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Energy Security Dimensions and Trends in Industrialized Countries

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ABSTRACT

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Abstract: This article represents one of the first scholarly efforts to correlate actual energy policy and practice with expert views of the multidimensional concept of energy security. Based on the energy security performance of 22 countries in the Organisation for Economic Co-operation and Development between 1970 and 2007, it concludes that many industrialized countries have been unable to make progress toward the goal of achieving secure, reliable and affordable supplies of energy while also transitioning to a low-carbon energy system. However, some national best practices exist, which are identified by examining the relative performance of four countries: the United Kingdom and Belgium (both with noteworthy improvements), and Sweden and France (which have experienced notable slippage in relative performance). The article concludes by offering implications for energy policy more broadly and by providing empirical evidence that our four dimensions of energy security (availability, affordability, energy efficiency, and environmental stewardship) envelop the key strategic dimensions of energy security.

Keywords: energy security; security of supply; low-carbon energy systems; Organisation for Economic Co-operation and Development (OECD)

1. Introduction

After 40 years of debate, the energy security discussion now rightly focuses on a critical global dilemma: can the world have secure, reliable and affordable supplies of energy while also transitioning to a low-carbon energy system? The evolution of this debate highlights the multi-faceted nature of the energy security dilemma, but the key dimensions of the problem are still being disputed. In turn, the global political economy exhibits a diverse array of energy security strategies and policies. This reflects a lack of consensus about the nature of the energy security problem as well as the need for different approaches to address diverse resource endowment, political levers, capital availability, risk aversion, and other particularities of individual nation-states.

Energy security has long centered on questions of reliable energy supplies, the regional concentration of energy resources, and the implications of the strategic withholding of energy. This view recognizes that energy is essential for any form of economic activities; increasing energy consumption has characterized industrialization and economic development over the past century (Warr and Ayres 2010). With the broadening of the range of energy supply disruptions, discussions of energy security have been expanded to embrace electricity reliability as well as natural gas and petroleum security, and the entire energy supply chain including energy delivery infrastructure (Yergin 2006). Many recent events have underscored the entire energy supply chain's vulnerability to many different types of disruption, including political instability in the Middle East, natural disasters such as the Japanese tsunami and with the Fukushima nuclear reactor meltdown in 2011, gas disputes with Russia (2006-2009) that have wreaked havoc in European electricity markets, and equipment breakdowns in the northeast US blackout of 2003. Hurricanes Katrina and Rita in 2005 illustrated the first major diversified energy disaster, with the simultaneous disruptions of oil, natural gas, and electric power.

In addition to diversifying the discussion of energy security to address multiple energy sources and infrastructures, additional dimensions of energy security have begun to surface. With rising energy costs, affordability and economic competitiveness have joined supply security as common objectives (IEA 2007). The volatility of energy prices and growing uncertainties about available imports of both oil and natural gas have elevated the role of energy efficiency policies (Umbach, 2010). With improved information about the climate change and air pollution impacts from energy systems, their environmental sustainability has also become an energy security objective (Chalvatzis and Hooper 2009; Badea, et al. 2011). At the extreme, when environmental conditions deteriorate to the point that society cannot function, nation-states could reach the point of collapse, impinging on energy security worldwide (Brown and Dworkin 2010).

Most recently, approaches incorporating a wide range of dimensions have begun to emerge. The Asia Pacific Energy Research Center, for instance, defines four dimensions of energy security: availability of resources, accessibility of resources, environmental acceptability, and affordability (APERC 2007). Energy, climate change, environmental and health issues are recognized by Pode (2010). Badea, et al. (2011) use eight individual indicators to measure energy security (energy and carbon intensity, import dependency of three fuels, primary production, electricity generation capacity, and energy demand in transport).

While supply availability remains the core concern of the energy security debate, the more current literature recognizes that priorities with respect to climate change, air pollution, economic growth and energy affordability will define how the transition to a secure energy future is to be achieved. There is also an emerging literature suggesting that integrated approaches to energy security can achieve significantly deeper reductions in oil consumption (Bollen, et al. 2010).

This emerging multidimensional view of energy security acknowledges that transforming energy systems is at the core of energy security solutions. At the same time, this broad approach complicates the assessment of national strengths and weaknesses and challenges the ability to develop a single index to calibrate the energy security of a single nation state.

2. Dimensions and Indicators of Energy Security

In some of our previous work, we have argued that energy security consists of four interconnected criteria or dimensions: availability, affordability, efficiency, and environmental stewardship (Sovacool and Brown. 2010; Sovacool 2010). **Availability** refers to 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 dependence on foreign suppliers. **Affordability** refers to providing energy services that are affordable for consumers and minimize price volatility.

Efficiency involves improving the performance of energy equipment and altering consumer behavior in order to reduce energy price exposure and mitigate energy import dependency. **Stewardship** consists of protecting the natural environment, communities, and future generations. Based on an assessment of 91 peer-reviewed academic articles on energy security from September 2003 to September 2008, these dimensions are listed above in their order of frequency as shown in Table 1 and detailed in Sovacool and Brown (2010).

Recognizing that each dimension does not exist in a vacuum and that each is of comparable importance, Table 1 presents ten indicators that comprise an energy security index. Note that in each case, the indicator is an inverse measure of security; that is, the higher the value, the lower the energy security.

Table 1 Defining and Measuring Energy Security

Dimension	**Explanation**	**Indicators**	**Percent of Articles**
Availability	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 dependence on foreign suppliers	–Oil import dependence; –Natural gas import dependence; –Dependence on petroleum transport fuels	82%
Affordability	Providing energy services that are affordable for consumers and minimizing price volatility	–Retail electricity prices; –Retail gasoline/petrol prices	51%
Energy and Economic Efficiency	Improving the performance of energy equipment and altering consumer attitudes to reduce energy price exposure and mitigate energy import dependency	–Energy intensity; –Per capita electricity use; –On-road fuel intensity of passenger vehicles	34%
Environmental and Social Stewardship	Protecting the natural environment and future generations	–Sulfur dioxide emissions; –Carbon dioxide emissions	26%

Our next step was to assign metrics to these four dimensions of energy security. To reflect availability, oil import dependence, natural gas import dependence, and dependence on petroleum transport fuels serve as useful indicators. Oil import dependence and natural gas import dependence reflect how dependent a country is on foreign supplies of petroleum (mostly used in transport) and natural gas (a feedstock for industrial activity and power generation), and also document changes in the supply mix for the world's first and third most used fuels (the second being coal). The presence of alternative fuels such as ethanol and biodiesel also reveals how far countries have moved away from dependence on petroleum.

To reflect affordability, electricity and gasoline/petrol prices at the retail level serve as important metrics. We have 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.

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 three is energy intensity, a measure that indicates the amount of energy used to produce a unit of GDP. 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 emissions and carbon dioxide emissions reveal how far countries have gone towards mitigating greenhouse gas emissions, acid rain precursors, and noxious air pollution. These indicators also help show relative progress in the implementation of domestic climate change programs.

3. Methodology for Evaluating the Dimensions and Indicators of Energy Security

We evaluate the validity of our energy security dimensions and indicators from two perspectives. First, are the indicators of energy security strengths and weaknesses correlated with the proposed four dimensions? If so, we could conclude that the four dimensions provide useful insights into common energy security conditions and strategic approaches.

Second, do countries have similarities and differences in energy security trends that align with the four dimensions? If so, we could conclude that the four dimensions provide a useful basis for developing a taxonomy of countries based on distinct energy security strategies.

To evaluate the four dimensions of energy security along these two lines of inquiry, we examine a sample of 22 geographically dispersed countries that belong to the OECD. The first reason for selecting this sample 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 involved with 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 offer a representative sample of different types of energy markets and cultures. The United Kingdom and New Zealand are examples of liberalized and privatized energy markets, while other countries such as Denmark and parts of the United States remain highly regulated. The final reason is pragmatic: because OECD countries are the most industrialized, 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 affect the global energy marketplace.

