Competing Dimensions of Energy Security: An International Perspective

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Annu. Rev. Environ. Resour. 2010. 35:77–108

First published online as a Review in Advance on August 10, 2010

The *Annual Review of Environment and Resources* is online at environ.annualreviews.org

This article's doi:
10.1146/annurev-environ-042509-143035

1543-5938/10/1121-0077$20.00

Key Words

energy policy, energy poverty, energy vulnerability, Organisation for Economic Co-operation and Development (OECD), security of supply

Abstract

How well are industrialized nations doing in terms of their energy security? Without a standardized set of metrics, it is difficult to determine the extent to which countries are properly responding to the emerging energy security challenges related to climate change: a growing dependency on fossil fuels, population growth, and economic development. In response, this article first surveys the academic literature on energy security and concludes that it is composed of availability, affordability, efficiency, and environmental stewardship. It then analyzes the relative energy security performance, based on these four dimensions, of the United States and 21 other member countries of the Organisation for Economic Co-operation and Development (OECD) from 1970 to 2007. Four countries are examined in greater detail: one of the strongest (Denmark), one of the most improved in terms of energy security (Japan), one with weak and stagnant energy security (United States), and one with deteriorating energy security (Spain). The article concludes by offering implications for public policy.

Contents

1. INTRODUCTION

On January 23, 1980, President Jimmy Carter issued a famous declaration that any effort by a hostile power to block the flow of oil from the Persian Gulf would be viewed as an assault on the "vital interests" of the United States, and would be repelled by "any means necessary, including military force" (1, p. 144). In addition to proposing to Congress that the country establish an Energy Security Corporation to invest in alternative sources of fuel, President Carter also created a Rapid Deployment Joint Task Force to protect the shipping lanes through which Middle Eastern oil flowed to American shores (2). In a policy later strengthened by the creation of the U.S. Central Command in the early 1980s and since termed the Carter Doctrine, the administrations of Presidents Ronald Reagan, George H. Bush, Bill Clinton, and George W. Bush have each relied on the threat of military force to deter and prevent major disruption in world oil supply.[1] The price of these military activities in the Persian Gulf is expected to cost the country between $29 billion to $80 billion per year.[2] Every presidential administration since Carter, in other words, has viewed national security and energy supply as inexorably intertwined.

The deepening of the Carter Doctrine, however, is not convincing proof that a military approach to energy security is optimal. Nor does it tell us how the United States has performed relative to other countries at improving energy security. This article therefore measures and assesses energy security for 22 countries from 1970 to 2007. The first section, much like other reviews in this journal, surveys the scholarly literature on energy security from 2003 to 2008 and argues that the concept should include accessibility, affordability, efficiency, and environmental stewardship. Because these four components are multidimensional, however, the second section goes above and beyond the standard literature review approach. It discusses 10 metrics that constitute an Energy Security Index and synthesizes published data and trends related to energy security across a variety of industrialized countries. The section

[1]The Carter Doctrine has significantly expanded since the 1970s. When Iranian forces began to attack Kuwaiti oil tankers traveling through the Persian Gulf in an attempt to discourage Kuwait from supplying loans to Iraq for arms procurement at the height of the Iran-Iraq war of 1980 to 1988, President Reagan authorized the reflagging of Kuwaiti tankers with the U.S. ensign to afford them naval protection. The Clinton administration and both Bush administrations have funneled billions of dollars into protecting the Persian Gulf and other oil-based assets. U.S. Southern Command now promotes security cooperation activities to grow U.S. influence and dissuade potential adversaries in oil-producing regions of South America, especially Colombia, including training, equipping, and developing security forces to protect refineries and offshore oil and gas platforms. In central Asia, the U.S. operates military and training programs to train and equip Georgian and Uzbek security forces to maintain the free flow of oil essential to the American and world economy. In western Africa, military aid and training have flowed to Nigeria to help bolster the security of their oil infrastructure (1–5).

[2]Researchers at the Oak Ridge National Laboratory estimated that from 1970 to 2004 American dependency on foreign supplies of oil has cost the country $5.6 to $14.6 trillion (6, 7).

relies on this Energy Security Index to measure and track progress on energy security between the United States and 21 Organisation for Economic Co-operation and Development (OECD) countries. The third section surveys the academic literature yet again to analyze the relative performance of two top-performing countries, Denmark (with high energy security) and Japan (with improving energy security), and two poorer performing countries, the United States (with weak and stagnant energy security) and Spain (with declining energy security). The article concludes by offering implications for policy.

In attempting to tackle a concept as complicated as energy security, we could have analyzed almost any scale and any group of countries. Instead of emphasizing smaller scales (such as individuals and firms) or international organizations (such as the World Bank or Organization of Petroleum Exporting Countries), we have focused exclusively on nation states. And instead of looking at countries in a single region, such as the European Union, Asia, the Caspian Sea, or the Black Sea, we have investigated energy security for 22 geographically dispersed countries that belong to the OECD. The first reason for this focus is practical: Data on patterns of energy production and use have been collected and compiled for OECD countries since the 1950s, and these countries are powerful members of a number of multilateral organizations dealing with energy issues, such as the United Nations and the International Energy Agency. The next reason is more theoretical: OECD countries have different types of energy markets and cultures. The United Kingdom and New Zealand are examples of liberalized and privatized energy markets, whereas other countries, such as Denmark and parts of the United States, remain highly regulated. The OECD countries we selected also include cultures as diverse as Australia, Greece, Japan, and Turkey. The final reason is pragmatic: Because OECD countries are the most industrialized in the world, they also possess the technical and financial capacity to implement policy changes that can improve their energy security. The OECD countries include many of the world's largest consumers of energy, so their decisions also affect the global energy marketplace.

The importance of such an exploration is threefold. First, energy security is arguably one of the most important forms of human security. Energy services are a ubiquitous component of modern lifestyles, needed to power modes of transport, light factories and workplaces, cultivate food, manufacture and distribute products, and cool and warm residences. Economist E. F. Schumacher once noted that energy services in modern society are "not just another commodity, but the precondition of all commodities, a basic factor equal with air, water, and earth" (8, pp. 1–2). They are used by almost every living person, which means assessing how securely they are provided is a crucial concern.

Second, perhaps because of its ubiquity, notions of energy security are either so narrow that they tell us little about comprehensive energy challenges or so broad that they lack precision and coherence. Trying to measure energy security by using contemporary methods in isolation—such as energy intensity or electricity consumption—is akin to trying to drive a car with only a fuel gauge or to seeing a doctor who only checks your cholesterol. This study provides precision, breadth, and standardization to the often ambiguous concept. Without such criteria, it is difficult to determine the extent that policy decisions, private investments, new technologies, and research and development are keeping pace with the challenges facing the growing global economy in a carbon-constrained world. Though considerable effort has been dedicated by energy and environmental groups to the development of composite indicators of transportation productivity and environmental quality, there are no standard composite metrics to evaluate energy security. Thus, the enduring question—"Are our energy systems becoming more or less secure?"—remains difficult to answer.

Third, international comparisons of energy security highlight the interdependence of countries, enmeshed in larger relationships between and within producers and consumers. Global trade in energy fuels and services amounted to $900 billion in 2006, and almost two-thirds of the oil produced in 2007 was traded on the global market (9). Of the hundreds of countries in the world, none is truly energy independent. Saudi Arabia exports crude oil but must import refined gasoline. Russia exports natural gas but must import uranium. The United States exports coal but imports oil and natural gas. This interdependence explains why our assessment of energy security examines the interactions between countries as much as within them and serves as a useful reminder that energy security does not stand abstractly by itself; rather, it is most meaningful in a comparative context.

2. CONCEPTUALIZING ENERGY SECURITY

Notions of energy security frequently differ by personal and institutional perspectives, national styles, geology, geography, and time. Scientists and engineers sometimes characterize energy security as a function of energy research and development, innovation, and technology transfer systems (10, 11). The World Bank, by contrast, tells us that energy security is based on the three pillars of energy efficiency, diversification of supply, and minimization of price volatility (12). Consumer advocates and users view energy security as reasonably priced energy services without disruption. Major oil and gas producers focus on the security of their access to new reserves as well as the security of demand for their product, whereas electric utility companies emphasize the integrity of the electricity grid. Finally, politicians dwell on securing energy resources and infrastructure from terrorism and war.

Distinct national styles, geology, and geography also influence conceptions of energy security. In the United States, energy security has generally meant the availability of sufficient supplies at affordable prices, protecting Middle East suppliers and shipping lanes against piracy and attack, maintaining a strategic petroleum reserve, and reducing physical threats to energy infrastructure (13–15). Russia appears to pursue an energy security strategy of asserting state influence over strategic resources to gain primary control over the infrastructure through which it ships its hydrocarbons to international markets. Restricting foreign investment in domestic oil and gas fields is an important element of this strategy (16). China has viewed energy security as an ability to rapidly adjust to its new dependency on global markets and engage in energy diplomacy, shifting from its former commitments to self-reliance and sufficiency ("*zili gensheng*") to a new desire to build a well-off society ("*Xiaokang Shehui*"). Buying stakes in foreign oil fields, militarily protecting vulnerable shipping lanes, and an all-out "energy scramble" for resources are key features of China's current approach to energy security (17–20). Japan envisions energy security as offsetting its stark scarcity of domestic resources through diversification, trade, and investment, as well as selective engagement with neighboring Asian countries to jointly develop energy resources (21, 22). Saudi Arabia pursues energy security as maintaining a security of demand for its oil and gas exports, while Australia cultivates a strong demand for uranium, natural gas, and coal exports (23–26). Venezuela and Colombia, in contrast, focus on minimizing attacks on oil, gas, and electric infrastructure (27).

Further complicating matters, conceptions of energy security change over time. The modern notion of energy security emerged in the early nineteenth century as the mechanization of warfare accelerated the energy requirements for coal-powered warships and vehicles. Global concerns about energy security became more prominent during the World Wars, the energy crises of the 1970s, and both invasions of Iraq. In the United States, depending on the presidential administration, energy security has meant ending all oil imports, eliminating imports only from the Middle East, merely reducing dependency on foreign imports, and entirely weaning the country off oil (28). Following the emergence of nuclear power in the 1970s, energy security expanded to include nuclear nonproliferation.

None of this, however, tells us which institutional, national, or temporal form of energy security is preferable. The contradictions and tensions among the various national approaches and meanings of energy security, and their differentiation over time, do not address the deeper question as to which is the preferred or most beneficial form. We argue, based on an extensive assessment of 91 peer-reviewed academic articles on energy security from September 2003 to September 2008,[3] that energy security should be based on the interconnected factors of availability, affordability, efficiency, and environmental stewardship.

2.1. Energy Security as Availability

The classic conception of energy security addresses the relative safety and source diversification of energy fuels and services (29). More than 80% of the academic literature we examined noted the importance of availability, a component often predicated on promoting independence and diversification.

Part of ensuring availability entails procuring a sufficient and uninterrupted supply and minimizing foreign dependency on fuels (1). Dependence can be costly, most recently illustrated with Russian efforts to negotiate natural gas prices in Europe. Russia was able to successfully triple the price of natural gas exported to Belarus and Ukraine because these countries were completely dependent on Russian supply. In more serious cases, growing dependency or perceived scarcity of domestic energy supply has precipitated international conflict (30). Energy supplies had a significant role to play in provoking the American Revolutionary War (30). In World War I, both Entente and Central powers believed control of coal, oil, and gas resources were a key to victory. During World War II, Japan, suffering from a dearth of available raw materials, invaded Manchuria in 1931 to acquire their coal reserves. In response to Japan's later invasion of China in 1937, the United States cut off oil exports in July 1941 (30). Without domestic resources, Japan invaded the oil-rich Indonesian islands, and the resulting tensions were a direct contributor to the Japanese decision to attack Pearl Harbor. That same year, Adolf Hitler declared war on the Soviet Union in part to secure oil for his war machine, and he launched *Operation Blau* to protect German oil fields in Romania while securing new ones in the central Caucasus (30). The Soviet Union attempted to invade northern Iran in 1945 and 1946 to acquire control of its oil resources precisely to reduce its own dependency. During the Gulf War of 1990–1991, Iraq invaded Kuwait explicitly to enhance its control of energy reserves. Lessening dependency on foreign supplies of energy fuels, therefore, is an important component of ensuring availability and improving energy security.

