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Forty years of energy security trends: A comparative assessment of 22 industrialized countries

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ABSTRACT

This article correlates energy policy and practice with the multidimensional concept of energy security and empirical performance over forty years. Based on an analysis of 22 countries in the Organization for Economic Cooperation and Development between 1970 and 2010, it concludes that many industrialized countries have made limited 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 (both with limited improvements). The article concludes by offering implications for energy policy more broadly and by providing empirical evidence that our four dimensions (availability, affordability, energy efficiency, and environmental stewardship) envelop the key strategic components of energy security.

1. Introduction

After decades 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 that do not impinge upon social stability nor involve climate-endangering greenhouse gases? The answer to this question 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 endowments, political levers, inter-state relations, capital availability, risk appetites, and other particularities of individual nations.

To offer readers a concise, high level view of global trends in energy security, this study investigates the energy security performance of 22 countries in the Organization for Economic Cooperation and Development (OECD) between 1970 and 2010. To do so, it evaluates their performance on a set of 10 energy security metrics, and then uses *z*-scores and factor analysis to tease out best performers and practices. We also present four brief, qualitative historical case studies of Belgium, France, Sweden, and the United Kingdom to help make sense of our results. Our study finds that many industrialized countries have made limited progress toward the goal of achieving secure, reliable and affordable supplies of energy while also transitioning to a low-carbon energy system.

Some of our work has explored the topic of energy security and industrialized countries before. What makes this analysis different, and relevant to this journal? Many things. Our earlier work ended with 2007 data, relied on simple *z*-scores to report results, and presented case studies of Denmark, Japan, the United States, and Spain. This study draws from more recent 2010 data, uses factor analysis to examine correlations between the energy security metrics, applies clustering analysis to identify sets of countries with common energy security trends, and presents four completely new case studies of Belgium, France, Sweden, and the United Kingdom.

In doing so, it connects to a number of key themes in this journal. By focusing on energy security as a multidimensional

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concept involving environmental, political, and economic elements, it moves away from narrow depictions of energy security centered on technology [1]. By offering a systematic method of measuring energy security performance, our study can inform energy planners making actual decisions about infrastructure or national policy [2], decisions that can affect those deciding the proper scale of energy systems [3,4], or wider patterns of poverty and economic development [5]. Our energy security index makes possible the correlation of energy security performance with exogenous events such as military conflicts [6], major embargoes [7], or the introduction of innovative, yet disruptive, energy technologies [8]. It lastly helps reveal energy vulnerabilities common to many countries, a process which could convince stakeholders to cooperate and work together politically to respond to collective threats [9].

2. Conceptualizing energy security

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 [10]. With the broadening of the range of energy supply disruptions, discussions of energy security have expanded to embrace electricity reliability as well as natural gas and petroleum security, and the entire energy supply chain including energy delivery infrastructure [11]. Numerous events have underscored the entire energy supply chain's vulnerability to many different types of disruptions, including political instability in the Middle East and Eastern Europe, natural disasters such as the earthquake and tsunami causing a shutdown of the Fukushima Daiichi complex in 2011, natural gas disputes with Russia (2006–2009) that have wreaked havoc in European electricity markets, and power system breakdowns such as the northeast US blackout of 2003. Hurricanes Katrina and Rita along the U.S. Gulf Coast in 2005 illustrated one of the first major diversified energy disasters, with the simultaneous disruptions of oil, natural gas, and electric power.

Yet other dimensions of energy security have begun to surface. With rising energy costs, affordability and economic competitiveness have joined supply security as common objectives [12]. The volatility of energy prices and growing uncertainties about available imports of both oil and natural gas have elevated the role of policies to promote energy efficiency [13]. With climate change and air pollution damages gaining greater clarity, the environmental sustainability of energy systems has also become an objective of a secure energy future [14–17]. At the extreme, when environmental conditions deteriorate to the point that society cannot function, nation states could reach the point of collapse, impinging on national security worldwide [18].

While supply availability remains a core concern of the energy security debate, the more current literature recognizes that priorities with respect to global warming, air pollution, economic growth, energy affordability and international energy relations will define how the transition to a secure energy future is to be achieved [19–24]. However, it has also been alleged that the need for global coordination is more urgent than securitization [25].

Most recently, approaches incorporating a diversity of dimensions have begun to emerge. Gracceva and Zeniewshi, for instance, define five dimensions of energy security: stability, flexibility, adequacy, resilience, and robustness [26]. Energy, climate change, environmental and health issues are recognized by Pode [27]. Badea et al. [14] 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).