We collected data on these ten indicators and metrics for 22 OECD countries from 1970 to 2007, with a few exceptions and caveats. First, reliable data for energy intensity were only available for 1980 and 2005; fuel economy data for 2005 instead of 2007; and sulfur dioxide emissions data for 2000 instead of 2007. Second, 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, or that instead more energy-intense products are being imported from elsewhere and energy-intensive jobs outsourced? (Brown and Sovacool 2007) Third, collecting the data for this study was tedious and difficult. Most of it was not available online and the data for 1970 involved much searching through libraries. Historical data from International Energy Agency publications and archives are inconsistent, and discrepancies exist in the data found in reports published by different agencies (e.g., the Energy Information Administration, World Resources Institute, United Nations, and the World Bank).

Tables 2 and 3 present data for each of the ten metrics for the 22 selected countries in 1970 and 2007. These tables provide a basis for identifying common trends, but more nuanced analysis is needed to identify the distinct changes experienced by individual countries and groups of countries. The indicators for most countries reflect global trends such as the increasing share of oil reserves located in non-OECD countries and improvements in vehicle fuel economy resulting from advances in transportation technologies. It is more difficult to discern instances where countries depart from the norm as the result of particular characteristics and conditions, such as energy policies or resource endowments. Using the nomenclature of the indicators literature, it is useful to distinguish between “common cause” and “special cause” variation (Pencheon 2008).

We use z-scores to evaluate the relative magnitudes of change in indicators and thereby identify divergences of individual countries and groups of countries from underlying trends (that is, special cause variation). Z-scores are “dimensionless” quantities that indicate how many standard deviations a country is above or below the mean of the 22 OECD countries. We created z-scores for each of the ten indicators in 1970 and 2007 by subtracting the mean value for each data point and dividing by the indicator’s standard deviation. The z-scores are then summed for 1970 and 2007, giving equal weight to each indicator and providing a total energy security score for each country in both years. Table 4 presents the differences in these overall energy security scores from 1970 to 2007.

The z-scores represent the normalized distances from the data points to the means in terms of standard deviation (see equation 1). For France, for instance, the electricity use is 2,882 kWh/capita in 1970, and 7,585 kWh/capita in 2007. While, for all countries in our sample, the average electricity use is 4,257 kWh/capita in 1970 (sd = 3,314), and 9,404 kWh/capita in 2007 (sd = 5,117). France’s electricity uses can be converted into z-scores using Equation (1), that is, -0.415 in 1970, and -0.355 in 2007. While France increased its per capita consumption of electricity (therefore compromising its energy security), France’s consumption remains below the mean for most OECD countries, and therefore the z-score for this indicator remains negative. Following the same logic, the other indicators for each country in our sample were converted into z-scores. The final scores for the 22 selected countries are the sum of z-score changes for the 10 indicators from 1970 to 2007.

$$Zscore_{d,y} = \frac{\text{Absolute value}_{\text{d,y}} - \text{Mean}_{\text{d,y}}}{\text{Standard Deviation}_{\text{d,y}}} \quad (1)$$

where, d: the energy security dimension;
y: year.

This z-scoring assessment of energy security conditions and trends indicates that the United States had the lowest energy security of all 22 countries, both in 1970 and still in 2007. In contrast, Figure 1 indicates that the United Kingdom, New Zealand, and Denmark had high energy security scores in 2007.

Table 2: Energy Security Performance Index for 22 OECD Countries, 1970 (in US$2007)*

	Availability			Affordability		Energy and Economic Efficiency			Environmental Stewardship	
	Oil import dependence (%)	Petroleum transport fuels (%)	Natural gas import dependence (%)	Real electricity retail prices (US¢/kWh)	Real gasoline prices ($/liter)	On-road fuel intensity (gpm)	Energy per GDP intensity (thousand BTU/US$GDP)	Electricity use (kWh/capita)	SO_2 emissions (million tons)*	CO_2 emissions (million tons)
Australia	67%	96.1%	0%	3.7	0.26	0.059	10.3	3,919	1.6	147.63
Austria	57%	94.3%	34%	18.0	1.32	0.048	8.5	3,302	0.4	50.69
Belgium	100%	98.4%	99%	18.5	1.74	0.045	12.2	3,399	1.2	125.62
Canada	46%	97.3%	1%	3.7	0.37	0.071	18.7	9,529	4.1	341.47
Denmark	99%	98.1%	0%	9.5	0.42	0.042	8.8	3,211	0.3	62.15
Finland	100%	97.7%	100%	5.3	0.53	0.045	12.6	4,885	0.4	40.39
France	98%	96.3%	35%	7.9	0.74	0.036	8.7	2,882	3.5	438.98
Germany	92%	96.4%	24%	15.9	1.16	0.042	9.8	2,962	6.9	1,027.00
Greece	99%	98.3%	0%	2.1	0.58	0.048	6.0	1,118	0.3	24.16
Ireland	98%	97.2%	0%	6.9	0.58	0.045	9.0	1,956	0.2	19.41
Italy	97%	98.7%	0%	6.3	0.42	0.036	7.1	2,262	2.6	296.72
Japan	100%	98.2%	32%	48.6	1.27	0.050	7.8	3,445	5.1	768.81
Netherlands	97%	98.0%	0%	15.3	1.00	0.040	12.9	3,110	1.4	141.93
New Zealand	100%	95.6%	0%	3.2	0.48	0.053	11.0	4,941	0.1	14.20
Norway	100%	97.5%	0%	2.6	0.42	0.043	16.4	14,785	0.2	28.01
Portugal	99%	98.0%	0%	20.6	1.59	0.043	4.4	830	0.1	15.26
Spain	99%	97.3%	85%	5.8	0.37	0.037	7.0	1,623	1.1	116.93
Sweden	100%	97.5%	0%	3.2	0.32	0.050	13.7	8,048	0.9	92.37
Switzerland	100%	96.9%	100%	4.0	1.59	0.043	7.6	4,693	0.1	40.29
Turkey	53%	97.7%	0%	21.1	0.11	0.067	5.0	241	0.8	42.64
UK	100%	97.7%	7%	5.3	0.58	0.048	9.9	4,489	8.6	653.06
United States	22%	95.1%	4%	7.0	0.42	0.077	14.7	8,022	31.2	4,412.97
Median	99%	97.5%	1%	6.6	0.56	0.045	9.4	3,351	1.0	104.65
Mean	87%	97.2%	24%	10.7	0.74	0.049	10.1	4,257	3.2	404.58

***For each indicator, the higher the number, the lower the energy security.**

Table 3: Energy Security Performance Index for 22 OECD Countries, 2007*

	Availability			Affordability		Energy and Economic Efficiency			Environmental Stewardship	
	Oil import dependence (%)	Petroleum transport fuels (%)	Natural gas import dependence (%)	Real electricity retail prices (US¢/kWh)	Real gasoline prices ($/liter)	On-road fuel intensity (gpm)	Energy per GDP intensity (thousand BTU/US$GDP)	Electricity use (kWh/capita)	SO_2 emissions (million tons)	CO_2 emissions (million tons)
Australia	37%	98.3%	0%	12.5	1.24	0.038	9.0	11,309	2.6	394
Austria	91%	96.3%	95%	22.6	1.81	0.032	7.0	8,090	0.2	66
Belgium	99%	98.1%	100%	16.5	2.20	0.034	9.2	8,688	1.3	103
Canada	0%	98.8%	0%	7.6	1.08	0.043	13.8	16,766	2.9	573
Denmark	0%	97.7%	0%	38.2	2.05	0.033	5.2	6,864	0.1	50
Finland	96%	98.1%	93%	17.1	2.12	0.034	8.8	17,178	0.3	64
France	96%	98.1%	97%	17.3	2.03	0.031	7.2	7,585	1.3	353
Germany	94%	98.1%	79%	23.1	2.10	0.034	7.0	7,175	2.4	790
Greece	99%	98.1%	99%	13.0	1.19	0.034	6.8	5,372	0.8	97
Ireland	100%	98.1%	86%	24.7	1.77	0.034	4.9	6,500	0.1	44
Italy	93%	97.5%	85%	27.2	2.06	0.030	5.8	5,762	1.5	430
Japan	97%	98.2%	93%	17.8	1.46	0.045	6.5	8,220	2.6	1,227
Netherlands	91%	98.1%	59%	24.2	2.28	0.033	9.8	7,057	1.0	179
New Zealand	69%	97.1%	0%	17.8	1.35	0.034	9.1	9,746	0.1	36
Norway	0%	98.1%	0%	17.5	2.32	0.034	12.8	24,295	0.6	36
Portugal	98%	98.1%	100%	23.3	2.07	0.034	5.9	4,799	0.2	55
Spain	98%	98.1%	100%	18.7	1.64	0.032	7.1	6,213	2.1	346
Sweden	99%	98.1%	100%	12.7	1.99	0.036	9.1	15,230	0.3	45
Switzerland	99%	98.1%	100%	15.6	1.65	0.034	5.8	8,279	0.1	38
Turkey	94%	96.3%	97%	15.8	2.60	0.034	6.1	2,053	2.1	266
UK	4%	96.3%	8%	22.7	2.07	0.032	6.0	6,192	1.6	524
United States	59%	97.1%	17%	10.3	0.82	0.050	9.1	13,515	17.8	5,725
Median	94%	98.1%	90%	17.7	2.01	0.034	7.1	7,838	1.2	141
Mean	73%	97.8%	64%	18.9	1.81	0.036	7.8	9,404	1.9	520