Related aspects of availability are diversification and preventing the sabotage or attack of critical infrastructure, such as power plants, pipelines, dams, and transmission and distribution networks so that the services they provide are uninterruptible. Diversification encompasses three dimensions: (*a*) source diversification requires utilizing a mix of different energy sources, fuel types, fuel cycles (i.e., relying not just on nuclear power or natural gas but also on coal, oil, wind, biomass, geothermal, and others); (*b*) supplier diversification refers to developing multiple points of energy production so that no single company or provider has control over the market (i.e., purchasing oil from not just one or two companies but a diversified mix of dozens of energy firms); and (*c*) spatial diversification means dispersing the locations of individual facilities so that they cannot be disrupted by a single attack, event, malfunction, or failure (i.e., building one oil refinery in every state instead of placing all of them in the Gulf Coast). The principle of diversification is rooted in ecology (natural ecosystems reveal

[3]The authors searched for the two words energy and security in the titles of articles compiled in seven separate academic databases: JSTOR, Science Direct, Project Muse, LexisNexis, SpringerLink, Taylor & Francis, and Hein Online. Two hundred and thirteen articles were collected, but only 91 dealt with energy security directly. For the sake of brevity, not all 91 articles are cited in this article but are on file with the authors and available by request.

that a diversity of flora and fauna are best able to prevent spread of disease and pests); finance (a diversified investment strategy is the best way to balance returns and risk in a way that offers the best likelihood of large profits in exchange for low risk); and politics (democracy can be viewed as a form of diversification of the idea of consensus building, decision making, and accountability in governance) (31–33). Multiplying one's supply sources by investing in multiple alternatives serves the interests of both consumers and producers because it ensures that the energy supply chain is not dependent on any single fuel source. The geographical dispersion of energy facilities not only improves their overall reliability, but it also makes the entire distribution network more secure and resilient to accidental disruption, systems failure, or intentional attack. Geographical dispersion creates multiple targets, all of which would have to be disrupted at the same time to elicit total systems collapse (34).

Diversification, too, has historical importance, for a variety of actors, saboteurs, terrorists, and insurgents have targeted energy infrastructure. Starting with North America, in 1975, the New World Liberation Front bombed pipelines of the Pacific Gas and Electric Company in California more than 10 times, and members of the Ku Klux Klan and San Joaquin Militia have been convicted of attempting to attack natural gas infrastructure throughout Mexico and the United States (35). In 1997 in Texas, police prevented the bombing of natural gas storage tanks at a processing plant by Ku Klux Klan members seeking to create a diversion for a robbery (36). In 1999, Vancouver police arrested a man for planning to blow up the trans-Alaskan pipeline for personal profit in oil futures (36). In 2001, an attack on the trans-Alaska pipeline with a high-powered rifle forced a two-day shutdown and caused extensive economic and environmental damage—all apparently part of a hunting trip gone awry.

Beyond North America, in the 1970s during the Russian invasion of Afghanistan, the mujahideen conducted so many attacks on Soviet oil and gas pipelines that the Russians lost more than 500 tons of petroleum every day. A few decades later in the midst of the Russian-Chechen conflict, both sides exploited pipelines as a way to intensify their military campaign, with the Chechens even tapping the Baku-Grozny-Novorossiysk pipeline hundreds of times to draw away oil to hidden refineries where it could be processed into cheap gasoline and then sold in Grozny to purchase weapons (37). The government of Saudi Arabia, which manages more than 11,000 miles of gas and oil pipelines, has repelled at least 30 attempts in the past four years to destroy or damage its pipelines by insurgents from nearby Iraq (38). Next door, in Iraq, more than 150 attacks on the country's 4,000-mile pipeline system occurred over the course of 12 months (36, 39). Suicide bombers have attacked the natural gas infrastructure in Nigeria, Sri Lanka, and Yemen, and in Pakistan, gunmen have frequently stormed Pakistan Petroleum Limited natural gas facilities, fired rockets at pipelines, and kidnapped employees of the Water and Power Development Authority (40). In Colombia, the 480-mile Cano Limon-Covenas pipeline has had so many holes blown in it that the locals jokingly refer to it as "the flute." In the Sudan, Arakis Energy Corporation and Greater Nile Petroleum Company sometimes have to repel daily attacks on their oil and gas pipelines (41). London Police also foiled a plot by the Irish Republican Army in 1996 to bomb gas pipelines and other utilities across the city with 36 explosive devices. Recently, pirates in the Gulf of Aden between Somalia and Yemen, and in the Straits of Malacca between Indonesia, Malaysia, and Singapore, have also begun targeting oil and liquefied natural gas tankers for kidnappings and hijackings. There are many precedents for diversification becoming a more significant component of energy security.

2.2. Energy Security as Affordability

A second component of energy security extends beyond availability to include the basic affordability and equitable access of energy services.

Slightly more than 50% of the examined literature suggested affordability as an important principle. Less affluent families in the developed world spend a larger proportion of their income on energy services (12% of household income, for instance, for the poorest quintile of households in the United States), so ensuring that energy is affordable can be central to meeting their basic needs (42). Moreover, people living below the international poverty line pay proportionally more for energy, hindering the accumulation of wealth needed to make investments to escape their poverty. The United Nations has warned that energy pollution has an often ignored class dimension: Infant mortality rates are more than 5 times higher among the poor, the proportion of children below the age of five who are malnourished is 8 times higher, and maternal mortality rates are 14 times higher (43). One study, looking at the effects of increases in energy prices in four developing Asian economies from 2002 to 2005, found that poorer households paid 171% more of their income for cooking fuels and 120% more for transportation, 67% more for electricity, and 33% more for fertilizers when compared to the expenditures on energy from middle- and upper-class households (44). Indirectly, higher energy prices tend to inflate the price of almost all other goods and services because energy can account for up to 15% of the total cost of food processing, textiles, lumber, paper processing, chemical manufacturing, and cement production (45).

Indeed, even within highly industrialized countries, access to energy services is often unequal. The poor must expend a larger proportion of their income on energy services despite using less energy than the rich. Using a metric known as a Gini coefficient or Lorenz curve, which looks at the degree of income concentration related to energy (varying between 0 for perfect equality and 1 for maximum inequality), one study looked at the equity of energy use in El Salvador, Kenya, Norway, Thailand, and the United States (46). The study found that no country was truly equitable in its energy use. The best country was Norway (where half of residential electricity was used by 38% of household customers with the highest-incomes), followed by the United States (25%), El Salvador (15%), Thailand (13%), and Kenya (6%) where the percentages shown represent the highest-income households using half of the residential electricity.

Energy fuels and services must not only be affordable, but their prices should be stable. When energy prices swing wildly, suppliers find it difficult to plan prudent investments. The enormous price spikes for natural gas seen over the past decade in the United States, for example, made natural gas-fired plants costly to operate, and resulted in significant increases in electricity prices in several areas, much to the consternation of utility executives (47, 48). At the same time, the energy affordability component of energy security can conflict with other energy security criteria. For instance, energy price controls in developing countries have resulted in artificially low prices, which thwart investments in energy-efficient and clean energy technologies (49).

A final dimension of affordability relates to quality. Even if the price is low and stable relative to household income, consumers and firms need access to a broad range of high-quality energy fuels and services. The World Health Organization and United Nations Development Program generally categorize access according to an "energy ladder" of different sets of fuels and technologies:

- Access to electricity, measured as the percent of people that have a household electricity connection, is at the top of the ladder;
- Access to modern fuels, such as liquefied petroleum gas, natural gas, kerosene, and ethanol, is on the next rung; and
- Access to traditional fuels, such as fuelwood, charcoal, dung, crop residues, and coal, is on the bottom rung (50).

High levels of access and fuel diversity often correlate with higher levels of energy consumption and lower rates of energy poverty, and lower levels of access and minimal choice correlate with low levels of use, reliance on biomass, and lack of efficient equipment (51).

2.3. Energy Security as Energy and Economic Efficiency

A third component, mentioned by about one-third of the literature, relates to energy efficiency, or the improved performance and increased deployment of more efficient equipment and conservation. Energy efficiency enables the most economically efficient use of energy to perform a certain task (such as light, torque, or heat) by minimizing the units of resources per unit of output. Energy efficiency can include substituting resource inputs or fuels, changing habits and preferences, or altering the mix of goods and services to demand less energy.

A key part of improving the efficiency of energy technologies and services relates to innovation, research, and development. Energy technology innovation is the process of leading to new or improved energy technologies that enhance the quality of energy services and reduce the negative externalities and costs associated with energy supply and use (52). As advanced societies grow their dependence on electric services with increasing automation, air-conditioning, and home entertainment systems, managing demand through load control devices and time-of-use pricing will become increasingly critical to grid stability. Another part of efficiency includes consumer demand for energy services and consumer behavior, ensuring that energy fuels and carriers are matched in scale and quality to end uses and that consumers use only as much energy as they truly need.

2.4. Energy Security as Environmental Stewardship

The final component, promoted by about one-fourth of the examined articles, relates to environmental stewardship, and it emphasizes the importance of sustainability. In its classic sense, the concept encompasses the notion of balancing current resource consumption with the resource requirements of future generations. For example, the landmark 1987 Brundtland report (published under the title *Our Common Future: World Commission on Environment and Development*) defined sustainable development as meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (53, pp. 11, 12). When applied to energy policy, sustainability has usually meant pursuing three rules simultaneously: ensuring that the harvest rates of renewable resources do not exceed regeneration rates; making sure that waste emissions do not exceed relevant assimilative capacities of ecosystems; and guaranteeing that nonrenewable resources are depleted only at a rate equal to the creation of renewable ones (54). Even groups, such as the International Energy Agency, and former American defense secretaries John Deutch and James Schlesinger have noted that mitigating and adapting to climate change must be considered a part of any attempt to create energy security (55, 56). The acceleration of global climate change, along with related water, waste, agriculture and deforestation challenges, act as "threat multipliers" impinging on energy security worldwide (57). The Deepwater Horizon spill in the Gulf of Mexico, with its deleterious impacts on local communities dependent on fisheries, wetlands, and tourism for their livelihoods, underscores all too well the nexus between environmental degradation and socioeconomic well-being.

2.5. All Together Now

A number of examples illustrate the necessity of meeting all four criteria—availability, affordability, efficiency, and environmental stewardship—holistically. Protecting the shipping lanes used by oil tankers with military force secures supply, meeting the criterion of availability, but diverts attention and resources from pursuing alternatives to petroleum, failing to meet the criterion of stewardship. Increasing energy crops to produce biofuels and reduce petroleum dependency in the transport sector could adversely affect environmental stewardship through the widespread use of fertilizers, destructive farming practices, and the replacement of biologically diverse ecosystems with monocultures. Stockpiling petroleum and natural gas through strategic reserves can serve as a buffer against price shocks, but also offers just the kind of centralized targets that terrorists and saboteurs find attractive. **Figure 1** illustrates some of the conflicts between components of energy security. Trade-offs often occur between options that are effective along one dimension but adversely impact other aspects of security. Given the abundant illustrations of such conflicts, it would appear that most countries overtly or inadvertently pursued technologies and policies that involve accomplishing progress in one energy security domain only by eroding another.

Consider a few examples from around the world of how some countries pursue one of the four criteria even at the expense of each of the other three. A study of large-scale energy projects in Thailand, Myanmar, and Laos found that, although the construction of regional interstate natural gas pipelines and hydroelectric projects enhanced the availability of energy supply, such projects exacerbated social tension, worsened the gap between rich and poor, hastened environmental degradation, and intensified various manifestations of human insecurity, ultimately making electricity and energy more expensive (58). International funding by the European Union on a coal-to-liquids project has helped some countries reduce dependency on foreign sources of oil, but this strategy conflicts with efforts to fight climate change (59). The United States has started shifting from the use of coal to natural gas in the power sector to reduce greenhouse gas emissions, but this has exacerbated dependency on foreign sources of liquefied natural gas (60).

3. QUANTIFYING ENERGY SECURITY AND EVALUATING PERFORMANCE

These examples, and the countless more that we have not mentioned, underscore the importance of pursuing a comprehensive notion of energy security, one that does not achieve secure supply and affordable prices at the expense of stewardship and efficiency, or vice versa. Recognizing that each criterion does not exist in a vacuum and that each is of comparable importance, we have developed 10 indicators that constitute an Energy Security Index (see **Table 1**). Note that, in each case, the metric is an inverse measure of security; that is, the higher the value is, the lower energy security is.