For this study, we thus define energy security as "equitably providing available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users." This conception of energy security comes from a literature review of energy security offered in Sovacool and Brown [28] as well as research interviews with energy experts and surveys of energy end-users [29–33]. This consequent 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 facilitates the development of a single index to evaluate and calibrate the energy security of individual nation states.

3. 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 [28,31,34,35]. **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 minimizing 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 these dimensions are listed above in their order of frequency as shown in Table 1.

Recognizing that each dimension does not exist in a vacuum and that each is of comparable importance, Table 1 also presents 10 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.

As Table 1 depicts, to reflect availability, oil import dependence, natural gas import dependence, and dependence on petroleum transport fuels serve as useful indicators. The reliance on oil and natural gas imports 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). More composite and complete indicators would reflect the sources of a country's imports and available delivery infrastructures including pipeline systems and facilities for handling the delivery of liquefied natural gas. The presence of non-petroleum transport fuels such as ethanol, biodiesel, natural gas, and electricity reveals how far countries have moved away from dependence on gasoline and diesel. Only a few countries have made meaningful progress on this dimension (most notably Brazil – which is not in our sample – with its reliance on ethanol from sugar cane). Still, alternative transport fuels (biofuels, natural gas, electricity, etc.) hold the potential to significantly reduce dependence on imported petroleum and will be critical as the world moves closer to eclipsing its peak oil production. According to an analysis by Brown and Sovacool [36] of proven oil reserves and their rates of depletion, the existing 1.3 trillion barrels of proven reserves will last 43 years at today's consumption rate, or for only 23 years if consumption grows by 5% annually. Thus, our index provides a higher score for those

Table 1
Defining and measuring energy security.

Dimension	Explanation	Percent of articles	Indicators[a]	Measurement unit
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	82%	–Oil import dependence; –Natural gas import dependence; –Dependence on petroleum transport fuels	% of oil consumption that is imported % of natural gas consumption that is imported % of transport fuel that is petroleum-based
Affordability	Providing energy services that are affordable for consumers and minimizing price volatility	51%	–Retail electricity prices; –Retail gasoline/petrol prices	US¢/kWh US$/L
Energy and economic efficiency	Improving the performance of energy equipment and altering consumer attitudes to reduce energy price exposure and mitigate energy import dependency	34%	–On-road fuel intensity of passenger vehicles; –Energy per GDP intensity; –Electricity use per capita	Gallons per mile 1000 Btu/US$GDP kWh/capita
Environmental stewardship	Protecting the natural environment and future generations	26%	–Sulfur dioxide emissions; –Carbon dioxide emissions	Million tons Million tons

[a] For measurement of the indicators, see Sovacool and Brown [28], and Table 2 below.

countries that are making progress diversifying their transport fuels, even if the magnitude of that progress remains modest to date.

To reflect affordability, electricity and gasoline/petrol prices 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. Since energy consumption is influenced by retail energy prices, low taxes promote affordability while also encouraging high demand, along with inefficient vehicle fleets and building stocks. This illustrates the tension and interplay between many of the indicators.

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 toward mitigating greenhouse gas emissions, acid rain, and noxious air pollution. The absolute numbers are used for these two indicators because they are what matters most from a climate change and public health standpoint. However, absolute indicators do create a tendency for large countries to be rated as less secure (although this tendency is moderated by our focus on changes in indicators). As a result, we repeat the entire analysis using per capita CO_2 and SO_2 emissions indicators instead of the absolute emissions measures, and report the differences that result.

To be sure, these indicators were not the only ones we could have chosen – for example, the *Routledge Handbook of Energy Security* depicts almost one *thousand* distinct metrics that relate to some aspect of energy security. We discuss import dependence but not energy exports; we discuss electricity consumption but not the diversification of electricity supply; we discuss energy intensity but not residual potential, or how a country's budget deficit could hamstring future policy choices. We chose 10 indicators rather than twenty or one hundred in an effort to keep our index simple. Kemmler and Spreng [37], for instance, have cautioned that indicator sets that are too large can be overwhelming and that simpler, smaller indices tend to be more useful for providing a concise general overview for policymakers and regulators. We could have included more variables in our index, but we felt these traded off with its coherence.

4. Methodology for evaluating the dimensions and indicators of energy security

We evaluate the validity and usefulness 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. Recall that the four dimensions were not derived deductively from a theoretical framework, but rather emerged from a review of the literature. Thus, it remains to be seen if these dimensions are empirically distinct from one another. 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 and trends.