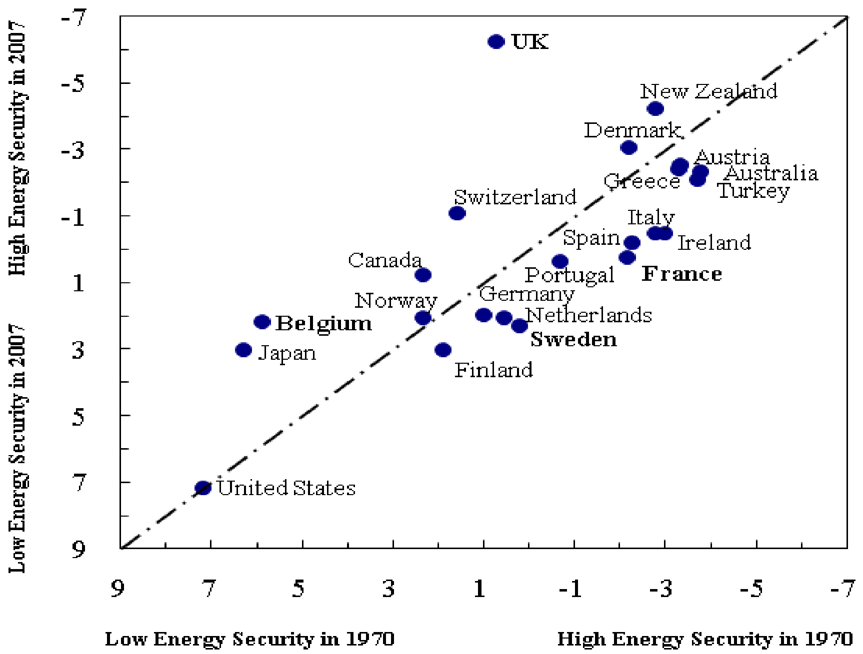
***For each indicator, the higher the number, the lower the energy security.**

Table 4: Change in Energy Security Z-Score, 1970 to 2007*

	Availability			Affordability		Energy and Economic Efficiency			Environmental Stewardship		
	Oil import dependence	Petroleum transport fuels	Natural gas import dependence	Nominal electricity retail prices	Nominal gasoline prices	On-road fuel intensity	Energy per GDP Intensity	Electricity use	SO2 emissions	CO2 emissions	Final score
Australia	0.051	-1.731	0.835	0.310	0.271	0.336	-0.455	-0.474	-0.432	-0.169	-1.460
Austria	-1.808	-0.459	-0.436	0.140	1.200	0.614	-0.083	-0.031	0.041	0.000	-0.823
Belgium	-0.117	0.580	1.206	1.108	1.209	-0.050	-0.022	-0.119	-0.139	0.050	3.706
Canada	0.094	-1.388	0.862	1.050	0.847	0.435	-0.232	0.152	-0.140	-0.111	1.568
Denmark	2.436	0.888	0.835	-3.022	-1.173	-0.155	0.778	0.181	0.053	0.026	0.847
Finland	-0.039	-0.036	1.395	-0.233	-1.101	-0.050	0.261	-1.330	0.014	-0.009	-1.128
France	-0.127	-1.269	-0.455	-0.017	-0.473	-0.261	-0.115	-0.059	0.206	0.176	-2.394
Germany	-0.340	-1.181	-0.337	-0.135	0.237	-0.396	0.273	0.045	0.416	0.440	-0.979
Greece	-0.162	0.492	-1.447	0.083	1.037	0.147	-0.681	-0.159	-0.137	-0.054	-0.880
Ireland	-0.232	-0.476	-1.147	-1.229	-0.232	-0.050	0.963	-0.127	0.038	-0.015	-2.508
Italy	-0.093	1.702	-1.124	-1.664	-1.195	-0.063	0.053	0.110	0.017	-0.040	-2.297
Japan	-0.065	0.261	-0.444	3.764	1.863	-1.935	-0.058	-0.014	0.092	-0.200	3.265
Netherlands	-0.040	0.228	-0.525	-0.358	-0.486	-0.307	-0.090	0.113	-0.027	0.004	-1.488
New Zealand	0.670	-0.457	0.835	-0.541	0.482	0.605	-0.307	0.140	0.023	-0.014	1.436
Norway	2.480	-0.212	0.835	-0.549	-1.764	-0.231	-0.429	0.267	-0.098	0.001	0.300
Portugal	-0.135	0.228	-1.470	0.280	1.185	-0.231	-0.730	-0.134	-0.004	-0.028	-1.039
Spain	-0.135	-0.388	0.828	-0.427	-0.379	-0.352	-0.537	-0.171	-0.371	-0.162	-2.095
Sweden	-0.117	-0.212	-1.470	0.233	-1.247	0.107	0.432	0.005	0.089	0.063	-2.119
Switzerland	-0.117	-0.741	1.233	-0.130	2.104	-0.231	0.190	0.351	0.023	0.012	2.696
Turkey	-2.063	2.535	-1.401	1.460	-3.013	1.886	-0.652	0.225	-0.416	-0.175	-1.614
UK	2.375	2.535	0.840	-1.079	-0.889	0.614	0.733	0.698	0.888	0.262	6.977
United States	-2.515	-0.898	0.551	0.955	1.518	-0.431	0.706	0.333	-0.135	-0.056	0.029

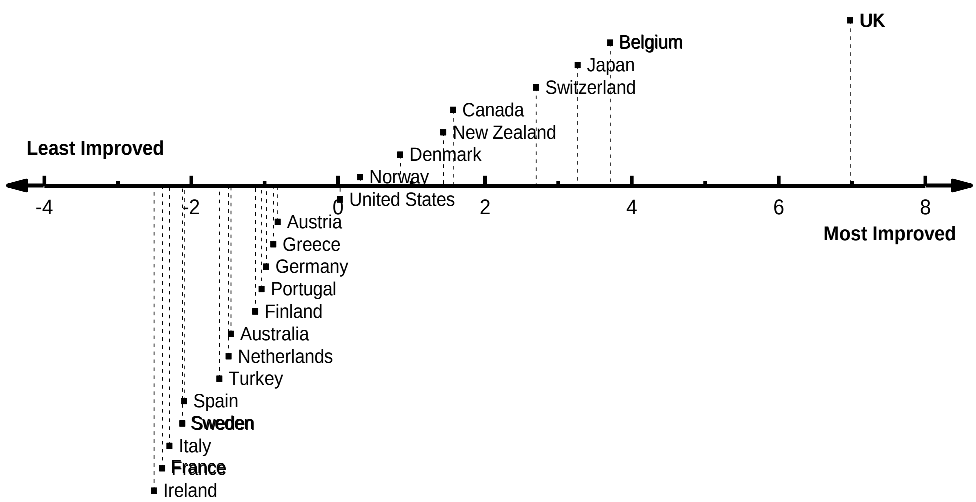
***Negative numbers indicate worsening energy security trends relative to other OECD countries.**

Figure 1: Energy Security "Z-Scores" in 1970 and 2007
Notes: Case study countries are highlighted in bold. Countries above the diagonal line have improved in energy security relative to other OECD countries.