To reflect availability, oil import dependency, natural gas import dependency, and dependency on petroleum transport fuels serve as useful indicators (6–7, 61). Oil import dependency and natural gas import dependency reflect how reliant a country is on foreign supplies of petroleum (mostly used in transport) and natural gas (a feedstock for industrial activity and electricity) and also document changes in the supply mix for the world's first and third most-used fuels (the second is coal). The presence of alternative fuels, such as ethanol and biodiesel, also reveals how far countries have moved away from dependency on petroleum (33). To reflect affordability, the prices of electricity and gasoline at the retail level serve as important metrics. We decided to track residential prices for electricity and gasoline consumption rather than diesel or jet fuel because homes and passenger vehicles account for a majority of the energy used by ordinary people (62, 63). We elected not to use Gini coefficients and other metrics associated with equitable access owing to concerns over data quality and availability as well as the fact that our sample of countries is from the OECD, and therefore highly industrialized, making access to energy less of an issue than for emerging economies and developing countries. To reflect energy and economic efficiency, metrics such as energy intensity, per capita electricity use, and on-road fuel intensity of passenger vehicles show different but important dimensions. Perhaps the most important of these is energy intensity, a measure indicating the amount of energy used to produce a unit of gross domestic product (GDP)

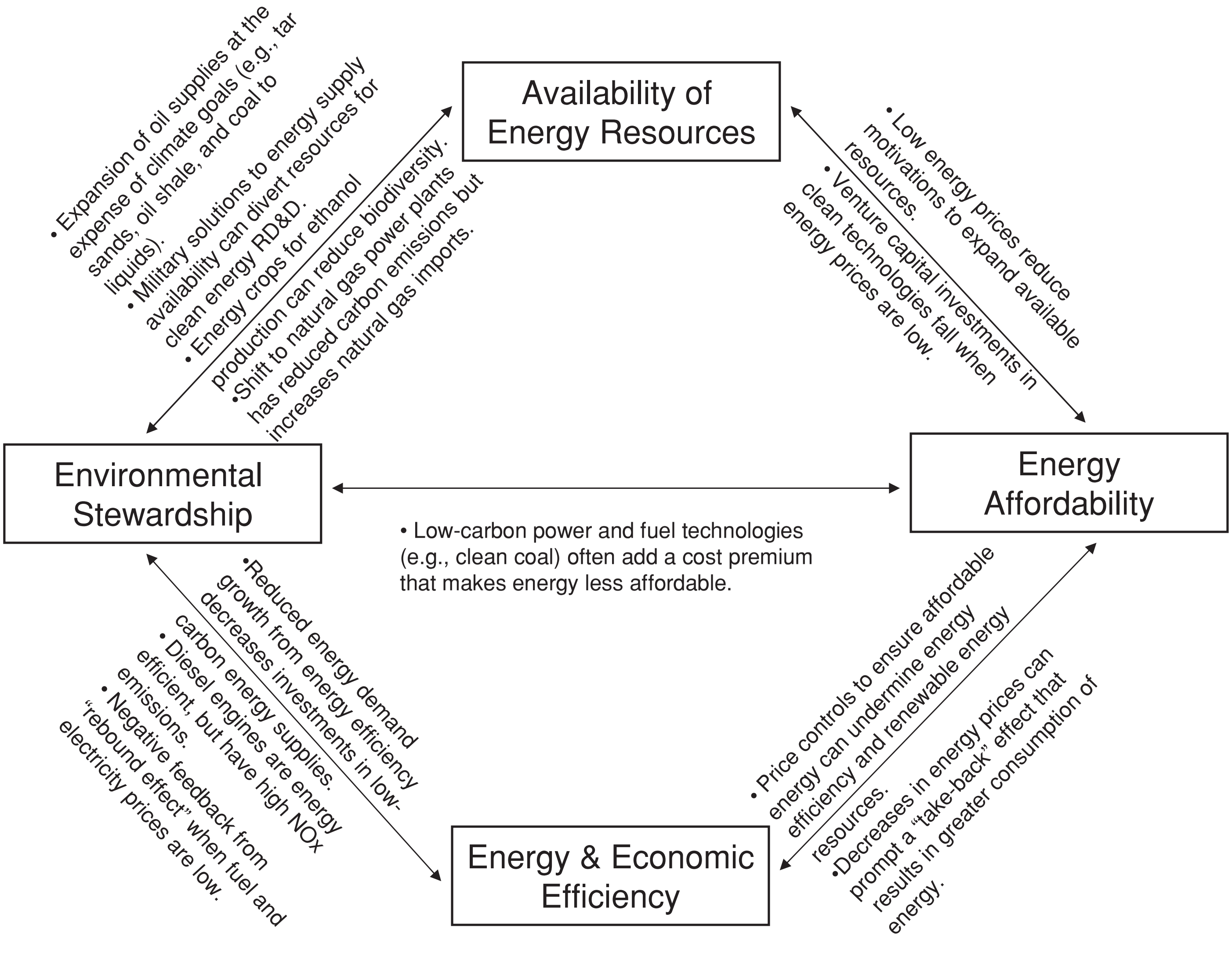


Figure 1

Conflicts between components of energy security. RD&D, research design and development.

Table 1 Defining and measuring energy security

Criteria	Underlying values	Explanation of criterion	Indicators of energy security
Availability	Independence, diversification, reliability	Diversifying the fuels used to provide energy services as well as the location of facilities using those fuels, promoting energy systems that can recover quickly from attack or disruption, and minimizing dependency on foreign suppliers	Oil import dependency, natural gas import dependency, dependence on petroleum transport fuels
Affordability	Equity	Providing energy services that are affordable for consumers and minimizing price volatility	Retail electricity prices, retail gasoline/petrol prices
Energy and economic efficiency	Innovation, resource custodianship, minimization of waste	Improving the performance of energy equipment and altering consumer attitudes	Energy intensity, per capita electricity use, on-road fuel intensity of passenger vehicles
Environmental stewardship	Sustainability	Protecting the natural environment and future generations	SO_2 and CO_2 emissions

(64, 65).[4] By correlating energy use with economic output, the measure thus encompasses patterns of consumption and use for industries, government facilities, consumers, and multiple sectors all at once. Per capita electricity consumption and on-road fuel economy for passenger vehicles also show how efficient individual technologies have become at the end-user level. To reflect environmental stewardship, aggregate sulfur dioxide (SO_2) emissions and carbon dioxide (CO_2) emissions reveal how far countries have gone toward mitigating greenhouse gas emissions, acid rain, and noxious air pollution (66, 67). These indicators also help show relative progress in how governments have implemented national climate change programs.

We collected data on these 10 indicators and metrics for 22 OECD countries from 1970 to 2007, with a few exceptions and caveats as follows:

- Reliable data for energy intensity was only available for 1980 and 2005; fuel economy data was available for 2005 instead of 2007; and SO_2 emissions data was available for 2000 instead of 2007.
- Our index is not meant to imply that quantitative measures of energy security are perfect or that reducing complex situations to numbers is without problems. Numerical indices often highlight not what is most significant or meaningful but merely what is measurable. Quantitative measurements, especially those taken out of context, can also conceal important nuances and variability. Does a reduction in the energy intensity of a given country mean that its economy is becoming more energy efficient, for instance, or that instead more energy-intense products are being imported from elsewhere and energy-intensive jobs outsourced? (See Reference 68.)
- Collecting data for this study was tedious and difficult. Most of it was not available online, and the data for 1970 involved much digging through libraries. Historical data from International Energy Agency publications and archives are inconsistent, and discrepancies found in data and reports published by different

[4]We also analyzed energy intensity in terms of energy use per unit of purchase power parity (PPP), which involves equalizing the purchasing power of different currencies based on a given basket of goods. Because the results were essentially identical between the two metrics, we elected to use the more common GDP measure. To those wishing to replicate our approach to non-OECD countries, converting from GDP based on exchange rate to GDP based on PPP produces roughly the same results because our dataset is limited to OECD countries. This would not be the case for countries that have large socioeconomic disparities between them.

Table 2 Energy Security Performance Index for 22 Organisation for Economic Co-operation and Development countries for 1970 (in \$2007)[a]

Country	Oil import dependence (%)[b]	Dependence on petroleum transport fuels (%)[c]	On-road fuel intensity (gpm)[d]	Energy per GDP intensity (thousand Btu/US\$GDP)[a,e,f]	Electricity use (kWh per capita)[g]	Natural gas import dependence (%)[d]	Nominal electricity retail prices (US¢/kWh)[h]	Nominal gasoline prices (US\$/liter)[i]	SO_2 emissions (million tons)[j]	CO_2 emissions (million tons)[b]
Australia	67	96.1	0.059	10.3	3,919	0	3.7	0.26	1.6	148
Austria	57	94.3	0.048	8.5	3,302	34	18	1.32	0.4	51
Belgium	100	98.4	0.045	12.2	3,399	99	18.5	1.74	1.2	126
Canada	46	97.3	0.071	18.7	9,529	1	3.7	0.37	4.1	341
Denmark	99	98.1	0.042	8.8	3,211	0	9.5	0.42	0.3	62
Finland	100	97.7	0.045	12.6	4,885	100	5.3	0.53	0.4	40
France	98	96.3	0.036	8.7	2,882	35	7.9	0.74	3.5	439
Germany	92	96.4	0.042	9.8	2,962	24	15.9	1.16	6.9	1,027
Greece	99	98.3	0.048	6.0	1,118	0	2.1	0.58	0.3	24
Ireland	98	97.2	0.045	9.0	1,956	0	6.9	0.58	0.2	19
Italy	97	98.7	0.036	7.1	2,262	0	6.3	0.42	2.6	297
Japan	100	98.2	0.050	7.8	3,445	32	48.6	1.27	5.1	769
Netherlands	97	98.0	0.040	12.9	3,110	0	15.3	1.00	1.4	142
New Zealand	100	95.6	0.053	11.0	4,941	0	3.17	0.48	0.1	14
Norway	100	97.5	0.043	16.4	14,785	0	2.6	0.42	0.2	28
Portugal	99	98.0	0.043	4.4	830	0	20.6	1.59	0.1	15
Spain	99	97.3	0.037	7.0	1,623	85	5.8	0.37	1.1	117
Sweden	100	97.5	0.050	13.7	8,048	0	3.2	0.32	0.9	92
Switzerland	100	96.9	0.043	7.6	4,693	100	4.0	1.59	0.1	40
Turkey	53	97.7	0.067	5.0	241	0	21.1	0.11	0.8	43
United Kingdom	100	97.7	0.048	9.9	4,489	7	5.3	0.58	8.6	653
United States	22	95.1	0.077	14.7	8,022	4	7.0	0.42	31.2	4,413

Median	99	97.5	0.045	9.4	3,351	1	6.6	0.56	1.0	105
Mean	87	97.2	0.049	10.1	4,257	24	10.7	0.74	3.2	405

[a] Data for energy intensity starts at 1980 instead of 1970 (70–79).
[b] All remaining figures come from the International Energy Agency (IEA) (78, 79).
[c] Specific values for on-road fuel intensity for Austria, Canada, Denmark, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, United Kingdom, and the United States are from Schipper & Fulton (70).
[d] On-road fuel intensity values for remaining countries are from OECD averages (74). Abbreviation: gpm, gallons per mile.
[e] Values for population figures and gross domestic product are from the U.S. Economic Research Service (71).
[f] Figures for energy intensity are from 1980 data compiled by the U.S. Energy Information Administration (72) and presume market exchange rates adjusted for 2007 U.S. dollars.
[g] Figures for electricity consumption per capita exclude electricity exports and are calculated by dividing IEA data (83) into the total national consumption (in GWh) by the reported national population (71).
[h] Values for retail electricity prices, adjusted to 2007 U.S. dollars, are from the IEA (75) and are adjusted according to the Organisation of Economic Co-operation and Development (OECD) (74).
[i] Values for retail gasoline prices presume premium gasoline, exclude taxes, are adjusted to 2007 U.S. dollars, are from Bentzen (73), and are adjusted according to the OECD (74).
[j] Some SO_2 emissions come from Spiro et al. (76, pp. 6023–36) and Lefohn et al. (77).

agencies (e.g., the Energy Information Administration, World Resources Institute, United Nations, and the World Bank) are troubling.

- Our study weighted the different components of energy security and their indicators equally, rather than assigning greater value to particular dimensions.
- The unit of analysis for our index was the nation state, which may gloss over the importance of energy policy decisions being made at different scales (i.e., multilateral organizations, such as the International Energy Agency, or substate actors, such as electric utilities, energy companies, nongovernmental organizations, and individuals).

That said, we do believe that these 10 indicators are valid representations of how well countries have provided energy services and promoted energy security, and the results may be surprising to some. **Tables 2** and **3** show the data for each of the 10 indicators for the 22 selected countries in 1970 and 2007. Note that the two environmental indicators are not normalized for economic activity or population. As a result, countries with large and proportionately increasing SO_2 and CO_2 emissions perform poorly. From the vantage point of the environment, this is appropriate because environmental damage is directly proportionate to total emissions. By contrast, one could argue that it is appropriate to normalize these trends to account for growing populations or economic activity. We have, therefore, presented per capita indicators for these two measures alongside aggregate numbers.