We have limited our analysis to 22 countries belonging to the OECD for multiple reasons. One is data reliability: the OECD is one of few organizations that have been collecting reliable energy related data for many decades now. Another reason is size: in 2012, countries belonging to the OECD collectively were home to 1.2 billion people, produced $47.3 trillion worth of Gross Domestic Product (about three-quarters of the world total), and covered 36 million square kilometers of territory [38]. One final reason is relevance: in 2010, OECD countries were responsible for 45 percent of total final energy consumption, 39 percent of global investment in energy infrastructure, and roughly one-third of carbon dioxide emissions from fossil fuel combustion [39,40].

We have, furthermore, designed our index to assess the performance of individual countries rather than regional blocs such as the European Union, or other scales such as municipalities and corporations. This is because the nation state remains where most energy planning and policymaking takes place, and it is also how most major energy statistics are collected, based on national boundaries. Moreover, despite the rise of new modes of governance above and below the state [41–43], most key political decisions are still made at the state level, and the state-based international system has exhibited a high degree of resilience. As political scientist Robert Falkner writes, "In the near-term, the international states system is unlikely to be replaced with a different form of global political organization" [44]. Political scholar Robyn Eckersley calls states the "gatekeepers of the global order," and adds that they remain the "preeminent political institution for addressing environmental problems" [45].

In evaluating energy security trends within these OECD countries, we could have measured progress every decade, or year-to-year. We intentionally avoided that type of analysis because too few studies take a long-term view. Most assessments of energy security focus on "near real-time" events which occur in less than a minute, the "short-term," less than 2 years, or "the medium run" of 2–15 years [46]. Long-term energy security concerns, however, involve an entirely different set of issues such as sunk costs and embedded infrastructure, the process of energy transitions, and diversifying technologies and providers [47]. Here, we wanted to investigate major trends and transitions over as large a period of time as possible. Focusing on the four decades between 1970 and 2010 enables us to determine, by simple comparison, how major events such as the OPEC embargo of the 1970s, energy restructuring programs of the 1980s and 1990s, emergence of climate change as a salient concern in the 2000s, and the global financial downturn post 2008 impacted energy security.

To assess OECD country performance, we collected data on our 10 indicators and metrics for 1970–2010, with a few exceptions and caveats. First, reliable data for on-road fuel economy is for 2005 instead of 2010. 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 [48]? Third, collecting the data for this study was tedious and difficult, reflecting the limited emphasis on energy monitoring even in the most advanced economies of the world. Most of the data 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). Table 2 shows the data on the 10 variables in 2010. The 1970 data is reported in Sovacool and Brown [28].

We admit that our method of constructing energy security indicators is not optimized, but rather limited by available data. For example, it does not include a comprehensive measure of a country's energy resource diversity. Also, no weighting is imposed on the 10 selected indicators; thus, a large change on a single attribute may dominant a country's energy security index. In addition, because the availability and efficiency dimensions each have three indicators, while the others have two, there is an inherent greater emphasis on them.

By imposing a z-score normalization, followed by a factor analysis, we are able to moderate these effects. z-Scores are also able to distinguish between "common cause" variation (when all countries experience similar shifts) and "special cause" variation (when a country's actions and situations result in a distinct change in energy security) [49]. The z-scores represent the normalized distances from the data points to the means in terms of standard deviation (see Eq. (1)).

$$z\text{-Score}_{d,y} = \frac{\text{absolute value}_{d,y} - \text{mean}_{d,y}}{\text{standard deviation}_{d,y}} \quad (1)$$

where d is the energy security dimension; y is year.

Because z-scores evaluate the relative magnitudes of change in indicators, they 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 10 indicators in 1970 and 2010 by subtracting the mean value for each data point and dividing it by the indicator's standard deviation. The z-scores are then summed for 1970 and 2010, giving equal weight to each indicator and providing a total energy security score for each country in both years. Because of the way each of the 10 indicators being measured (e.g., percent oil import dependence), positive z-scores in 1970 and 2010 indicate lower energy security relative to other OECD countries. As a result, we reversed the signs of the z-scores to be consistent with the measurement of "energy security." Table 3 presents the differences in these overall energy security scores by subtracting the 1970 z-scores from the 2010 z-scores. Thus, positive numbers indicate improving energy security trends relative to other OECD countries.

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 2010. In contrast, Austria, the United Kingdom, Canada, and Australia had high energy security scores in 2010. The distance between each country's coordinates and the diagonal line in Fig. 1 indicates how much the country has improved or deteriorated in energy security. From this perspective, Canada, Belgium, and Japan are the most improved, while countries such as Turkey, Ireland, and Greece have experienced the least improvement relative to other OECD countries over the past several decades. When we examine the results produced by replacing the CO_2 and SO_2 raw emissions with per capita emissions, a few notable changes occur. The energy security of the United States improves over time based on its shrinking per capita CO_2 emissions, from 21 tons per capita in 1970 to 18 tons per capita in 2010. Australia, on the other hand, has higher CO_2 emissions per capita in 2010, while its per capita emission of SO_2 are slightly lower, illustrating how these two indicators can diverge.