We then assessed the relative progress of each country over time by comparing the sum of their z-scores on the ten indicators in 1970 and 2007. The results of our analysis indicate that the United Kingdom experienced the largest improvement in energy security over this time frame. Its energy security improved on six of the ten indicators, and was particularly strengthened with respect to oil import dependence, shifting from 100% oil imports in 1970 to only 4% in 2007. Figure 2 illustrates that Belgium, Japan, Switzerland, Canada, and New Zealand also experienced significant improvements in their energy security over this same time frame. In contrast, Ireland, France, Italy, Sweden, and Spain experienced the largest declines in energy security over this same period.

Figure 2: Most to Least Improved Energy Security (Based on Differences in Z-Scores: 1970 and 2007) Note: Case study countries are highlighted in bold.



A few general trends are worth noting. First, comparing Tables 1 and 2 shows that the energy security of most countries has deteriorated over the four decades. A majority of the 22 industrialized countries have experienced declines in energy security, with 13 countries scoring worse on a majority of the ten indicators between 1970 and 2007. No country improved along all ten indicators of energy security. The United Kingdom and Denmark both scored better on six indicators over the past four decades, exhibiting the greatest breadth of improvement, but they deteriorated in four indicators.

Second, changes in energy security scores over time have been highly variable within the OECD, suggesting that the countries examined have taken diverse and divergent paths towards energy policy and security, and also reflecting different natural resource endowments.

Third, some metrics, such as energy intensity per GDP and fuel economy for passenger vehicles, have almost universally improved, while others, such as dependence on petroleum imports, electricity consumption per capita, electricity prices, and gasoline prices have almost universally deteriorated. Further analysis is needed to understand the unique variability of other indicators and of individual countries.

4. Correlation of Energy Security Indicators

Using factor analysis, we can determine if the ten energy security indicators are correlated in a way that resembles our four dimensions. In statistical terms, does the factor analysis identify latent variables (i.e., factors) that are similar to the four dimensions described in Table 1? In addition to identifying the underlying factors, the analysis can estimate the strength of each factor in terms of the percent of total variance that it explains, and it can indicate if a particular number of factors is statistically sufficient.

In theory, factor analysis assumes the variability in observed variables is due to commonality (usually a smaller set of latent variables), where the observed variables are linear combinations of the latent variables, plus error terms. This study assumes the four dimensions (availability, affordability, energy & economic efficiency, and environmental stewardship) function as the latent variables and the result confirms that these four dimensions highly correlate with our ten indicators.

The results are presented in Table 5. We elect to describe four factors, which in total explain 73.4% of variation. The goodness of fit for this four factor model is represented by the chi square statistics, which equals to 14.1 with 11 degrees of freedom. The fitness test is based on the maximum likelihood solution minimizing the discrepancy between the model and the data. The null hypothesis for this test is that the four factors are sufficient and the discrepancy is insignificant. The test result, the chi square statistics, gives the p-value of 0.228, which indicates that we cannot reject the null hypothesis. It is clear that the model with these four factors (shown in Table 5) can adequately account for the data of 44 observations (the indicators for the selected 22 countries in 1970 and 2007).

Table 5 Factor Loadings and Variance Explained,
Based on Z-scores of Energy Security Indicators in 1970 and 2007

	Factor 1 *Environmental Stewardship*	**Factor 2** *Energy & Economic Efficiency*	**Factor 3** *Availability*	**Factor 4** *Affordability*
Availability				
Oil import dependence	-0.235	-0.192	**0.948**	
Petroleum transport fuels	-0.289	0.138	0.260	-0.204
Natural gas import dependence		-0.142	**0.575**	0.245
Energy and Economic Efficiency				
On-road fuel intensity	0.557	0.227	-0.393	-0.319
Energy per GDP intensity		**0.971**	-0.172	-0.124
Affordability				
Electricity use		**0.799**	-0.164	-0.112
Nominal electricity retail prices		-0.406		**0.514**
Nominal gasoline prices	-0.179		0.234	**0.952**
Environmental Stewardship				
SO_2 emissions	**0.970**	0.121	-0.132	-0.117
CO_2 emissions	**0.982**		-0.118	-0.103
SS loadings	2.411	1.897	1.602	1.431
Proportion Variances	24.1%	19.0%	16.0%	14.3%
Cumulative Variances	24.1%	43.1%	59.1%	73.4%

The environmental stewardship factor explains 24% of the variance with strong weightings on both SO_2 and CO_2 emissions. Next in explanatory power is energy and economic efficiency, with the largest factor loading on energy intensity and electricity use per capita. Supply availability is highlighted by the third factor, with high weights on oil and natural gas import dependence. Finally, affordability is the focus of the fourth factor, with high loadings on electricity and gasoline prices.

The correspondence of these four factors to the hypothesized four dimensions of energy security is strong. The composition of these four factors suggests that countries have energy security conditions that are generally weak or strong along our proposed four dimensions. If they have good air quality (based on SO_2 emissions), they also tend to have low CO_2 emissions. If their economy is energy intensive based on consumption per GDP, the consumption of electricity per capita is also high. If they import a lot of oil, they also import a lot of natural gas. If their electricity prices are low, so are their gasoline/petrol prices.

5. Taxonomy of Countries

The energy security dillema is played out in very different ways across the states that make up the global political economy (Bradshaw 2010). Through cluster analysis of changes in the energy security Z-scores between 1970 and 2007, we can see if groups of countries are distinct in ways consistent with the four dimensions. We use a hierarchical clustering technique based on a Euclidean cluster method.

Figure 5 presents the numerically derived dendogram of countries in a hierarchical scheme. This approach allows the analyst to examine taxonomies with just a few clusters or with many clusters. We elect to examine the three clusters defined by the first two divisions selected by the cluster analysis (Table 6). \

Figure 5. Clusters of Countries with Common Changes in Z-scores for 10 Energy Security Indicators, from 1970 to 2007