We then assessed the relative progress of each country according to each indicator. This was done first by assigning a value of −1 if the indicator worsened over time, 0 if it stayed the same, and +1 if it improved, something we call the "simple scoring exercise." All indicators were weighed equally, with the results presented in **Table 4** and **Figure 2**. This approach prevents large changes in any one indicator from dominating the measure of relative progress. However, the approach also means

Table 3 Energy Security Performance Index for 22 Organisation for Economic Co-operation and Development (OECD) countries for 2007

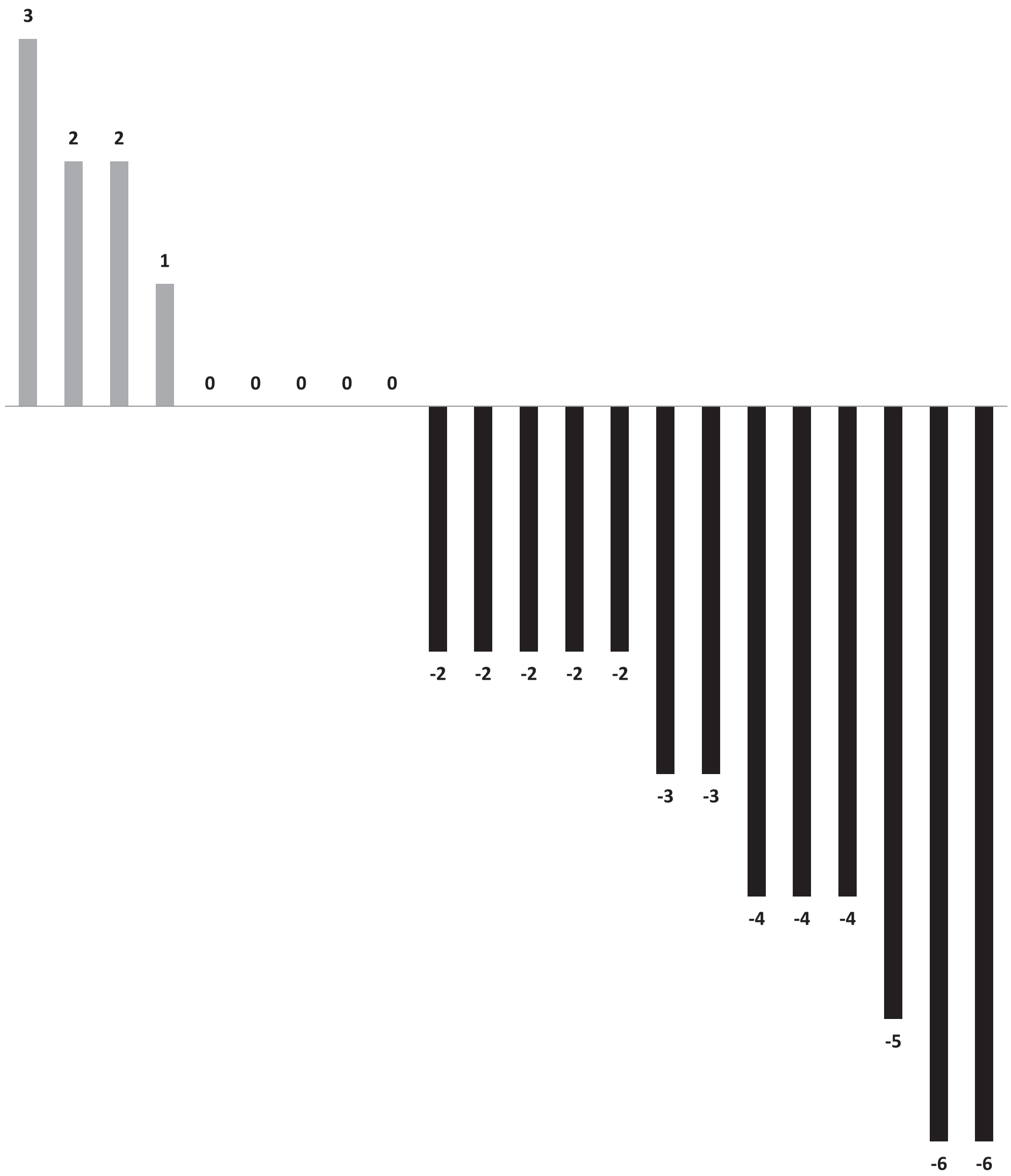
Country	Oil import dependence (%)[a]	Dependence on petroleum transport fuels (%)[b]	On-road fuel intensity (gpm)[c,d,e]	Energy per GDP intensity (thousand Btu/US$GDP)[c,f]	Electricity use (kWh/capita)[a]	Natural gas import dependence (%)[a]	Real electricity retail prices (US¢/kWh)[a]	Real gasoline prices ($/liter)[g]	SO_2 emissions (million tons)[h]	CO_2 emissions (million tons)[h]
Australia	37	98.3	0.038	9.0	11,309	0	12.5	1.24	2.6	394
Austria	91	96.3	0.032	7.0	8,090	95	22.6	1.81	0.2	66
Belgium	99	98.1	0.034	9.2	8,688	100	16.5	2.20	1.3	103
Canada	0	98.8	0.043	13.8	16,766	0	7.6	1.08	2.9	573
Denmark	0	97.7	0.033	5.2	6,864	0	38.2	2.05	0.1	50
Finland	96	98.1	0.034	8.8	17,178	93	17.1	2.12	0.3	64
France	96	98.1	0.031	7.2	7,585	97	17.3	2.03	1.3	353
Germany	94	98.1	0.034	7.0	7,175	79	23.1	2.10	2.4	790
Greece	99	98.1	0.034	6.8	5,372	99	13.0	1.19	0.8	97
Ireland	100	98.1	0.034	4.9	6,500	86	24.7	1.77	0.1	44
Italy	93	97.5	0.030	5.8	5,762	85	27.2	2.06	1.5	430
Japan	97	98.2	0.045	6.5	8,220	93	17.8	1.46	2.6	1,227
Netherlands	91	98.1	0.033	9.8	7,057	59	24.2	2.28	1.0	179
New Zealand	69	97.1	0.034	9.1	9,746	0	17.8	1.35	0.1	36
Norway	0	98.1	0.034	12.8	24,295	0	17.5	2.32	0.6	36
Portugal	98	98.1	0.034	5.9	4,799	100	23.3	2.07	0.2	55
Spain	98	98.1	0.032	7.1	6,213	100	18.7	1.64	2.1	346
Sweden	99	98.1	0.036	9.1	15,230	100	12.7	1.99	0.3	45
Switzerland	99	98.1	0.034	5.8	8,279	100	15.6	1.65	0.1	38
Turkey	94	96.3	0.034	6.1	2,053	97	15.8	2.60	2.1	266
United Kingdom	4	96.3	0.032	6.0	6,192	8	22.7	2.07	1.6	524
United States	59	97.1	0.050	9.1	13,515	17	10.3	0.82	17.8	5,725
Median	94	98.1	0.034	7.1	7,838	90	17.7	2.01	1.2	141
Mean	73	2.2	0.036	7.8	9,404	64	18.9	1.81	1.9	520

[a] All remaining figures are from the U.S. Energy Information Administration (82) and International Energy Agency (83), with adjustments made according to the OECD (74) when data was not available for 2007.
[b] Data for dependence on petroleum transport fuels is derived from oil, ethanol and biodiesel use, report EU targets for most European countries, and come from the OECD (81).
[c] Data for energy per GDP intensity and on-road fuel intensity is for 2005 instead of 2007 (78, 79, 80, 81). Abbreviation: gpm, gallons per mile.
[d] Specific values for on-road fuel intensity economy for Austria, Canada, Denmark, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, United Kingdom, and United States are from Schipper & Fulton (70).
[e] On-road fuel intensity values for remaining countries are from European and OECD averages.
[f] Energy intensity is from the U.S. Energy Information Administration (72) and adjusted for purchase power parity (PPP).
[g] Values for retail gasoline exclude taxes for the United States and presume unleaded premium or equivalent grade fuel.
[h] Data for SO_2 emissions are from 2000 instead of 2007 and are from the World Resources Institute (80).

Table 4 **Energy security performance z-scores 1970 to 2007**

Country	Oil import dependence (%)	Petroleum transport fuels (%)	On-road fuel intensity (gpm)	Energy per GDP intensity (thousand Btu/ US$GDP)	Electricity use (kWh per capita)	Natural gas import dependence (%)	Nominal electricity retail prices (US¢/kWh)	Nominal gasoline prices (US$/liter)	SO_2 emissions (million tons)	CO_2 emissions (million tons)	Final score
Australia	1	−1	1	1	−1	0	−1	−1	−1	−1	**−3**
Austria	−1	−1	1	1	−1	−1	−1	−1	1	−1	**−4**
Belgium	1	1	1	1	−1	−1	1	−1	−1	1	**2**
Canada	1	−1	1	1	−1	1	−1	−1	1	−1	**0**
Denmark	1	1	1	1	−1	0	−1	−1	1	1	**3**
Finland	1	−1	1	1	−1	1	−1	−1	1	−1	**0**
France	1	−1	1	1	−1	−1	−1	−1	1	1	**0**
Germany	−1	−1	1	1	−1	−1	−1	−1	1	1	**−2**
Greece	0	1	1	−1	−1	−1	−1	−1	−1	−1	**−5**
Ireland	−1	−1	1	1	−1	−1	−1	−1	1	−1	**−4**
Italy	1	1	1	1	−1	−1	−1	−1	1	−1	**0**
Japan	1	0	1	1	−1	−1	1	−1	1	−1	**1**
Netherlands	1	−1	1	1	−1	−1	−1	−1	1	−1	**−2**
New Zealand	1	−1	1	1	−1	0	−1	−1	0	−1	**−2**
Norway	1	−1	1	1	−1	0	−1	−1	−1	−1	**−3**
Portugal	1	−1	1	−1	−1	−1	−1	−1	−1	−1	**−6**
Spain	1	−1	1	−1	−1	−1	−1	−1	−1	−1	**−6**
Sweden	1	−1	1	1	−1	−1	−1	−1	1	1	**0**
Switzerland	1	−1	1	1	−1	0	−1	−1	0	−1	**−2**
Turkey	−1	1	1	1	−1	−1	1	−1	−1	−1	**−2**
United Kingdom	1	1	1	1	−1	−1	−1	−1	1	1	**2**
United States	−1	−1	1	1	−1	−1	−1	−1	1	−1	**−4**
Mean	0.5	−0.4	1.0	0.7	−1.0	−0.6	−0.7	−1.0	0.3	−0.5	−1.7

Denmark	3
Belgium	2
United Kingdom	2
Japan	1
Canada	0
Finland	0
France	0
Italy	0
Sweden	0
Germany	-2
Netherlands	-2
New Zealand	-2
Switzerland	-2
Turkey	-2
Australia	-3
Norway	-3
Austria	-4
Ireland	-4
United States	-4
Greece	-5
Portugal	-6
Spain	-6



that a minute change in one indicator has the same influence as a large change in another indicator. Of course, to the extent that most of the countries are responding to global trends (such as the increasing share of oil reserves located in non-OECD countries), the indicators could reflect "common cause variation" (69).

To account for "special cause variation," which occurs when a country departs from the norm as the result of particular characteristics, such as energy policies or resource endowments, we evaluated relative magnitudes of change using z-scores. Z-scores are deployed as a method for normalizing indicators that use diverse units of measurement. The result is a dimensionless quantity that indicates how many standard deviations a country is above or below the mean of the 22 OECD countries. To complete our comparative scoring, we created z-scores for each of the 10 indicators in 1970 and 2007 by subtracting the mean value for each data point and dividing by the indicator's standard deviation. We first did this for the 10 indicators shown in **Table 2**, and then we repeated the process using the two per capita environmental indicators (along with the other eight indicators). By comparing z-scores, we can assess how a country has performed relative to the performance of other countries. The results of this z-scoring exercise are shown in **Figure 3** and **Tables 5** and **6**. **Figure 3*a*** indicates that the United States has the lowest energy security of all 22 countries, both in 1970 and still in 2007. Although four of its indicators deteriorated over this time period, the difference between its z-scores over time was close to zero, placing the United States right on the diagonal line in **Figure 3*a***. Countries to the right of the diagonal line have worsened in terms of their energy security relative to the z-scores of other countries, e.g, Spain, France, and Ireland, whereas Japan and Denmark are both above the line.

When emissions are normalized for population, **Figure 3*b*** shows that the United States still exhibits a lower-than-average energy security, but it no longer has the worst scores in 1970 and 2007 (Belgium moves into that position). The adjustment occurs because the large absolute SO_2 and CO_2 emissions of the United States are not as extreme compared to other countries when normalized by population. Japan and Denmark continued to have improving scores over the nearly four decades. However, Japan's energy security in 2007 becomes more comparable to that of the United States when per capita indicators are used, reflecting a strong improvement by Japan.

4. DISCUSSION OF RESULTS

The results of our simple scoring exercise suggest that Denmark, Belgium, the United Kingdom, and Japan have experienced the greatest improvement in energy security; Canada, Finland, France, Italy, and Sweden have stagnated; Germany, the Netherlands, New Zealand, Switzerland, Turkey, Australia, Norway, Austria, Ireland, and the United States have done poorly; and Greece, Portugal, and Spain have experienced the worst declines in energy security.

