles scheduled for publication in an upcoming Asian Energy Security Special Issue of the journal *Energy Policy*. See, for example, von Hippel, D. F. 2004. “Energy Security Analysis: A New Framework,” *reCOMMEND* 1(2) (December): 4–6; Hayes, P. and D. von Hippel. 2006. “Energy Security in Northeast Asia,” *Global Asia* 1(1): 91–105; von Hippel, D. F., T. Suzuki, J. H. Williams, T. Savage, and P. Hayes. Forthcoming. “Energy Security and Sustainability in Northeast Asia,” Asian Energy Security Special Issue of *Energy Policy*; and von Hippel, D. F., T. Savage, and P. Hayes. Forthcoming. “Introduction to the Asian Energy Security Project: Project Organization and Methodologies,” Asian Energy Security Special Issue of *Energy Policy*.

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