Fig. 2 then quantifies the progress of each country over time by comparing the sum of their z-scores on the 10 indicators in 1970 and 2010. The results of that analysis indicate that the United Kingdom's large uptick in energy security is the most multidimensional, with improvements on six of the 10 z-score indicators. It was particularly strengthened with respect to oil import dependence, shifting from 100 percent dependence in 1970 to only 14 percent in 2010. Canada, Belgium, Japan, the U.S., and Switzerland also experienced significant improvements in their energy security over this same time frame. In contrast, Turkey, Ireland, Greece, and Italy experienced the largest declines in energy security over this same period. Turkey's decline is largely due to rising gasoline prices, while Greece and Ireland experienced significant increases

Table 2
Energy security performance index for 22 OECD countries, 2010.[a]

	Availability			Affordability		Energy and economic efficiency			Environmental stewardship	
Country	Oil import dependence (%)	Petroleum transport fuels (%)[b]	Natural gas import dependence (%)	Real electricity retail prices (US¢/kWh)	Real gasoline prices ($/L)[c]	On-road fuel intensity (gpm)[d]	Energy per GDP intensity (tBtu/ 2005US$GDP)*	Electricity use (kWh/ capita)	SO_2 emissions (million tons)[e]	CO_2 emissions (million tons)
Australia	21.2%	95.8%	0.0%	12.5	1.27	0.038	7.7	10,386	2.4	424
Austria	82.7%	88.8%	74.8%	20.1	1.63	0.032	5.2	7728	0.0	69
Belgium	98.1%	94.4%	99.3%	16.5	1.87	0.034	7.9	8141	0.1	136
Canada	0.0%	93.2%	0.0%	7.6	1.21	0.043	10.5	15,841	1.4	547
Denmark	0.0%	98.6%	0.0%	39.6	2	0.033	4.6	6083	0.0	46
Finland	93.3%	95.4%	100.0%	17.2	1.94	0.034	7.8	16,185	0.1	55
France	94.4%	91.9%	98.4%	16.9	1.98	0.031	5.6	7300	0.3	389
Germany	92.7%	90.3%	78.0%	26.3	1.9	0.034	5.3	6666	0.4	793
Greece	98.0%	97.9%	100.0%	13.0	2.05	0.034	4.7	5247	0.3	93
Ireland	98.2%	97.5%	93.3%	26.7	1.78	0.034	4.1	5449	0.0	38
Italy	91.0%	92.0%	90.5%	30.5	1.87	0.030	4.9	5050	0.2	417
Japan	96.1%	97.9%	90.4%	20.6	1.6	0.045	5.6	7801	0.8	1180
Netherlands	94.9%	96.6%	0.0%	24.3	2.13	0.033	7.0	6638	0.0	255
New Zealand	46.4%	99.8%	0.0%	16.4	1.47	0.034	7.6	9585	0.1	37
Norway	0.0%	95.3%	0.0%	16.4	2.12	0.034	8.0	25,570	0.0	45
Portugal	97.6%	94.2%	100.0%	22.0	1.85	0.034	5.0	4681	0.1	54
Spain	97.4%	94.7%	99.3%	21.8	1.56	0.032	5.3	5366	0.5	312
Sweden	97.4%	91.8%	105.5%	12.7	1.87	0.036	6.8	15,066	0.0	59
Switzerland	96.2%	94.8%	100.0%	15.4	1.66	0.034	4.4	7728	0.0	42
Turkey	85.4%	98.1%	98.1%	16.5	2.52	0.034	5.3	2190	0.5	269
UK	13.8%	96.3%	40.4%	23.1	1.92	0.032	4.2	5307	0.4	529
United States	48.6%	93.1%	10.8%	11.6	0.76	0.050	7.5	12,564	6.8	5637
Median	93%	95.0%	90%	17.1	1.87	0.034	5.5	7514	0.1	195.6
Mean	70%	94.9%	63%	19.4	1.77	0.036	6.1	8935	0.7	519.4

[a] The data for oil and natural gas import dependence, electricity retail prices, energy intensity (GDP adjusted for purchase power parity), electricity use, and CO_2 emissions is from the U.S. Energy Information Administration's country statistics [50].
[b] Data for petroleum transport fuel is from the International Energy Agency.
[c] Retail gasoline price is from the World Bank [51].
[d] Data for on-road fuel economy is for 2005 instead of 2010. 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 and Fulton [52]. *Abbreviation*: gpm, gallons per mile.
[e] Data for SO_2 emission is from OECD country statistics.