A few additional trends are worth noting. First, scores are highly variable within the OECD, implying that the countries examined have taken diverse and divergent paths toward energy policy and security as well as reflecting different natural resource endowments. Second, no country scored perfectly, meaning that none improved in all categories. Denmark, with one of the best scores, led the pack with an improvement on three indicators of energy

Figure 2

Most to least improved energy security rankings, based on 1970–2007 trends. The relative progress of each country according to each of the 10 indicators described above is shown as follows: by assigning a value of −1 if the indicator worsened over time, 0 if it stayed the same, and +1 if it improved.

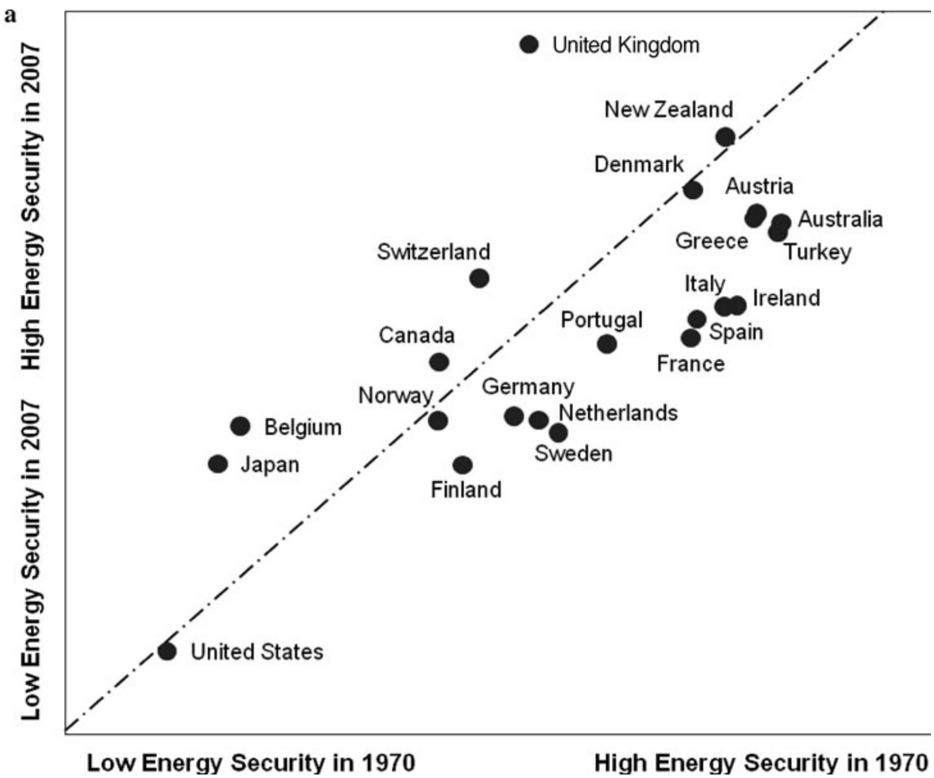


Figure 3

Z-scores of energy security in 1970 and 2007: (*a*) unadjusted and (*b*) adjusted using per capita emission values. Countries to the right of the diagonal line have deteriorated in energy security.

security—more than any other country—and a high z-score. Third, a majority of countries did poorly, with 13 countries experiencing a "net" deterioration on two to six indicators between 1970 and 2007, implying that their energy security has worsened. Fourth, some metrics, such as energy intensity and on-road fuel intensity for passenger vehicles, have almost universally improved, whereas others, such as electricity consumption per capita, electricity prices, and gasoline prices have almost universally deteriorated.

Using the same statistical data, supplemented by a review of the published literature, we explore four countries in greater detail, focusing on their energy security scores and the strategic actions that have led to them. The four countries represent one of the strongest (Denmark), one of the most improved in terms of energy security (Japan), one with weak and stagnant energy security (United States), and one with deteriorating energy security (Spain) (see **Figures 2** and **3**). We explore each of these cases in detail in the following four subsections, which provide results from a deeper review of country-specific literature for policies and energy-related datasets (64, 84, 85–95). **Figure 4** profiles each of the 10 energy security indicators for these four countries from 1970 through 2007.

4.1. Denmark

Denmark has exhibited considerable success in improving its energy security compared to the other countries analyzed. Since 1970, Denmark has transitioned from being 99% dependent on foreign energy sources, such as oil

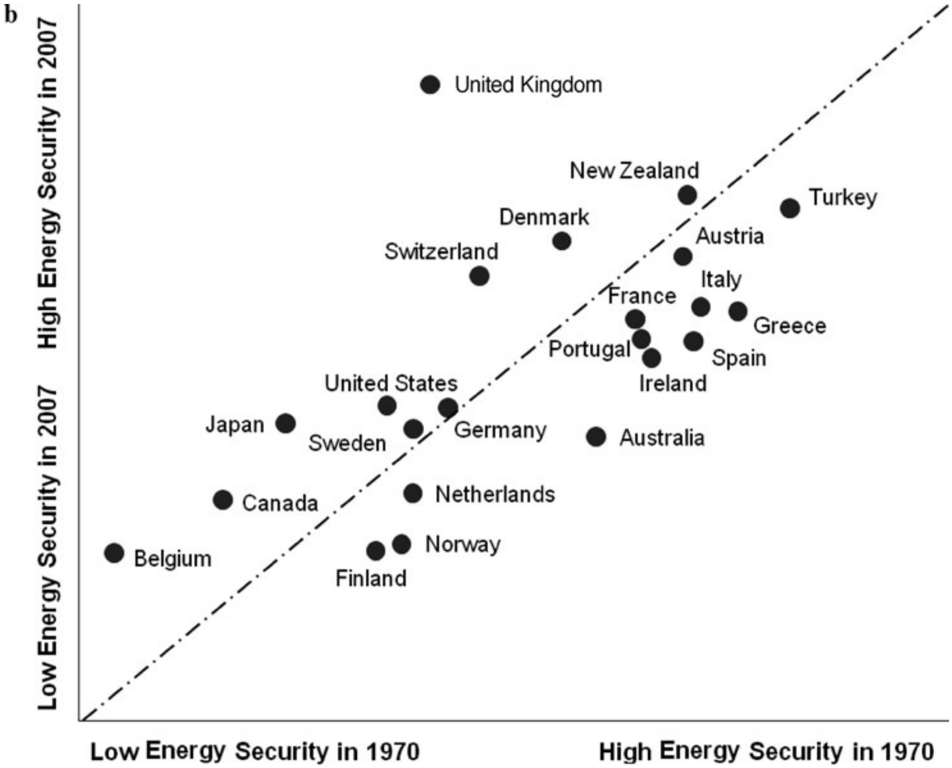


Figure 3

(*Continued*)

and coal, to becoming a net exporter of natural gas, oil, and electricity today. Over the same period, Denmark has improved its reliance on nonpetroleum transportation fuel, decreased its energy intensity by almost a factor of two, and lowered its aggregate CO_2 and SO_2 emissions. The only areas where Denmark did not improve were in electricity use per capita, electricity prices, and gasoline prices, and these were areas where almost no country improved.

Denmark is now the unchallenged world leader in terms of wind energy, exporting $8 billion in wind turbine technology and equipment per year, and Denmark also boasts one of the lowest energy intensities in the European Union (96). Primary energy consumption nationally grew just 4% from 1980 to 2004, even though the economy grew more than 64% in fixed prices. At the same time, more renewable energy replaced fossil fuels, and total CO_2 emissions decreased by 16%. Therefore, the CO_2 emission intensity—the amount of CO_2 emitted per unit of GDP—was 48% lower in 2004 than it was in 1980.

The most obvious factor responsible for such improvement is strong political leadership and well-designed, consistent policy mechanisms aimed at improving energy efficiency and promoting renewable energy. Denmark implemented energy taxes in 1974 as a response to the energy crises and used the billions in dollars of revenue to invest in wind power, biomass, and small-scale combined heat and power units. Furthermore, the taxes sent price signals that encouraged voluntary energy efficiency measures. Denmark mandated energy efficiency standards for new buildings and tightened them over a period of 30 years. Danish regulators also designed investment subsidies and

Table 5 Unadjusted energy security performance z-scores 1970 to 2007

Country	Energy security index[a]		Difference
	1970	2007	
United Kingdom	0.716	−6.261	6.977
Belgium	5.884	2.178	3.706
Japan	6.278	3.013	3.265
Switzerland	1.603	−1.093	2.696
Canada	2.329	0.761	1.568
New Zealand	−2.790	−4.225	1.436
Denmark	−2.199	−3.046	0.847
Norway	2.350	2.050	0.300
United States	7.183	7.154	0.029
Austria	−3.339	−2.516	−0.823
Greece	−3.291	−2.411	−0.880
Germany	0.985	1.964	−0.979
Portugal	−0.671	0.367	−1.039
Finland	1.907	3.035	−1.128
Australia	−3.777	−2.317	−1.460
Netherlands	0.554	2.042	−1.488
Turkey	−3.723	−2.109	−1.614
Spain	−2.276	−0.181	−2.095
Sweden	0.198	2.317	−2.119
Italy	−2.763	−0.465	−2.297
France	−2.166	0.228	−2.394
Ireland	−2.993	−0.485	−2.508

[a]Larger indexes indicate lower energy security; positive differences therefore indicate improved energy security.

feed-in tariffs, forcing utilities to buy all power produced from renewable energy technologies at a rate equal to 70% to 85% the consumer retail price of electricity in a given distribution area, and they later regulated that all renewable power providers be given priority access to the grid (97). The government levied a general carbon tax on all forms of energy, set strict vehicle fuel economy standards, and later adopted European standards pledging to decrease CO_2 emissions from automobiles to 140 g of CO_2 emitted per kilometer driven by 2008, which help explain Denmark's lowered emissions of greenhouse gases.

Although these efforts have improved many aspects of energy security, they have also made energy more expensive. Denmark's taxes do mean that electricity prices are the highest in the European Union at about 38 cents per kWh, and the price of petrol is more expensive than that of 13 other OECD countries. Denmark's experience does suggest that improving availability, efficiency, and stewardship can trade off with affordability, but overall the country appears to be one of the most energy secure in the OECD.

4.2. Japan

A similar pattern of strong government support for energy security exists in Japan, which has seen improvements to five of our energy security indicators, offset by deterioration in only four. Since 1970, Japan has lessened its dependency on oil and has improved vehicle fuel economy slightly but has increased its dependency on natural gas and has significantly increased its SO_2 and CO_2 emissions despite

Table 6 Energy security performance z-scores 1970 to 2007 adjusted with per capita emissions

Country	Energy security index[a]		Difference
	1970	2007	
United Kingdom	1.762	−6.975	8.737
Belgium	8.278	4.781	3.498
Japan	4.739	1.520	3.220
Switzerland	0.752	−2.183	2.935
Canada	6.034	3.434	2.600
Denmark	−0.949	−3.054	2.105
United States	2.654	1.072	1.582
New Zealand	−3.532	−4.219	0.687
Sweden	2.108	1.654	0.453
Germany	1.392	1.129	0.263
Austria	−3.441	−2.669	−0.772
Netherlands	2.125	3.276	−1.151
France	−2.454	−1.095	−1.359
Turkey	−5.643	−3.874	−1.769
Finland	2.887	4.722	−1.835
Portugal	−2.581	−0.586	−1.995
Norway	2.353	4.561	−2.208
Italy	−3.807	−1.404	−2.404
Ireland	−2.794	−0.121	−2.673
Spain	−3.662	−0.535	−3.127
Greece	−4.571	−1.294	−3.276
Australia	−1.651	1.859	−3.510

[a]Larger indexes indicate lower energy security; positive differences therefore indicate improved energy security.

its promises under the Kyoto Protocol. Electricity use per capita more than doubled, and gasoline prices rose. But Japan was also one of only three countries where electricity prices decreased, and its energy intensity also improved.

Overall, Japan recorded unprecedented levels of economic growth between 1970 and 2007, closing the gap in per capita income, raising standards of living, and improving labor productivity compared to Western Europe and North America while drastically improving energy efficiency (98). Devastated after World War II, Japan's immediate problem was securing an adequate supply of energy to fuel reconstruction and industrial growth, and the country's energy needs were met predominately by imported oil and domestic coal. Population density in major cities, such as Tokyo, however, made the mounting costs of air and water pollution visible, and environmental awareness was starting to rise at the same time the Arab oil embargo hit. By 1973, the time of the oil crisis, petroleum accounted for nearly 80% of total energy demand, and the crisis precipitated nothing less than panic (99).