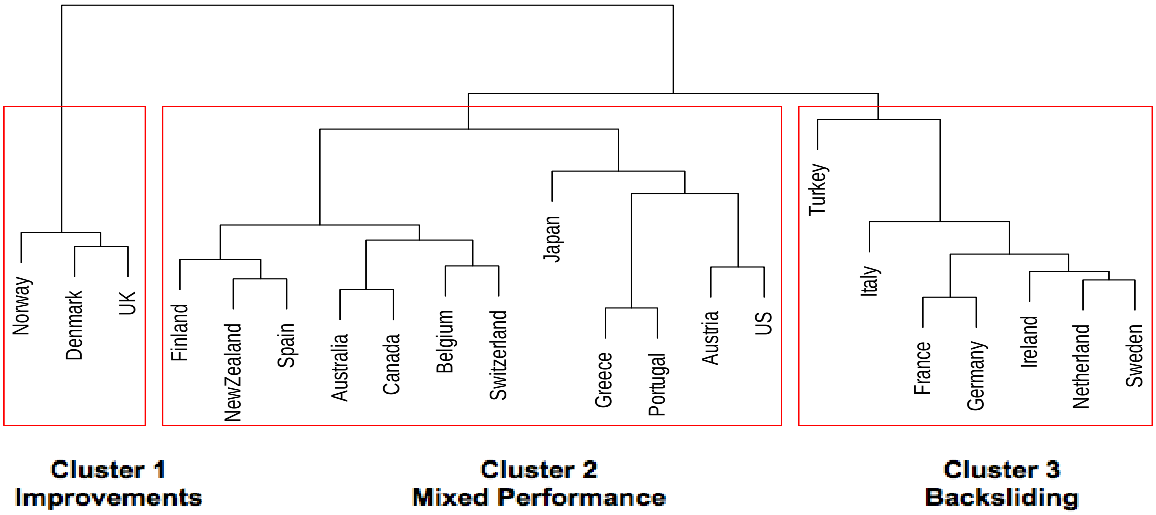


Table 6. Country clusters based on Changes in Energy Security Performance

Country Clusters	**Cluster 1: Improvements Dominate** (Denmark, Norway, and **UK**)	**Cluster 2: Mixed Performance** (Australia, Austria, **Belgium**, Finland, Japan, Portugal, Spain, Greece, Switzerland, US, New Zealand, and Canada)	**Cluster 3: Degradation Dominate** (Turkey, **France**, Germany, Ireland, Italy, Netherlands, and **Sweden**)
Availability			
Oil import dependency	↑	↓ (except Australia, Canada and New Zealand)	↓
Petroleum transport fuels			
Natural gas import dependency	↑		↓
Affordability			
Real electricity retail price	↓		
Real gasoline price	↓	↑ (except Finland and Spain)	↓ (except Germany)
Energy and Economic Efficiency			
On-road fuel intensity			
Energy per GDP intensity			
Electricity use per capita	↑		
Environmental Stewardship			
SO_2 emission			
CO_2 emission	↑	↓ (except Austria, Belgium, and Switzerland)	

Notes: ↑ = every country in this cluster improved on this dimension of energy security (with exceptions noted)

↓ = every country in this cluster deteriorated on this dimension of energy security (with exceptions noted).

Case study countries are highlighted in bold.

The three countries in Cluster 1 (Denmark, Norway and the UK) exhibit the strongest performance in terms of improved energy security. They have improved, relative to other

OECD countries, on two measures of energy "availability", with decreased oil and natural gas import dependence, and they also have improved on a measure of "energy and economic efficiency" with reduced electricity use per capita, and on an indicator of "environmental stewardship", with decreased CO2 emissions. However, they do not perform as well on the "affordability" dimension of energy security, with higher than average increases in electricity and gasoline prices.

At the other end of the spectrum, the seven countries in Cluster 3 (Turkey, France, Germany, Ireland, Italy, Netherlands, and Sweden) have experienced significant backsliding on several indicators of energy security. Specifically, they have performed worse than others in oil and natural gas import dependence. These countries have also experienced larger-than-average increases in gasoline prices.

Between these extremes are the twelve countries in Cluster 2 (including the US), that exhibit mixed performances across the 10 indicators. Most of these countries have slipped more than others in terms of oil import dependency, although there are exceptions (Australia, Canada and New Zealand). In addition, they have experienced more rapid increases in CO_2 emissions than other OECD countries (with the exception of Austria, Belgium, and Switzerland). Their gasoline prices, on the other hand, have increased less than the average of other countries in our sample (with the exception of Finland and Spain).

Overall, the composition of these trends shows some correspondence to the hypothesized four dimensions of energy security. Indicators of availability, in particular, track together and distinguish between countries where improvements dominate (Cluster 1) and those where degradation dominates (Cluster 3). There is also some evidence of common trends in affordability, with electricity and gasoline/petrol prices tracking together in Denmark, Norway, and the UK (Cluster 1 countries). Interestingly, affordability often competes with availability – improvements along one dimension leading to degradation of the other (Cluster 2).

6. Four Case Studies of Energy Security Performance

Using the same statistical data, supplemented by a review of the published literature, we explore four countries in greater detail, focusing on their improved, or worsened, energy security scores and the strategic actions that have led to them. Figure 2 shows that the United Kingdom and Belgium had their national energy security improve significantly between 1970 and 2007, whereas Sweden and France saw energy security deteriorate. Being members of the European Union, all four countries are influenced in some degree by EU directives and policies on climate change and energy. EU has strong orientation on climate mitigation, illustrated by the "20-20-20" targets, which bind and guide its member states to reduce GHG emissions and promote renewable energy and energy efficiency measures. In spite of the common external impacts imposed by the EU, these four countries have chosen different energy security strategies when continuing on their own energy use trajectories. By focusing on the "special cause variations", we explore each of these cases more closely in order to determine what major policy changes, or events, may explain the country-specific changes over time.

3.1 United Kingdom

The UK experienced the greatest improvement in energy security of all the OECD countries between 1970 and 2007. Perhaps most notable is the decline in its oil import dependence from 100% in 1970 to 4% in 2007. The UK also bolstered its energy security by shrinking the reliance on petroleum-based transport fuels, increasing on-road fuel economy, reducing energy usage per GDP, and reducing SO_2 and CO_2 emissions. But the UK was less successful at controlling the rise of electricity and gasoline prices compared with other countries in our sample.

The exploitation of North Sea oil reserves has greatly reduced the UK's oil imports. As an island nation, the UK is not rich in on-shore coal and natural gas resources, but it has broad access to the North Sea oil reserve. The UK has managed to meet domestic demand by drilling oil in the North Sea, transitioning to an oil exporting country in the 1980s. Its off-shore oil production peaked at about 140 million tonnes in 1999, declining to 75 million tonnes in 2007. Although its oil production is expected to continue to decline, only a small portion (4% in 2007) of UK's oil consumption came from imports (BP 2010; UK DECC 2010)

The progress of the country's performance on reducing SO_2 emissions can be largely attributed to the aggressive environmental and energy regulations driven by the public's heightened awareness of environment issues. The Great London Smog in 1952, which ranks as the worst fog in human history, triggered the domestic environmental movement and directly led to the Clean Air Act in 1956. Thanks to the continuous regulatory effort of the Clean Air Act (with major amendments in 1968 and 1993), the 8.6 million tons of SO_2 emissions in 1997 was reduced by 81% in the year 2007. As the second biggest SO_2 emitter in 1997, the UK has succeeded in shrinking its SO_2 emissions (both in total and per capita) to below the OECD average.

An economic driver for the UK's escalating performance on energy security is its energy market liberalization. Under the Conservative Party in the 1980s and early 1990s, the government gradually lost direct control of energy markets as state-controlled energy companies became privatized (Ilie, et al. 2007). Intended to build a competitive energy market and reduce energy prices, market liberalization, and subsequently induced investment and regulatory efforts have stimulated the efficient transformation of the energy sector (Green and Pricef 1995; Helm 2002). The positive consequences are a more diverse energy supply and the reduction of carbon emissions. Coal is no longer the predominant source of electricity generation (from 60% in 1990 to 30% in 2005) with the rise of gas-fired generation and nuclear power. Correspondingly, total CO_2 emissions fell 15% from 1990 to 2005 (CBI 2005; DTI 2006). Market liberalization also provided an opportunity for renewable energy since the public now has the option to switch utility companies to those providing green energy (Stanford 1998).

A series of market-based incentives and regulations also contribute to the UK's accomplishments. In 1995, the UK participated in the EU Voluntary Agreement target to stimulate technical improvements in vehicle efficiency. The same year, a "road tax" – or vehicle excise tax based on CO_2 emissions – was introduced to promote on-road fuel economy for new cars. Proposed in 1999 and introduced in 2001, the Climate Change Levy (CCL) imposes a tax on delivered energy for non-domestic users, providing incentive for energy efficiency and carbon emission reduction. The Renewables Obligation (RO), introduced in 2002, requires that 10.4% of the electricity supply come from renewable sources in 2010 and 15% by 2015. For suppliers who are not able to meet the requirement, they are able to purchase a tradable Renewables Obligation Certificates (ROC) for renewable energy generation. Non-compliant generators are penalized at the buy-out price set by policymakers on the proportion of sales not covered by ROCs, with resultant revenues subsidizing renewable energy generation. The RO and ROC have successfully tripled the proportion of renewable energy generation from 2002 to 2009 (Chalvatzis and Hooper 2009).

The Energy Efficiency Commitment program (2002-2005) urged electricity and gas suppliers to achieve (tradable) energy savings by promoting energy efficiency measures in the residential sector. This program has been highly successful with overachieved targets and a continuation of the program, which now is called the Carbon Emission Reduction Target

(Forfori 2006). A set of domestic policies and programs reflect UK's significant efforts targeting CO_2 emission to comply with the Kyoto Protocol. In 2002, the Climate Change Programme was launched to facilitate the reduction of carbon emissions. In the next year, the energy white paper – *Our Energy Future* – was published to guide energy policymaking toward a low-carbon economy. These regulations and policies combined have motivated energy-efficiency and emission-reduction measures leading to the UK's gradually improving energy security performance.