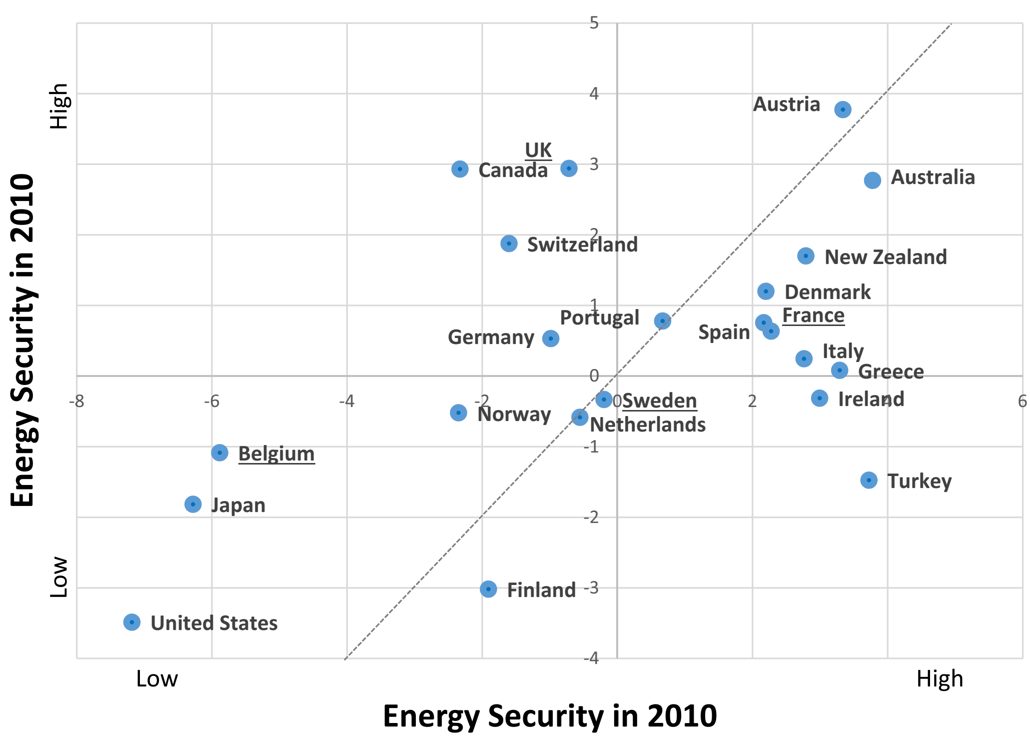

Fig. 1. Energy security "z-scores" in 1970 and 2010. *Note*: case study countries are underlined. Countries above the diagonal line have improved in energy security relative to other OECD countries.

Table 3
Change in energy security z-scores, 1970–2010.[a]

	Availability			Affordability	
	Oil import dependence	Petroleum transport fuels	Natural gas import dependence	Electricity retail prices	Gasoline retail prices
Australia	0.386	−1.257	0.757	0.308	0.370
Austria	−1.673	−0.395	0.009	0.604	1.573
Belgium	−0.179	1.228	1.220	1.153	1.786
Canada	0.015	0.706	0.784	0.992	0.758
Denmark	2.357	−0.488	0.757	−2.921	−1.275
Finland	−0.053	0.270	1.231	−0.195	−0.887
France	−0.170	0.268	−0.491	0.093	−0.564
Germany	−0.391	0.912	−0.334	−0.460	0.514
Greece	−0.219	−0.066	−1.473	0.087	−1.082
Ireland	−0.271	−0.907	−1.323	−1.368	−0.352
Italy	−0.125	2.347	−1.261	−1.955	−0.924
Japan	−0.125	−0.159	−0.393	3.433	1.551
Netherlands	−0.226	0.109	0.757	−0.238	−0.436
New Zealand	1.182	−3.099	0.757	−0.286	0.281
Norway	2.401	0.149	0.757	−0.340	−1.600
Portugal	−0.208	0.971	−1.473	0.585	1.532
Spain	−0.203	0.181	0.841	−0.789	−0.189
Sweden	−0.161	1.357	−1.594	0.233	−1.129
Switzerland	−0.128	−0.204	1.231	−0.067	2.046
Turkey	−1.922	−0.671	−1.430	1.399	−3.318
UK	2.038	−0.054	0.046	−1.018	−0.731
United States	−2.325	−1.197	0.624	0.750	2.077