Energy security was given highest priority, and from 1973 to 1975, the government announced a formal energy security strategy that consisted of reducing dependency on petroleum, diversifying domestic energy supply, aggressively promoting energy conservation, and pushing research and development on solar energy, geothermal technologies, hydrogen, and coal gasification under its Sunshine Project (100). Japan's Ministry of International Trade and Industry (MITI) began their Moonlight Project in 1978 to develop more efficient power technologies

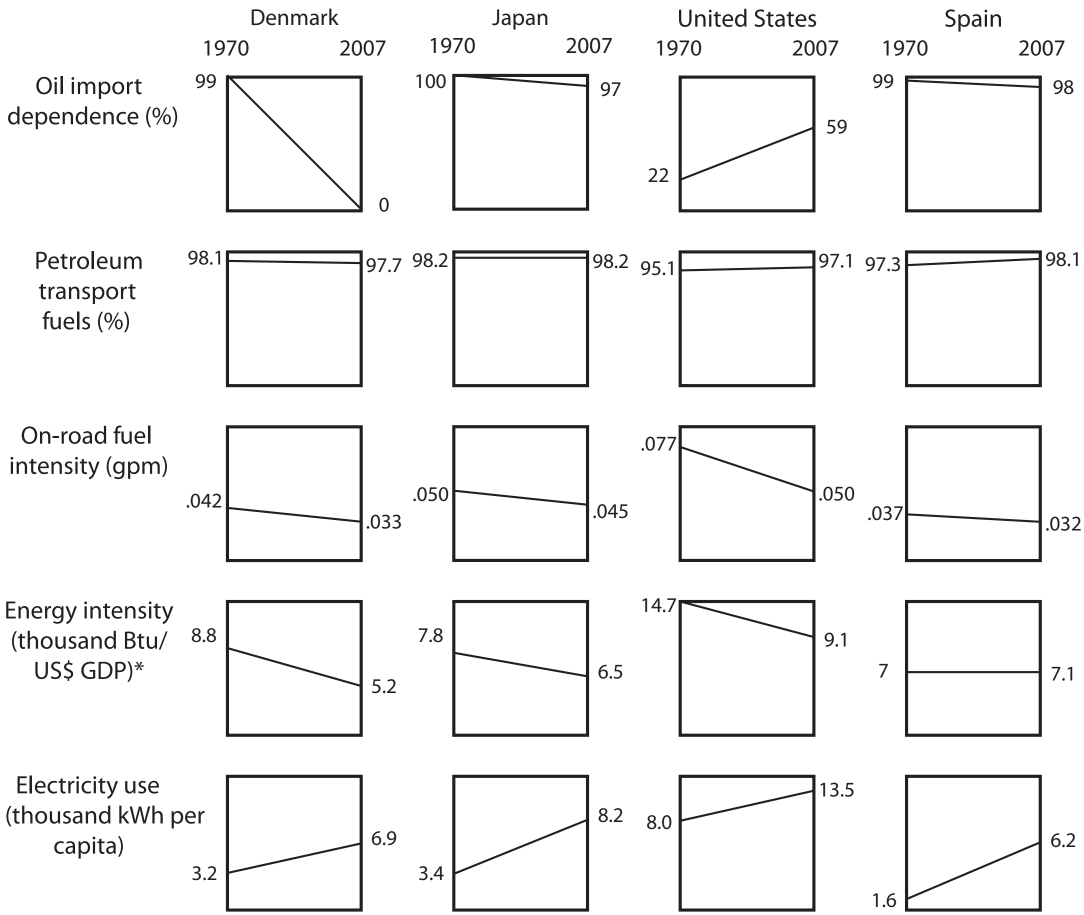


Figure 4

Energy security progress for Denmark, Japan, United States, and Spain, 1970 to 2007. Because each of the indicators is inversely related to energy security, rising lines represent worsening trends.

and early fuel cells. In addition, the government offered free energy audits for smaller firms and issued standards for combustion and heating devices in industry to improve energy efficiency. These standards applied to more than 3,500 factories in the manufacturing, mining, and energy supply sectors, and the government also required these facilities to hire a certified energy manager and to publicly disclose their energy consumption annually.

The 1980s saw Japan pass its Alternative Energy Law with provisions forcing suppliers to adopt natural gas and renewable power sources, along with the creation of tax incentives and low-interest loans for industrial energy efficiency measures, emphasizing the petrochemicals, refining, cement, and paper industries (101). The first minimum energy performance standards came in 1983 for refrigerators and air conditioners, and such standards were later expanded to virtually all appliances, including the underrated electric toilet seat warmer. The appliance standards were very successful at reducing electricity consumption. Average electricity use for refrigerators, for example, declined by 15% from 1979 to 1997 while the average refrigerator size increased by 90%. Japanese regulators also applied their performance

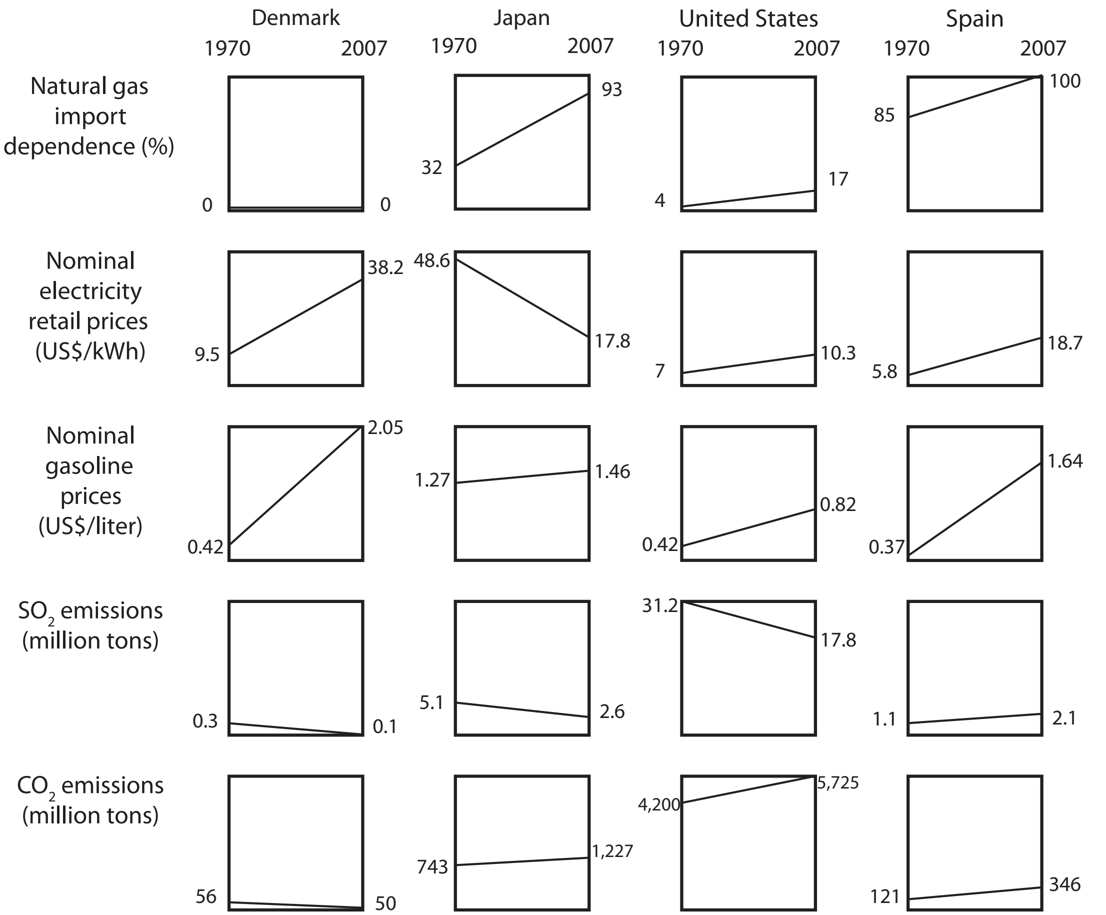


Figure 4

(*Continued*)

standards to imported technology, ranging from automobiles and televisions to air conditioners and computers, and demanded that the efficiency level of new products meet the best-performing product in the market, in some cases requiring energy efficiency improvements of more than 50% (95). Japanese regulators used a combination of net metering guidelines, ambitious targets, direct subsidies, and a solar roofs initiative to grow the installed capacity of solar photovoltaics from 19 MW in 1992 to 887 MW in 2003 (and expect capacity to surpass 4,820 MW by 2010) (102). With far less land area and about half the solar insolation of California, Japan has about three times as much solar PV capacity as the entire United States and is the world's second largest producer and user of solar PV (102).

Japanese progress, however, has been more tempered than that of Denmark. Energy use per capita increased from 1973 to 2005 for both Japanese households and passenger travel. Although the government promoted strict performance standards for appliances, it set only voluntary standards for buildings and did not ramp up financial incentives until the late 1990s. Japan did require efficiency standards and efficiency labeling for automobiles, and these led to a 12% increase in fuel economy from 1979 to 1985 and another 8.5% increase from 1990 to 2000. Such improvement, however, was offset by a doubling of transport energy use between 1973 and 2001 owing to the growth in vehicle ownership and increases in vehicle size. Private automobile travel rose in Japan from a modest 42.5% in 1970 to 55.9% in 1987 (84). Moreover, cheap oil prices in the mid-1980s encouraged energy consumption. Energy demand growth as a whole averaged only 0.2% between 1973 and 1986, but jumped to 4% between 1987 and 1991 (99).

4.3. United States

Based on the simple directional change of our 10 energy security indicators, the United States fared poorly compared to most of the other 21 countries—with only Greece, Portugal, and Spain performing worse. The country has improved in only three of the indicators from 1970 to 2007—energy intensity, fuel economy, and SO_2 emissions. In contrast, the country has become significantly more dependent on foreign supplies of natural gas and oil and remains the world's leading emitter of greenhouse gases.

From 1990 to 2008, the United States expanded its economic output by nearly 65% and per capita incomes grew 35%, yet demand for energy and power resources grew by only 23%, demonstrating that economic growth need not always grow in lock-step with energy consumption (103). Although progress in the adoption of more energy-efficient technologies has saved billions of dollars throughout the economy, most other indicators of energy autonomy demonstrate that the country has become less energy secure over time. Even though energy efficiency has taken root in some sectors of the economy, it has not compensated for the growth in energy consumption that has occurred since 1973, nor will it (if current trends continue) accommodate the growth that forecasters anticipate in coming decades. Moreover, America's dependency on oil from insecure and politically unstable countries has required extensive diplomatic and military efforts that incur huge costs borne by energy users and taxpayers. The country's information economy also remains inextricably tied to reliable power and to just-in-time manufacturing and distribution processes that depend on fleets of petroleum-guzzling trucks and airplanes (104).

The United States remains more susceptible today to oil supply disruptions and price spikes than at any time in the recent past. It has grown to become the world's largest oil consumer by a considerable margin while, at the same time, its domestic oil production has plummeted. Oil imports have filled the expanding gap, accounting for 59% of total U.S. oil consumption in 2007—up from 22% in 1970. The United States has so many automobiles that the number of cars exceeds the number of people with driver's licenses (84).

The United States also continues to see increasing demand for electricity in a way that threatens its ability to meet customer load requirements. The country consumed about 170% more electricity in 2007 than it did in 1970, with electrical power usage growing from 25% of the nation's total energy use in 1970 to 40% today. Efforts resulting from three decades of clean air legislation have decreased SO_2 emissions from electric generators in the United States. Nevertheless, air pollution remains a serious threat to human and ecosystem health. Americans have experienced a rise in respiratory illnesses, and visibility continues to degrade in formerly pristine areas as a result of pollution from vehicles and coal-burning power plants. Beyond air pollution issues, current energy trends will lead to expanded emissions of greenhouse gases, which appear to be contributing to increased global temperatures, recession of glaciers, and more frequent and powerful weather events such as hurricanes.

Because of its huge dependency on imported oil to fuel a transportation sector that has seen little improvement in energy efficiency, the nation could be ravaged by disruptions to oil supplies caused by weather, war, or terrorist attacks. At the same time, growing electricity consumption and reliance on power plants employing natural gas (which increasingly comes from foreign sources) make the electric utility infrastructure more vulnerable to service disruptions. And, although efficiency efforts have successfully stemmed the growth rate of fuel consumption in the past few decades, population increases and economic expansion have forced up the nation's overall use of energy, exacerbating the country's environmental problems.

4.4. Spain

Tied for last in terms of the directional change of our 10 energy security indicators, Spain has shown improvement in only two indicators: a meager reduction in dependency on foreign sources of oil from 99% to 98% and a modest improvement in on-road fuel economy from 27 to 31 miles per gallon. Spain has worsened in every other metric, including energy intensity. Total primary energy use per unit of GDP has fallen for 19 other OECD countries (the two other exceptions are Greece and Portugal), and overall, major OECD economies used a third less primary energy to generate a unit of GDP in 2006 than in the 1970s (95).