Nevertheless, the UK has failed to decrease electricity and gasoline prices in its quasi-competitive energy market. As appears to be true of the other Cluster 1 countries, the UK has relied on regulations and market-based incentives targeting energy efficiency, carbon emissions and renewable energy, while focusing less on the affordability. Not surprisingly, market liberalization alone has not been able to lower energy prices as expected, and instead has caused price volatility (Bonneville and Rialhe 2005). Energy prices are the result of a quasi-competitive market that does not closely track costs. For this reason, some analysts have recommended stronger government regulation of UK energy markets (Bonneville and Rialhe 2005).

3.2 Belgium

Over the period from 1970 to 2007, Belgium has improved greatly on several dimensions of energy security, reflected by increased on-road fuel economy, reduced energy per GDP intensity, lowered electricity retail prices and reduced carbon dioxide emissions. In terms of z-scores, Belgium gains credits on controlling for natural gas import dependence and gasoline price compared to other OECD countries in our sample. But Belgium has shown little improvement in transport fuel diversification, and has grown its per capita electricity use and its overall SO_2 emissions in proportion with its population increase.

The structure of Belgium's energy market is largely limited by its scarce natural resources. Belgium has no indigenous oil or natural gas reserves. The country imports 100% of its primary energy since its last coal mine was closed in 1993 (IEA 2006; D'haeseleer 2007). Energy policy in Belgium has focused on diversifying supply by switching from the Middle East to the North Sea (Norway and the UK) and the former Soviet Union as the main crude oil suppliers (D'haeseleer 2007). With little indigenous resource, Belgium must concentrate on diversifying geographical sources to secure its energy supply.

At present, the Belgian electricity market is highly liberalized and partially integrated with the markets of neighboring countries. Along with the political transition to a Federal Authority state from the 1970's to the 1990's, Belgium has made continuous efforts to privatize the energy market. Up to 2005, more than 90% of electricity consumption is supplied through a liberalized retail market (IEA 2006). Continuing to diminish the market power of dominant players, Belgium exchanges electricity capacity with France and the Netherlands since both countries have relatively lower electricity retail prices. Cross-border cooperation and the liberalization of electricity market have successfully lowered the electricity retail price in Belgium.

The change in fuel portfolio for electricity generation serves as the major driver for Belgium's better-than-average performance on reducing CO_2 emissions. The steady decrease (70% over the period 1973-2003) of coal consumption is highly noticeable, as well as the rise in natural gas and nuclear power (D'haeseleer 2007). From 1990 to 2003, carbon emissions from coal dropped by more than 40%. In the 1970's and 1980's, seven nuclear power plants were built with the net capacity of over 5.5 GW to generate 55.7% of the country's electricity without emitting air pollutants and carbon dioxide (IEA 2006).

Fuel switching is not the only factor, however, because federal/regional energy policies and programs also help to lower energy intensity and reduce emissions. Under the

Kyoto Protocol, Belgium's target is to reduce its greenhouse gas (GHG) emission by 7.5% below 1990 levels by 2012. In order to attain this reduction goal, federal and regional governments have established several market-based incentives, policies and programs. These measures include the National Climate Plan providing financing assistance for renewable energy, a federal electricity levy targeting GHG emissions, a federal motor tax, federal tax credits and regional Green/Combined Heat and Power (CHP) certificate schemes to facilitate renewable electricity generation (Van Stappen, Marchal et al. 2007; EREC 2009). The National Climate Plan also has fiscal incentives to promote biofuel uptake, implementing the EU CO_2/cars strategy, and setting up government funding schemes. The federal government also established an energy service company (FEDESCO) with government capital from the Kyoto Fund to promote energy efficiency in public buildings (IEA 2006; D'haeseleer 2007). Unlike other countries in Cluster 2, Belgium has a very clear focus on carbon emission regulations and has successfully reduced its carbon emissions while many of the countries in the same cluster have worse than average performance on carbon emissions.

Besides the market-based measures, Belgium also successfully transposes and implements the EU Directives on Emission Trading, household appliance labeling, fuel economy of passenger vehicles, and renewable energy. Currently, the regions are in various stages of implementing the EU Directive of Building Codes (IEA 2006; Geldhof, Delahaije et al. 2010). This set of domestic policies together with the incorporation of EU directives assist Belgium not only with lowering energy intensity and reducing carbon emissions, but also with promoting on-road fuel economy and constraining the growth of per capita electricity consumption.

However, Belgium's practices on energy security measures are highly constrained by several domestic factors. The country has little indigenous primary energy resources and has to depend on imports to meet domestic energy demand. The production of renewable energy has not taken off yet since the share of renewable energy is still low (2.7% in 2007) in total primary energy consumption (EREC 2009). Oil continues serving as the major energy source (over half in 2005), and the country has failed to reduce its SO_2 emissions. The privatized energy market is far from competitive since it is dominated by the Suez Group as the monopoly supplier for gas and electricity. With regard to regulation, the dynamics between the federal and the regional governments add political complexity to this energy security issue.

These hurdles have prevented Belgium from reducing its dependence on energy imports and SO_2 emissions. But other OECD countries can still learn from Belgium for its experience in the electricity market integration with neighboring countries, which has reduced its electricity rates, and its successful domestic implementation of EU directives on energy efficiency measures. The other Cluster 2 countries can also learn from Belgium on its policy experience of reducing carbon emissions.

3.3 France

Compared to the z-scores of other countries in our sample, France improved only on two of our ten metrics: carbon dioxide emissions and sulfur dioxide emissions, scoring negatively in every other aspect. In absolute terms, oil dependence decreased from 98% to just 96% from 1970 to 2007. The share of petroleum in transport energy usage actually grew and the country saw virtually no improvement in on-road fuel economy. Electricity use per capita almost tripled over the same period, growing from 2,882 kWh per capita to 7,585 kWh per capita, and natural gas import dependence increased almost threefold from 35% to 97%. Retail electricity and gasoline prices both more than doubled in real terms as well.

France's performance on energy security is weaker than the other countries in Cluster 3, where backsliding dominates (though to be fair, this could be because France started from a relative position of energy security strength). Though almost every country in Cluster 3 has improved in energy intensity (per GDP), France made the second smallest improvement behind Turkey. France has increased its electricity use (per capita) while other Cluster 3 countries have decreased (except for Ireland). France has the most degradation in the reliance on petroleum as transportation fuel comparing to the other countries in the same cluster. But, France has better than average performance on reducing SO_2 emissions due to its reliance on nuclear power.

Part of the problem is geological: France has a paucity of primary energy resources. Its national coal reserves could barely cover consumption in the 1980s and domestic natural gas reserves were largely depleted during that same decade. Despite its reliance on nuclear energy, France is home to a mere 2.2% of known recoverable uranium reserves (De Carmoy 1982).

But a large part is also social and political. Although our index starts assessing progress in the 1970s, the explanation for France's poor performance goes back further, as French energy policy was deeply shaped by World War II. Humiliated and defeated, French technical and scientific experts linked technological advancement to French national prestige and identity (Scheinman 1965; Hecht 1998). These elites promoted notions of rational public administration and central planning, and used their expertise to maintain autonomy from the public. They were thrust into the forefront of French political life as authorities for how reconstruction ought to progress, and strengthened by *dirigisme*, a tradition of state intervention to subsidize and protect certain industrial enterprises. Such expertise was widely considered a prerequisite to participate in policy discussions, and was rarely questioned (Barkenbus 1984; Sovacool and Valentine 2010).

France thus embarked on an extremely centralized energy policy, run by state elites, oriented towards investments in infrastructure and technology. The Commissariat à l'Énergie Atomique (CEA), formed in 1945, had a close association with bureaucracy in Paris and the military and was charged with developing a French gas-graphite reactor. The CEA slowly came to share their authority with Électricité de France (EDF), the state-owned national electricity provider created in 1946, and Framatome, the single government-owned nuclear vendor.