	Energy and economic efficiency			Environmental stewardship		Change in z-score totals[b]
	On-road fuel intensity	Energy per GDP intensity	Electricity use per capita	SO2 emissions	CO2 emissions	
Australia	1.276	−0.872	−0.376	−1.406	−0.193	−1.007
Austria	0.266	0.105	−0.060	0.002	0.004	0.434
Belgium	0.064	−0.485	−0.109	0.092	0.027	4.797
Canada	2.417	−0.251	0.284	−0.355	−0.090	5.259
Denmark	−0.279	0.599	0.224	−0.010	0.036	−1.000
Finland	0.064	−0.334	−1.182	−0.031	0.005	−1.113
France	−0.818	−0.056	−0.105	0.285	0.147	−1.411
Germany	−0.281	0.397	0.039	0.689	0.432	1.516
Greece	0.262	−0.249	−0.249	−0.179	−0.044	−3.212
Ireland	0.064	0.921	−0.035	−0.033	−0.003	−3.307
Italy	−0.816	−0.089	0.133	0.199	−0.028	−2.520
Japan	0.457	−0.312	−0.030	0.209	−0.171	4.461
Netherlands	−0.431	0.260	0.088	0.142	−0.056	−0.030
New Zealand	0.719	−0.638	0.083	−0.081	−0.008	−1.089
Norway	−0.116	0.575	0.030	−0.029	0.000	1.828
Portugal	−0.116	−0.855	−0.229	−0.078	−0.021	0.107
Spain	−0.699	−0.322	−0.120	−0.210	−0.132	−1.641
Sweden	0.477	0.573	−0.016	0.068	0.057	−0.136
Switzerland	−0.116	0.381	0.360	−0.039	0.016	3.479
Turkey	2.000	−0.910	0.064	−0.238	−0.174	−5.199
UK	0.266	1.125	0.756	0.968	0.257	3.655
United States	2.905	0.435	0.450	0.035	−0.060	3.694

[a] The 1970 data is taken from Sovacool and Brown [28], Table 2. Recall that positive numbers indicate improving energy security trends relative to other OECD countries.
[b] "Change in z-score total" is the difference between each country's overall energy security z-scores in 1970 and 2010. It can also be calculated by adding the rows in this table.

in retail electricity prices. In addition, Greece experienced broad-based and multidimensional slippage in its energy security, with 7 of its 10 z-scores declining over the 40-year timeframe.

A few general trends are worth noting. First, Table 2 shows that the energy security of most countries has slipped over the four decades. A majority of the 22 OECD countries scored worse on six or more of the 10 indicators between 1970 and 2010. No country improved on more than six of the 10 indicators of energy security. 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 toward energy policy, 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 oil import dependence, 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.

5. Correlational strength of energy security indicators

Using factor analysis, we can determine if the 10 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 accounting for the overall variance.

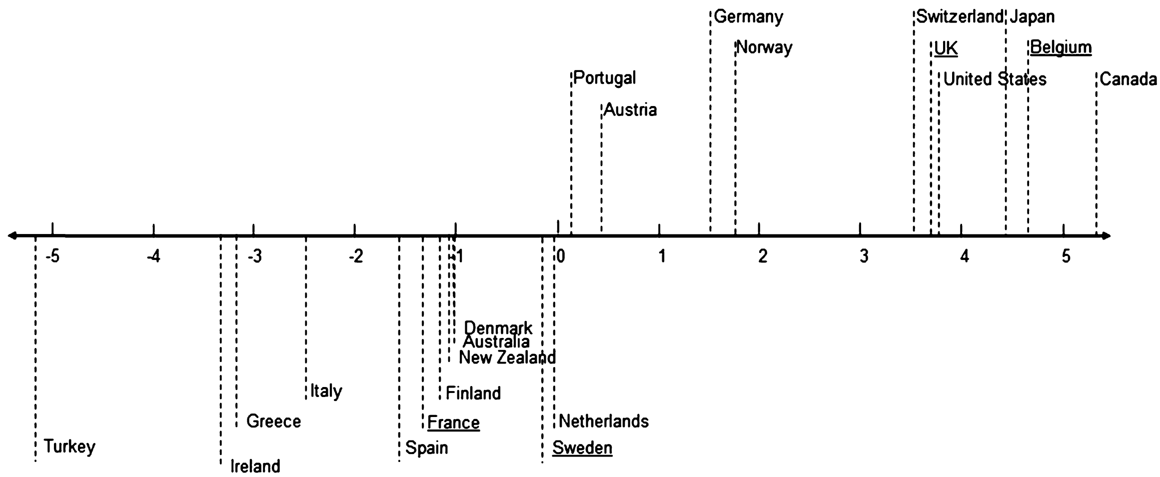

Fig. 2. Most to least improved energy security (based on differences in z-scores: 2010–1970). *Note*: case study countries are underlined.