Spain has defied this trend. The country lacks sufficient supplies of domestic coal, oil, gas, and uranium; it has experienced ongoing industrialization but has made little improvement in energy efficiency. Thus, the Spanish energy sector is currently suffering from difficulty in controlling greenhouse gas emissions, high prices, increasing reliance on imported fuels, rising levels of growth in energy demand, and stagnating energy efficiency and energy intensity, culminating in a situation even Spanish analysts consider unsustainable (85). Spain's gradual transition to democracy left intact the prevailing economic structures that existed during the Franco regime. Unlike the comparatively progressive governments implementing energy reforms in other OECD countries during the 1970s, bankers and industrial managers continued to play the primary role in Spanish energy policy making (86). Rather than promote energy efficiency or diversification, these stakeholders sought ways to ensure a smooth political transition, maintain economic growth, and retain their political power. These leaders also sought to make Spain itself an island with very little energy exchange with France and Portugal, meaning that improvements in other European markets had little impact on Spain. From 1975 to 1982, alternative sources of policy, such as left-wing parties, environmental groups, trade unions, and consumer advocates, were able to exert little influence over Spanish energy policy. The country thus remained committed to developing conventional forms of supply and strengthening agreements to import energy fuels, but neglected energy efficiency and alternative energy (82, 87, 88). When the Spanish Socialist Workers Party came to power in 1982, energy policy did not break significantly with past patterns.

Whereas energy intensity declined in almost every other OECD country, the late 1980s and most of the 1990s saw sustained growth in energy consumption per unit of GDP in Spain, which increased at an annual rate of 0.75% from 1990 to 1997. Per capita electricity consumption and CO_2 emissions also increased at rates between 2.3% and 2.8% annually over the same period (89). Spanish regulators focused heavily on building nuclear plants in the early 1980s, but their plans were threatened by high costs and the Chernobyl disaster in 1986. Despite a few early policy documents and royal decrees, the country did not seriously consider energy efficiency and conservation until the early 1990s (90, 91). At this time, however, Spanish regulators restructured and liberalized the Spanish electricity market. Although it is often assumed that liberalization improves energy governance and competition, in the case of Spain, it served to only further enhance previous elements of state and corporate control. Regulators abandoned the notion of public service and enabled the privatization of national electricity resources into the hands of a small number of companies. A significant number of mergers and acquisitions occurred in the energy sector, creating massive levels of concentration. The newly integrated energy companies, rather than focusing on the domestic Spanish market, initiated plans for international expansion, attempting to privatize and invest in emerging markets in Latin America (92, 93). Spanish companies established production, refining, and manufacturing centers in Argentina, Brazil, Colombia, and Mexico. The Spanish oil company REPSOL-YPF, the seventh largest in the world, expanded exploration and production to four Latin American countries. Endesa and Iberdrola, some of the world's largest electricity companies, became leading power suppliers for seven countries in South America and Central America. The Spanish company Gas Natural Group also became the largest single investor in Latin American gas markets.

The consolidation and concentration of Spanish energy companies, coupled with comparatively weak political oversight, lack of competition, and a focus on global markets, left little space for consumer advocacy or environmental policy. Throughout the late 1990s, Spanish customers had some of the highest electricity prices in all of Europe, and most consumers generally believed that such high prices reflected a proindustry bias that allowed large cash flows to be funneled into the international expansion of Spanish firms. The consequence has been a deterioration of energy security in almost every metric. Spanish energy intensity increased from 1990 to 2000 by 5% while European intensity decreased by 10.4% (94). The Spanish economy continues to be highly dependent on high-carbon fossil fuels such as oil and coal, which accounted for roughly 60% of energy use in 2007. The situation is further compounded by the mismatch between state, territorial, and national energy policy, which has been very sporadic and irregular, with some regions aggressively pursuing renewables, such as wind and solar, whereas other regions have little penetration of renewable power supplies.

5. CONCLUSIONS

Contemporary notions of energy security are indeed diffuse. Our analysis of more than 90 academic articles on the topic revealed many dimensions, from the security of supply and the affordability of energy services to the efficiency of economic output and the well-being of humans and the natural environment. Although its multidimensional nature does create challenges for measurement and evaluation, energy security is too important a concept to be incoherently defined and poorly measured. In response, we have created an Energy Security Index, utilizing 10 indicators that encompass economic, social, political, and environmental aspects of energy security, and analyzed the status of energy conditions in 22 OECD countries from 1970 to 2007. At least four interconnected conclusions can be drawn from our exercise.

First, our Energy Security Index shows that a majority of countries analyzed have regressed in terms of their energy security. This conclusion is discouraging, especially considering that the oil shocks of 1973 and 1974 culminated in the establishment of the International Energy Agency, the creation of strategic petroleum reserves among its members, and the diversification of the fuel base for electricity. In the United States, the crisis forced sweeping energy legislation through Congress, resulted in the establishment of the Department of Energy, and even provoked President Carter to cite the energy challenge as "the moral equivalent of war" (105). Since that time, the international community has seen advances in low-income energy services, efficiency and demand reduction programs, renewable resources initiatives, and market restructuring of the various energy industries. Many individual states in Europe and the United States have implemented aggressive renewable portfolio standards, feed-in tariffs, and systems benefits funds; started emissions trading schemes; and invested heavily in alternative fuels such as hydrogen, ethanol, and biodiesel. Despite all of this effort, our index reveals that most countries have regressed in their efforts to improve energy security.

Second, notwithstanding the near universal deterioration of energy security, a great disparity exists between countries. Some clear leaders, such as Denmark and Japan, stand above the rest and offer many lessons. Neither country left improving energy security to the marketplace, and their experience underscores the importance of government intervention through a progression of energy policy mechanisms. Perhaps equally important, the overarching explanation for the success of Danish and Japanese energy policy lies in coordinated and consistent political support and policy. Unlike the United States and Spain, where lack of synchronization between state and federal policy, constant changes in authorization and appropriations, a focus on other priorities, and expiration of programs has impeded energy policy, Japan and Denmark stand as testaments to the importance of consistency.

Third, contrary to the progress made by Japan and Denmark (as well as Belgium and the United Kingdom), no nation scored perfectly. This is because efforts to promote energy security, even for the most successful nations, have tended to focus on meeting the demands of consumers. Strategies have involved increasing the energy efficiency of buildings, appliances, industrial operations, and vehicles, but not on changing consumer patterns, encouraging them to drive less, buy fewer vehicles, or own fewer appliances. Virtually none of the countries examined tax urban sprawl, heavily promote mass transit and limited personal vehicle ownership, attempt to change consumer awareness, provide feedback on energy consumption in the form of real-time prices, or change underlying values by encouraging people to value nature, community involvement, and conservation (95). Thus, no country was able to completely promote availability and affordability alongside efficiency and stewardship. Trade-offs have often been involved between them, and most countries have seemingly pursued one or two of the criteria at the expense of the others.

Fourth and finally, the relative success of Denmark and Japan and the relative failure of the United States and Spain serve as an important reminder that creating energy security is as much a matter of policy from within as it is from without. Policy makers need not focus only on geopolitical power structures in energy resource-producing states or on drafting new contracts with Nigeria and Russia for oil and gas supply. It is not sufficient to build trade alliances and share intellectual property, send more troops to the Middle East, or bolster naval deployments throughout the world's shipping lanes. Equally effective and important can be coordinated and robust domestic policy changes directed at altering consumer behavior, promoting energy efficiency, and lowering greenhouse gas emissions. Tools such as research and development expenditures, subsidies, tariffs, and standards can be just as important, possibly more, for achieving available, dependable, affordable, efficient, and responsible forms of energy supply and use.

SUMMARY POINTS

1. The dominant conceptualization of energy security focuses on the availability of energy fuels, with source, supplier, and spatial diversification seen as key strategies for improvement. However, affordability, efficiency, and environmental stewardship are emerging as important additional energy security dimensions.
2. Trade-offs often occur between technologies and policies that are effective along one dimension but adversely impact other aspects of energy security. Countries often choose options that involve progress in one energy security domain by eroding another.
3. Little scholarship so far has attempted to compare energy security dimensions or the relative strength and weaknesses of different national approaches to energy security to identify progress or regression.

4. To fill this void the article develops an Energy Security Index consisting of 10 metrics related to each of the four dimensions of energy security iterated above, and it then tests this index on 22 countries belonging to the OECD.
5. Despite the near universal deterioration of energy security among the 22 countries studied, a great disparity exists between them. Top performers, such as Denmark and Japan, did not rely on the market alone, implementing a progression of consistent policies.

FUTURE ISSUES

1. Our Energy Security Index focused only on 22 countries belonging to the OECD. One relatively simple extension of our research would be to apply such an index to other geographic areas, such as Asia or South America.
2. The energy security challenges facing countries within the OECD may differ starkly from other categories of countries, such as those in the developing world, energy exporters, small island states, or states recently plagued by social, political, or military conflict. These countries may necessitate a new index that better matches their unique energy security issues.
3. Our scoring technique was relatively crude: indicators of energy security were weighted equally and the scoring was limited to either directional changes or z-scores. More sophisticated multivariate statistical analysis could yield promising (and different) results.
4. Not all components of energy security were included in our index. Reflecting the ubiquitous and pervasive nature of energy services, fruitful additions might include energy accidents, electricity blackouts, community cohesion and welfare, reserve to production ratios, other fuels (such as coal, uranium, biofuels, and renewable electricity sources), other pollutants (such as mercury, particulate matter, lead, benzene, ozone, and others), and water and land consumed for energy production.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

Lee Schipper from the World Resources Institute, David Victor from Stanford University, Bernard Gourley of the Georgia Institute of Technology, and Daniel Kammen from the University of California at Berkeley provided invaluable suggestions in the revision of the manuscript. Ms. Yanchun Ong, a research associate for the Centre on Asia and Globalisation, assisted with data collection, and Yu Wang, a graduate research assistant at the Georgia Institute of Technology's School of Public Policy, helped with the spreadsheet statistical analysis. Despite their help, of course, all errors, assumptions, and conclusions presented in the article are solely those of the authors.

LITERATURE CITED

1. Klare MT. 2007. The futile pursuit of energy security by military force. *Brown J. World Aff.* 13(2):139–53
2. Mo RC. 1979. Government corporations and the erosion of accountability: the case of the proposed energy security corporation. *Public Adm. Rev.* 39(6):566–71
3. Noël P. 2006–2007. The new US Middle East policy and energy security challenges. *Int. J.* 62:43–54
4. Stokes D. 2007. Blood for oil? Global capital, counter-insurgency and the dual logic of American energy security. *Rev. Int. Stud.* 33:245–64
5. Kalicki JH. 2007. Prescription for oil addition: the Middle East and energy security. *Middle East Policy* 14(1):76–83
6. Delucchi MA, Murphy JJ. 2008. US military expenditures to protect the use of Persian Gulf oil for motor vehicles. *Energy Policy* 36:2253–64
7. Greene D, Ahmad S. 2005. Costs of U.S. oil dependence: 2005 update (January 2005), *Rep. to U.S. DOE, ORNL/5002−MT/45*, Oak Ridge, TN
8. Schumacher EF, Kirk G. 1977. *Schumacher on Energy: Speeches and Writings of E.F. Schumacher*, ed. G. Kirk, pp. 1–2. London: Cape
9. Verrastro F, Ladislaw S. 2007. Providing energy security in an interdependent world. *Wash. Q.* 30(4):95–104
10. Pacala, Socolow R. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305:968–72
11. Hoffert MI, Caldeira K, Benford G, Criswell DR, Green C, et al. 2002. Advanced technology paths to global climate stability: energy for a greenhouse planet. *Science* 298:981–87
12. World Bank Group. 2005. *Energy Security Issues*. Washington, DC: World Bank. **http://siteresources.worldbank.org/INTRUSSIANFEDERATION/Resources/Energy_Security_eng.pdf**
13. Zillman DL, Bigos MT. 2004. Security of supply and control of terrorism: energy security in the United States in the early twenty-first century. See Ref. 106, pp. 145–70
14. Kalicki JH, Goldwyn DL, eds. 2005. *Energy and Security: Toward a New Foreign Policy Strategy*. Washington, DC: Woodrow Wilson Cent.
15. Deese DA, Nye JS, eds. 1981. *Energy and Security*. Cambridge, MA: Ballinger
16. Sevastyanov S. 2008. The more assertive and pragmatic new energy policy in Putin's Russia: security implications for Northeast Asia. *East Asia* 25:35–55
17. Kim MJ, Jones RE. 2004–2005. China's energy security and the climate change conundrum. *Natl. Resour. Environ.* 19:3–8
18. Cheng JYS. 2008. A Chinese view of China's energy security. *J. Contemp. China* 17(55):297–317
19. Dadwal SR. 2007. China's search for energy security: emerging dilemmas. *Strateg. Anal.* 31(6):889–914
20. Xu Yi-C. 2006. China's energy security. *Aust. J. Int. Aff.* 60(2):265–86
21. Atsumi M. 2007. Japanese energy security revisited. *Asia-Pacific Rev.* 14(1):28–43
22. Toichi T. 2003. Energy security in Asia and Japanese policy. *Asia-Pacific Rev.* 10(1):44–51
23. Yergin D. 2006. Ensuring energy security. *Foreign Aff.* 85(2):69–82
24. Leaver R. 2008. Factoring energy security into Australian foreign and trade policy: Has luck run out? *Int. J. Glob. Energy Issues* 29(4):388–99
25. Leaver R. 2007. Australia and Asia-Pacific energy security: the rhymes of history. In *Energy Security in Asia*, ed. M Wesley, pp. 91–111. New York: Routledge
26. Wu J, Garnett ST, Barnes T. 2008. Beyond an energy deal: impacts of the Sino-Australia uranium agreement. *Energy Policy* 36:413–22
27. Barrera-Hernandez L. 2004. The Andes: so much energy, so little security. See Ref. 106, pp. 217–52
28. Sovacool BK. 2007. Solving the oil independence problem: Is it possible? *Energy Policy* 35(11):5505–14
29. Chow E, Elkind J. 2005. Hurricane Katrina and energy security. *Survival* 47(4):145–60
30. Cleveland C, Kaufmann R. 2008. Fundamental principles of energy. In *Encyclopedia of Earth*, ed. T Lawrence, pp. 79–87. Washington, DC: Environ. Inf. Coalit.
31. Holling CS. 1973. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* 4:1–23
32. Markowitz H. 1952. Portfolio selection. *J. Financ.* 7(1):77–91