Collectively these major players dedicated almost all of their energy efforts to energy supply rather than energy demand and energy efficiency, even throughout the energy shocks of the 1970s. France did make some initial efforts to reduce crude oil consumption—annual growth in energy consumption, for example, dropped from 5.7% in 1960 to 4% in 1970 and then less than 1% per year after 1973 (Taylor, Probert et al. 1998). But reduced oil imports were compensated by an increase in gas and coal imports, and falling oil prices in the 1980s convinced the government to abandon its energy conservation programs. The 1990s saw "diminishing energy efficiency gains" and a significant increase in industrial and commercial electricity and energy consumption. A growing French population, expanding economy, an increase in the number of dwellings, more industrial output, and a shift to private vehicle transport combined to increase national energy demand by almost 50 million tons of oil equivalent from 1973 to 1993. Thus, the energy shocks did not seem to impact France as much as others in Europe, with no major lasting changes on national policy and "very little progress" in improving energy security (Bossebouef and Richard 1997).

Despite these shortcomings, France has improved some aspects of its energy security. Consumers enjoy some of the cheapest electricity and gasoline/petrol prices in Europe and all of the OECD, and the country has a low level of greenhouse gas emissions per unit of GDP (IEA 2004). Indeed, France is one of the only countries in Europe to have already reduced its emissions below Kyoto Protocol targets. Though France has no large energy reserves of its own, it is well situated in the middle of European energy markets. Due mostly to reliance on nuclear power, self-sufficiency in energy production has grown from 22.5% in 1973 to 51.5% in 1995 (Taylor, Probert et al. 1998) and in 2008, nuclear power accounted for 40%% of total primary energy supply (IEA 2009). For the mid-2000s France also boasted the most renewable energy production of any European Union country and spent more than all other European countries on energy research.

But overall, French energy policy has limited energy security accomplishments. Such stagnation can be explained in part by the closed nature of the French energy system. One key aspect of the energy policy in France was a lack of debate and discussion among Parliament, the media, and the public. For most of the past three decades there has been an absence of disagreement among the major political parties, with the Gaullists (RPR) and the Republicans (PR) differing on minor points (Sovacool and Valentine 2010). When Pierre Messmer, the Minister of France under Georges Pompidou, proposed to construct 63 new nuclear power plants from 1974 to 1985, the decision to go forward was not even debated in Parliament. The lack of discussion contributed to, and was a symptom of, a low level of environmental awareness and weak checks and balances. The French electoral system is designed to keep small parties from gaining access to Parliament, meaning none of the few anti-nuclear leaders ever had access to policymaking (Hadjilambrinos 2000). To protect its nuclear industry, France also resisted restructuring efforts that would have introduced more competition in the electricity sector (Jasper 1992; Finon and Staropoli 2001). The transport sector is also carbon-intensive, responsible for more than one-third of all emissions in 2008 (IEA 2009). The implication is that France may begin to lose one of the two key areas, carbon emissions, where it is ahead, and the lack of debate and discussion could keep its existing energy configurations path dependent for the foreseeable future.

3.4 Sweden

Over the 1970 to 2007 period, Sweden's energy security index dropped by a relative 2.1 standard deviations against the mean. The largest negative scores came from emerging natural gas import dependence (a fuel that only entered Sweden's energy mix in 1985) and a six-fold increase in real gasoline prices. Prominent gains came from a 34% reduction in economy-wide energy intensity, a reduction in on-road fuel intensity, and a relatively slower rise in retail electricity prices against other OECD countries. Per capita annual electricity consumption increased from 8,048 kWh to 15,230 kWh, which approximated the indicator's mean difference and therefore contributed a nominal z-score improvement. Sweden's oil import dependence barely moved over the period while the share of petroleum-based transport fuels increased slightly. Compared to other countries in the same cluster, Sweden has better than average performance in on-road fuel economy and electricity price stability.

Unlike its neighbor to the West (Norway), Sweden possesses no major indigenous energy resources aside from forests in the north, where biomass for electricity and biofuels is sourced, and 598 MW of hydropower capacity. Without domestic oil or natural gas reserves, Sweden has had difficulty reducing its import dependence, which negatively impacts its z-score. The country's nuclear fleet of ten reactors is also powered exclusively by imports. Sweden has neither plans for nor ongoing domestic uranium production activities (NEA/IAEA 2006). Coal, like natural gas, is a minor fuel and contributes less than 5% of total primary energy supply (TPES) (IEA 2008).

The 1970s was a watershed decade for Sweden's energy policy. The two oil crises had lasting effects on the economy in the form of rising budgets and deficits, and a contraction of export industries (Ysander 1983). To reduce the country's vulnerability to similar shocks in the future, an energy research program was started in 1975 to chart an energy pathway away from fossil fuel dependence (Björheden 2006). Energy efficiency measures were implemented and oil-fired power stations replaced by nuclear plants (Collier and Löfstedt 1997). While Sweden had already begun incorporating nuclear power into the grid, the oil crises triggered its exponential growth over several decades. In 1970, nuclear energy generated 0.1 TWh, rising to 76.8 TWh by 1991, against a TPES increase of only 25% over the same period (BP 2010).

The Three Mile Island accident in 1979 instigated a referendum on nuclear energy which resulted in the Swedish Parliament passing in 1980 a measure to forego nuclear expansion and shut down all operating reactors by 2010, so long as replacement energy sources would be available (Wang 2006; World Nuclear Association 2010). However, this did not mark an outright rejection of nuclear power. According to the World Nuclear Association (2010), most voters supported the operation of nuclear plants for the duration of their operating life if still economical. This coincided with an infusion of environmental sentiment into politics in the 1980s, with NGOs and environmental interest groups enjoying greater influence. NGO representatives were able to enter government positions and challenge the standing orthodoxy of energy as infrastructure. These political factors, in addition to the Chernobyl accident in 1986, fast-tracked the nuclear phase out and led to a 1997 decision to close two nuclear reactors, Barsebäck 1 and 2, before the 2010 deadline (Nilsson 2005).

Since the 1970s, the country has used fiscal policy to drive environmentally-sound energy use, first through taxes on oil products (Ericsson, Huttunen et al. 2004; IEA 2008) and later differentiated across all energy sources and end-uses. The energy tax's objective has evolved over time, shifting from reducing oil demand in the 1970s to its current focus of reducing both oil and electricity demand for heating. Carbon taxes were introduced in 1991 which resulted in increased biomass use for district heating systems since bioenergy and peat were tax-exempt. A sulfur tax was implemented the same year, applicable to coal, peat, and oil (Swedish Energy Agency 2009). These levies tilted the economics in favor of wood fuels and biofuels for electricity which saw a greater than three-fold increase over the decade following 1990 (Johansson 2000). Tax levels track the consumer price index, with the carbon tax recently trending at SEK 1050 (US$150) per ton of CO_2.

While the volume of fuel oil used for heating dramatically dropped since the 1970s, electricity demand largely filled the gap and hence the increase in per capita demand. Electricity use in the residential and service sectors has stayed constant from 1990 to 2008 at around 70 TWh, more than triple the value of 1970 when electric heating represented only a small share of total electricity use. Larger homes and more electrical appliances are also contributing factors to the rise in demand. In addition, Sweden also has energy-intensive industries like paper and pulp, steel, and chemicals for which energy represents a sizable share of production costs (Thollander and Ottosson 2010). Given that industry consumes 38% of final energy, energy efficiency instruments have been established, like the Program for Energy Efficiency Improvement in Energy-Intensive Industry (PFE) which refunds companies their electricity taxes if they implement in full the recommendations outlined in an energy audit (Swedish Energy Agency 2009).