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 and economic efficiency, and environmental stewardship) function as the latent variables and the factor analysis confirms that these four dimensions highly correlate with our 10 indicators.

The results are presented in Table 4. We elect to describe four factors, which in total explain 73.4% of the data set's variation. The goodness of fit for this four-factor model is represented by the chi square statistic, which is 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 between them and the hypothesized four dimensions is not significant. The test result, the chi square statistics, gives the p-value of 0.228, which indicates that the hypothesis of perfect fit model cannot be rejected. It is clear that the model with these four factors (shown in Table 3) can adequately account for the data of 44 observations (the indicators for the selected 22 countries in 1970 and 2010).

The environmental stewardship factor explains 21% of the variance with strong weightings on both SO_2 and CO_2 emissions. Supply availability is highlighted by the third factor, with high weights on oil and natural gas import dependence as well as on-road fuel intensity. Next in explanatory power is energy and economic efficiency, with the largest factor loading on energy intensity and electricity use per capita. 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 compositional strength of these four factors suggests that countries have energy security conditions that are generally weak or strong exactly 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 significant amounts of oil, they also likely import substantial amounts of natural gas. If their electricity prices are low, so are their gasoline/petrol prices.

6. Taxonomy of countries

The energy security dilemma is played out in very different ways across the states that make up the global political economy [23]. Through cluster analysis of changes in the energy security z-scores between 1970 and 2010, 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. Fig. 3 presents the numerically derived dendrogram 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 shown in Table 5.

The nine countries in Cluster 1 exhibit improved energy availability and affordability. Most of these countries reduced both their oil and gas import dependence. In addition, both their gasoline and electricity prices have increased less than average. The consistent shift of indicators within these two energy security dimensions gives credence to their internal validity.

The three countries in Cluster 2 (Denmark, Norway and the UK) 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 lower energy per GDP intensity. They also exhibit improvement on an indicator of "environmental stewardship", with decreased CO_2 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.

The 10 countries in Cluster 3 (Turkey, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, and Sweden) have

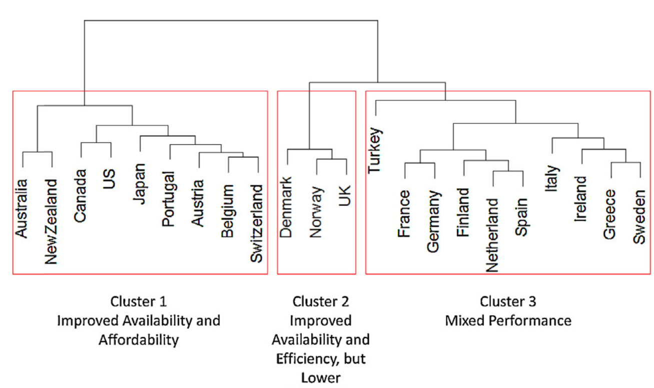

Fig. 3. Clusters of countries with common changes in z-scores for 10 energy security indicators, from 1970 to 2010.

Table 4
Factor loadings and variance explained, based on *z*-scores of energy security indicators in 1970 and 2010.

	Factor 1 *Environmental stewardship*	Factor 2 *Availability*	Factor 3 *Energy and economic efficiency*	Factor 4 *Affordability*
Availability				
Oil import dependence	−0.211	**0.965**	−0.139	
Petroleum transport fuels	−0.264		−0.127	
Natural gas import dependence		**0.522**	−0.128	0.218
Energy and economic efficiency				
On-road fuel intensity	0.291	**−0.528**		
Energy per GDP intensity	0.133	−0.220	**0.693**	−0.389
Electricity use per capita	0.104	−0.171	**0.960**	−0.166
Affordability				
Electricity retail prices			−0.302	**0.658**
Gasoline retail prices	−0.257	0.205		**0.586**
Environmental stewardship				
SO_2 emissions	**0.916**	−0.246		−0.259
CO_2 emissions	**0.975**	−0.162		−0.131
SS loadings	2.089	1.700	1.560	1.086
Proportion variances	20.9%	17.0%	15.6%	10.9%
Cumulative variances	20.9%	37.9%	53.5%	64.4%

experienced mixed performance. They are importing more oil and natural gas. At the same time, they have experienced larger-than-average increases in gasoline prices, but lower-than-average electricity price increases. Focusing on their growing natural gas import dependence underscores the usefulness of considering the dominance of different energy resources in meeting a country's energy needs. For France, where the consumption of natural gas accounts for a growing but relatively small share of total primary energy, a shift to 98% natural gas imports is not as worrisome as for most of the other countries in this cluster. For example, Italy's natural gas consumption has grown significantly at the same time that its natural gas import dependence grew to 91%.