33. Li X. 2005. Diversification and localization of energy systems for sustainable development and energy security. *Energy Policy* 33:2237–43
34. Sovacool BK. 2009. Reassessing energy security and the trans-ASEAN natural gas pipeline network in Southeast Asia. *Pac. Aff.* 82(3):467–86
35. Farrell S, Zerriffi H, Dowlatabadi H. 2004. Energy infrastructure and security. *Annu. Rev. Environ. Resour.* 29:421–69
36. Parfomak PW. 2004. Pipeline security: an overview of federal activities and current policy issues. *CRS Rep. for Congress.* Order code RL31990. Washington, DC. **http://www.fas.org/sgp/crs/RL31990.pdf**
37. Grau LW. 2001. Hydrocarbons and a new strategic region: the Caspian Sea and central Asia. *Mil. Rev.*
38. US Energy Inf. Adm. (US EIA). 2007. *Country Analysis Brief: Saudi Arabia*. Washington, DC: US EIA
39. Luft G, Korin A. 2004. Terrorism goes to sea. *Foreign Aff.* 83:64–72
40. Luft G. 2005. *Iran-Pakistan-India pipeline: the Baloch wildcard*. Inst. Anal. Glob. Secur. Policy Brief, Washington, DC
41. Amnesty Int. 2000. *Sudan: the human price of oil*. **http://web.amnesty.org/library/Index/engAFR540042000?OpenDocument&of=COUNTRIES%5CSUDAN**
42. Shammin MR, Bullard C. 2009. Impact of cap-and-trade policies for reducing greenhouse gas emissions on U.S. households. *Ecol. Econ.* 68:2432–38
43. UN Dev. Program. (UNDP). 1997. *Energy After Rio: Prospects and Challenges*. Geneva: UNDP
44. UN Econ. Soc. Comm. Asia Pac. (UNESCAP). 2008. *Energy Security and Sustainable Development in Asia and the Pacific*. Geneva: UNESCAP
45. Natl. Econ. Res. Assoc. 1996. *The Role of Energy Costs in Industry Products*. Washington, DC: Natl. Econ. Res. Assoc.
46. Jacobson A, Milman A, Kammen DM. 2005. Letting the (energy) Gini out of the bottle: Lorenz curves of cumulative electricity consumption and Gini coefficients as metrics of energy distribution and equity. *Energy Policy* 33(14):1825–32
47. Adelman MA, Watkins GC. 2005. U.S. oil and natural gas reserve prices, 1982–2003. *Energy Econ.* 27:553–71
48. Pindyck RS. 2004. Volatility in natural gas and oil markets. *J. Energy Dev.* 30(1):L1–19
49. Herring H. 2006. Energy efficiency—a critical review. *Energy* 31(1):10–20
50. Legros G, Havet I, Bruce N, Bonjour S, Rijal K,et al. 2009. *The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa*. New York: World Health Organ./UN Dev. Program
51. Pachauri S, Mueller A, Kemmler A, Spreng D. 2004. On measuring energy poverty in Indian households. *World Dev.* 32(12):2083–104
52. Gallagher KS, Holdren JP, Sagar A. 2006. Energy-technology innovation. *Annu. Rev. Environ. Resour.* 31:193–237
53. Brundtland GH. 1987. *Our Common Future: World Commission on Environment and Development*. Oxford, UK: Oxford Univ. Press
54. Daly HE. 1979. On thinking about future energy requirements. In *Sociopolitical Effects of Energy Use and Policy*, ed. CT Unseld, pp. 232–40. Washington, DC: Natl. Acad. Sci.
55. Int. Energy Agency (IEA). 2007. *Energy Security and Climate Policy—Assessing Interactions.* Paris: IEA
56. Deutch J, Schlesinger J. 2006. National security consequences of US oil dependency. *Counc. Foreign Relat. Indep. Task Force Rep. 58*, Washington, DC
57. CNA Mil. Advis. Board. 2007. *National security and the threat of climate change*. **http://securityandclimate.cna.org/**
58. Simpson A. 2007. The environment-energy-security nexus: critical analysis of an energy 'love triangle' in Southeast Asia. *Third World Q.* 28(3):539–54
59. Sovacool BK. 2007. Solving the oil independence problem. *Energy Policy* 35(11):5505–14
60. Sovacool BK. 2008. The Problem with the 'portfolio approach' in American energy policy. *Policy Sci.* 41(3):245–61
61. Greene DL. 2010. Measuring energy security: Can the United States achieve oil independence? *Energy Policy* 38:1614–21

62. Fankhauser S, Tepic S. 2007. Can poor consumers pay for energy and water? An affordability analysis for transition countries. *Energy Policy* 35:1038–49
63. Bacon R, Bhattacharya S, Kojima M. 2009. *Changing Patterns of Household Expenditures on Energy. Extractive Industries for Development Series 6*. Washington, DC: World Bank
64. Howarth R, Schipper LJ, Andersson B. 1993. The structure and intensity of energy use: trends in five OECD nations. *Energy J.* 14(2):27–45
65. Int. Energy Agency (IEA). 2009. *Towards a More Energy Efficient Future: Applying Indicators to Enhance Energy Policy*. Paris: OECD
66. Holdren JP, Smith KR. 2000. Energy, the environment, and health. In *World Energy Assessment: Energy and the Challenge of Sustainability*, ed. T Kjellstrom, D Streets, X Wang, pp. 61–110. New York: UN Dev. Program
67. Schipper L, Haas R. 1997. The political relevance of energy and CO_2 indicators. *Energy Policy* 25(7):639–49
68. Brown MA, Sovacool BK. 2007. Developing an 'Energy Sustainability Index' to evaluate energy policy. *Interdiscip. Sci. Rev.* 32(4):335–49
69. Pencheon D. 2008. *The Good Indicators Guide: Understanding How to Use and Choose Indicators*. Washington, DC: UK NHS Inst. Innov. Improv.
70. Schipper L, Fulton L. 2009. *Disappointed by diesel? The impact of the shift to diesels in Europe through 2006*. Presented at Transp. Res. Board Annu. Meet., Washington, DC
71. US Econ. Res. Serv. 2008. *International Macroeconomic Data Set*. Washington, DC: US Dep. Agric.
72. US Energy Inf. Adm. 2007. *World Energy Intensity—Total Primary Energy Consumption per Dollar of Gross Domestic Product*. Washington, DC: US Dep. Energy
73. Bentzen J. *An empirical analysis of gasoline price convergence for 20 OECD countries*. Aarhus School Bus. Work. Pap. 03–19, Denmark
74. Organ. Econ. Co-op. Dev. (OECD). 2008. Consumer price indices—energy. In *Main Economic Indicators*, pp. 112–31. Paris: OECD
75. Int. Energy Agency (IEA). 2008. *Energy Prices and Taxes—Quarterly Statistics*. Paris: IEA
76. Spiro PA, Jacob DJ, Logan JA. 1992. Global inventory of sulfur emissions with 1×1 resolution. *J. Geophys. Res.* 97:6023–36
77. Lefohn AS, Husar JD, Husar RB. 1999. Estimating historical anthropogenic global sulfur emission patterns for the period 1850-1990. *Atmos. Environ.* 33(21):3435–44
78. Int. Energy Agency (IEA). 1991. *Energy Statistics of OECD Countries, 1960 to 1979*. Paris: OECD/IEA
79. Int. Energy Agency (IEA). 1984. *Energy Balances of OECD Countries, 1970 to 1982*. Paris: OECD/IEA
80. World Resourc. Inst. (WRI). 2007. *Climate and Atmosphere Indicators: Sulfur Dioxide Emissions*. Washington, DC: WRI
81. Organ. Econ. Co-op. Dev. (OECD). 2008. *Biofuel Support Policies: An Economic Assessment*. Paris: OECD
82. US Energy Inf. Adm. 2008. *Country Energy Profiles*. Washington, DC: US Dep. Energy
83. Int. Energy Agency. (IEA). 2008. *Key World Energy Statistics 2008*. Paris: IEA
84. Lee Schipper, Ruth Steiner, Peter Duerr, Feng An, Steinar Strom. 1992. Energy use in passenger transport in OECD countries: Changes since 1970. *Transportation* 19:25–42
85. Linares P, Santos FJ, Perez-Arriaga IJ. 2008. Scenarios for the evolution of the Spanish electricity sector: Is it on the right path towards sustainability? *Energy Policy* 36:4057–68
86. Leonor Moral Soriano. 2008. New modes of governance in the Spanish electricity and gas sectors. *J. Public Policy* 28:93–111
87. Lancaster TD. 1989. *Policy Stability and Democratic Change: Energy in Spain's Transition*. London: Pa. State Univ. Press
88. Correlje A. 1991. Spanish energy policy overview. *Energy Policy* 19(9):901–2
89. Hernandez F, Gual M, Rio P, Caparros A. 2004. Energy sustainability and global warming in Spain. *Energy Policy* 32:383–493
90. Perez Y, Ramos-Real FJ. 2008. The public promotion of wind energy in Spain from the transaction costs perspective, 1986 to 2007. *Renew. Sustain. Energy Rev.* 13(5):1058–66
91. Gonzalez P. 2008. Ten years of renewable electricity policies in Spain: an analysis of success feed-in tariff reforms. *Energy Policy* 36:2917–29

92. Arocena P, Contin I, Huerta E. 2002. Price regulation in Spanish energy sectors: who benefits? *Energy Policy* 30:885–95
93. Rio P, Unruh G. 2007. Overcoming the lock-out of renewable energy technologies in Spain: the cases of wind and solar electricity. *Renew. Sustain. Energy Rev.* 11:1498–513
94. Climent F, Pardo A. 2007. Decoupling factors on the energy-output linkage: the Spanish case. *Energy Policy* 35:522–28
95. Geller H, Harrington P, Rosenfeld AH, Tanishima S, Unander F. 2006. Policies for increasing energy efficiency: thirty years of experience in OECD countries. *Energy Policy* 34:556–73
96. Sovacool BK, Lindboe HH, Odgaard O. 2008. Is the Danish wind energy model replicable for other countries? *Electr. J.* 21(2):27–38
97. Morthorst PE. 2000. The development of a green certificate market. *Energy Policy* 28:1085–94
98. Hayami Y. 1999. Changes in the source of modern economic growth: Japan compared with the United States. *J. Jpn. Int. Econ.* 13:1–21
99. Fukasaku Y. 1995. Energy and environment policy integration: the case of energy conservation policies and technologies in Japan. *Energy Policy* 23(12):1063–76
100. US Energy Inf. Adm. 2005. *Policies to Promote Non-Hydro Renewable Energy in the United States and Selected Countries*. Washington, DC: US Dep. Energy
101. Yamamoto S. 1986. Japan's new industrial era—restructuring traditional industries. *Long Range Plan.* 19(1):61–66
102. Sawin J. 2004. *Mainstreaming Renewable Energy in the 21st Century*. Washington, DC: Worldwatch Institute
103. Laitner JA, Ehrhardt-Martinez K, McKinney V. 2009. *Examining the scale of the behavior energy efficiency conundrum*. Presented at 2009 ACEEE Summer Study, Washington, DC
104. Brown MA, Sovacool BK, Hirsh RF. 2006. Assessing U.S. energy policy. *Daedalus: J. Am. Acad. Arts Sci.* 135(3):5–11
105. Carter J. 1977. The President's proposed energy policy. *KTEH telev. broadcast*, Apr. 18. **http://www.pbs.org/wgbh/amex/carter/filmmore/ps_energy.html**
106. Barton B, Redgwell C, Ronne A, Zillman DR, eds. 2004. *Energy Security: Managing Risk in a Dynamic Legal and Regulatory Environment*. London: Oxford Univ. Press

Annual Review of
Environment
and Resources

Volume 35, 2010

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