Both the Swedish government and the public are mindful of the country's contribution to climate change and have therefore enacted measures to curb their greenhouse gas emissions. Under the European Union's Climate and Energy Package which entered into law in 2009, Sweden agreed to legally binding targets for a 17% reduction in GHG emissions over 2005 levels in sectors not covered by the EU Emissions Trading Scheme, and for renewables to supply 49% of final energy demand by 2020 (European Parliament 2009). This will be facilitated by opening the "Renewable Electricity with Green Certificates" Government Bill to international certificate markets in a measure to be considered in the Bill's 2012 review. A 2030 target for fleet-wide independence from fossil fuels has also been designated, though its achievement seems highly improbable and expensive. At the same time, since GHG emissions were significantly slashed in the wake of the oil crises, less scope for further reductions exists, especially since hydropower and nuclear sources already generate 89% of total electricity (IEA 2008). Sweden will have to closely investigate the energy security implications of substituting fossil fuels with alternatives that may either drive up energy prices even higher than current levels, or subject the country to a different set of supply vulnerabilities.

7. Conclusion

This paper has evaluated an energy security index comprised of four dimensions (energy availability, affordability, energy efficiency, and environmental stewardship) and ten indicators, based on the status of energy conditions in 22 OECD countries from 1970 to 2007. At least four interconnected conclusions can be drawn from this research.

First, our energy security index shows that a majority of the industrialized countries in our sample have regressed in terms of their energy security. No country improved along all ten indicators, and the UK and Belgium (the most improved countries) scored better on six indicators and worse on four, over the past four decades. 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 as most countries moved away from their use of oil to produce electricity. Despite all of this effort, our index reveals that the energy security of most countries has degraded.

Second, despite the near universal deterioration of energy security, a great disparity exists between countries. Some clear leaders, such as the U.K. and Belgium (described in this article) as well as Denmark and Japan (described in Sovacool and Brown 2010) stand above the rest and offer many lessons. These countries did not leave the improvement of energy security to the marketplace, and their experience underscores the importance of government intervention through a progression of energy policy mechanisms. Energy taxes, standards, and R&D tended to come first, followed by mechanisms such as tariffs and quotas, demonstrating the necessity of using a variety of mechanisms at once to promote sound energy policy. Successful countries also focused on energy efficiency as well as combined heat and power and district heating to meet energy needs, and not just one type of policy mechanisms, but a variety of mechanisms.

Timing also plays an important factor. We rank our countries by their relative progress or backsliding on energy security. This is done by calculating the change in total z-square over time, meaning that where countries start at a particular time becomes salient. For instance, France was doing well in 1970 so it was easy for them to slip slightly relative to other OECD countries. In contrast, Belgium started off with relatively weak indicators in 1970, but it made significant improvements by 2007. Because France started out from a position of strength and slipped, while Belgium started off relatively weak, but improved, France performs worse in our index.

Third, the emerging multidimensional view of energy security acknowledges that transforming energy systems is at the core of energy security solutions. At the same time, this broad approach complicates the assessment of national strengths and weaknesses and challenges the ability to develop a single index to calibrate the energy security of an individual nation state. Our analysis provides evidence that our four hypothetical dimensions of energy security provide useful insights into common energy security conditions and strategic approaches.

Fourth, and finally, our analysis of OECD countries suggests that countries have similarities and differences in energy security trends that align with the four dimensions, suggesting that the countries can be categorized based on distinct energy security strategies and resource endowments. Two of the countries that degraded most rapidly in energy security among our sample are France and Sweden. Both countries that have failed to enact aggressive energy efficiency policies as a means of moderating electricity prices and oil import dependence. This dimension of energy security plays a successful role in other countries that have strengthened their energy systems.

This article represents one of the first scholarly efforts to correlate actual energy policy and practice with expert views of the multidimensional concept of energy security. Based on 22 OECD countries, it concludes that many industrialized countries have been unable to make progress toward the goal of achieving secure, reliable and affordable supplies of energy while also transitioning to a low-carbon energy system. However, some best practice models exist, and the examination of actual trends suggests that our four dimensions of energy security represent a useful place to begin considering the design of strategic approaches to energy security.

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Appendix A. 1970 data background

Data for energy intensity starts at 1980 instead of 1970. Specific values for fuel economy for Austria, Canada, Denmark, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, United Kingdom, and United States taken from Schipper, Lee and Lew Fulton. 2009. *Disappointed by Diesel? The Impact of the Shift to Diesels in Europe Through 2006.* Presentation to the Transportation Research Board Annual Meeting, Washington, DC. Values for remaining countries are taken from OECD averages. Values for population figures and Gross Domestic Product (GDP) are taken from US Economic Research Service. 2008. *International Macroeconomic Data Set* (Washington, DC: US Department of Agriculture). Figures for electricity consumption per capita exclude electricity exports, and were calculated by dividing IEA data in total national consumption (in GWh) by the reported national population. Figures for "energy intensity" taken from 1980 data from: US Energy Information Administration. 2007. *World Energy Intensity: Total Primary Energy Consumption per Dollar of Gross Domestic Product* (Washington, DC: US Department of Energy), and presumed market exchange rates adjusted for 2007 US dollars. Values for retail gasoline prices presume premium gasoline, exclude taxes, have been adjusted to 2007 US dollars, and are taken from: Bentzen, Jan. *An Empirical Analysis of Gasoline Price Convergence for 20 OECD Countries*, Working Paper 03-19 (Denmark: Aarhus School of Business2003) , and adjusted according to: Organization of Economic Cooperation and Development. 2008. "Consumer Price Indices: Energy," *Main Economic Indicators* (Paris: OECD). Values for retail electricity prices have been adjusted to 2007 US dollars, are taken from: International Energy Agency. 2008. *Energy Prices & Taxes: Quarterly Statistics* (Paris: IEA), and adjusted according to: Organization of Economic Cooperation and Development. 2008. "Consumer Price Indices: Energy," *Main Economic Indicators* (Paris: OECD). Some data on sulfur dioxide emissions come from: Spiro, Peter A., Daniel J. Jacob, and Jennifer A. Logan. 1992. "Global Inventory of Sulfur Emissions With 1x1 Resolution," *Journal of Geophysical Research* 97: 6023–6036; and Brimblecombe, Peter. 1999. *Historical Sulfur Emissions* (Norwich, UK: School of Environmental Sciences, University of East Anglia). All remaining figures come from: International Energy Agency. 1991. *Energy Statistics of OECD Countries, 1960 to 1979* (Paris: Organization for Economic Cooperation and Development); International Energy Agency. 1984. *Energy Balances of OECD Countries, 1970 to 1982* (Paris: Organization for Economic Cooperation and Development).

Appendix B. 2007 data background

Data for energy intensity and fuel economy is for 2005 instead of 2007. Energy intensity is taken from: US Energy Information Administration. 2007. *World Energy Intensity: Total Primary Energy Consumption per Dollar of Gross Domestic Product* (Washington, DC: US Department of Energy), and adjusted for purchase power parity (PPP). Specific values for fuel economy for Austria, Canada, Denmark, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, United Kingdom, and United States are taken from: Schipper, Lee and Lew Fulton. 2009. *Disappointed by Diesel? The Impact of the Shift to Diesels in Europe Through 2006*. Presentation to the Transportation Research Board Annual Meeting, Washington, DC. Values for remaining countries were taken from European and OECD averages. Data for sulfur dioxide emissions are from 2000 instead of 2007, and are taken from: World Resources Institute (WRI). 2007. *Climate and Atmosphere Indicators: Sulfur Dioxide Emissions* (Washington, DC: WRI). Values for retail gasoline exclude taxes for the United States and presume unleaded premium or equivalent grade fuel. Data for alternative fuels include only ethanol and biodiesel, report EU targets for most European countries, and come from: Organization for Economic Cooperation and Development. 2008. *Biofuel Support Policies: An Economic Assessment* (Paris: OECD). All remaining figures are taken from: US Energy Information Administration. 2008. *Country Energy Profiles* (Washington, DC: US Department of Energy); and International Energy Agency. 2008. *Key World Energy Statistics 2008* (Paris: International Energy Agency), with adjustments made according to: Organization of Economic Cooperation and Development. 2008. "Consumer Price Indices: Energy," *Main Economic Indicators* (Paris: OECD) when data were not available for 2007.