Overall, the composition of these clusters shows some correspondence to the hypothesized four dimensions of energy security. Indicators of availability, in particular, tend to track together and distinguish between countries where improvements dominate (Clusters 1 and 2) or where degradation dominates (Cluster 3). There is also some evidence of common trends in affordability, with electricity and gasoline/petrol prices tracking together except in Cluster 3. Interestingly, affordability can compete with availability. For example, improvements in energy availability in Cluster 1

Table 5
Country clusters based on changes in energy security performance.

Country clusters	Cluster 1: improved availability and affordability (Australia, Austria, Belgium, Japan, Portugal, Switzerland, US, New Zealand, and Canada)	Cluster 2: improved availability and efficiency, but lower affordability (Denmark, Norway, and UK)	Cluster 3: Mixed performance (Turkey, France, Finland, Germany, Ireland, Italy, Spain, Greece, Netherlands, and Sweden)
Availability			
Oil import dependency	↑ (except New Zealand and Switzerland)	↑[a]	↓
Petroleum transport fuels			
Natural gas import dependency	↑ (except Japan and Portugal)	↑	↓ (except for Finland, the Netherlands, and Spain)
Affordability			
Electricity retail price	↑ (except Switzerland and New Zealand)	↓[b]	↑ (except New Zealand and Switzerland)
Gasoline retail price	↑	↓	↓ (except Germany)
Energy and economic efficiency			
On-road fuel intensity	↑ (except Portugal and Switzerland)		
Energy per GDP intensity		↑	
Electricity use per capita		↑	
Environmental stewardship			
SO_2 emission			
CO_2 emission		↑	

Case study countries are highlighted in bold.
[a] ↑, every country in this cluster improved on this dimension of energy security (with exceptions noted).
[b] ↓, every country in this cluster deteriorated on this dimension of energy security (with exceptions noted).

countries (Norway, Denmark and the UK) with declining natural gas and oil import dependency are concurrent with rising electricity and gasoline prices. Similarly, degradation in energy availability as the result of increased oil import dependency corresponds with declining gasoline prices (Cluster 3). Cluster 1 shows that improved energy availability can occur at the same time that energy becomes more affordable.

7. 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. Fig. 2 shows that the United Kingdom and Belgium had their national energy security improve significantly between 1970 and 2010, whereas Sweden and France made more limited progress. Being members of the European Union, all four countries are influenced in some degree by EU directives and policies on climate change and energy. The EU has strong orientation on energy efficiency as a carbon mitigation option, illustrated by the energy end-use and energy services directive (Directive 2006/32/EC), which requires an energy saving target of 9% by 2016 for its member states. The directive aims to encourage cost-effective and efficient energy use by promoting the deployment of appliances and information technologies such as intelligent metering systems in the residential and commercial sectors [53]. 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.

7.1. United Kingdom

The UK experienced notable improvement in energy security metrics between 1970 and 2010. Perhaps most striking is the decline in its oil import dependence from 100% in 1970 to 14% in 2010. The UK also bolstered its energy security by shrinking its 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, and home to the industrial revolution, the UK is no longer 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 tons in 1999, declining to 75 million tons more recently. Although its oil production is expected to continue to decline, only a small portion of UK's oil consumption came from imports [54,55].

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 1970 was reduced to 0.4 million tons in 2010. Once the second biggest SO_2 emitter in Europe, the UK has succeeded in shrinking its SO_2 emission to below the OECD average. A dash for gas in the 1990s also saw the displacement of coal-fired power plants, along with energy sector restructuring, further accounting for reductions in emissions.

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 [56]. 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 [57,58]. The positive consequence of the combination of privatization and regulation was more diversified energy supply, which gradually led to carbon emission reductions. Coal is no longer the predominant source of electricity generation (from 67% in 1970 to less than 40% today) with the rise of gas-fired generation and nuclear power [59]. Correspondingly, CO_2 emissions fell roughly 20% from 1970 to 2010. Competition provides an opportunity for renewable energy and energy service companies to thrive. Utility companies are driven to become "green" when environmentally aware customers have the option to switch to more progressive suppliers to fulfill their demand for sustainability [60].

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, the "road tax" – or vehicle excise tax – was linked to a vehicle's CO_2 emissions 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 on energy users in business and the public sector, providing incentives for energy efficiency and carbon emission reduction. The Renewables Obligation (RO), introduced in 2002, required 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 certificate, the Renewables Obligation Certificate, for renewable energy generation. The penalty for non-compliance is the requirement for suppliers to pay the buy-out price that is set by policymakers on the proportion of sales not covered by ROCs, and the resulting revenues are used to subsidize renewable generation. The RO and ROC have successfully tripled the proportion of renewable energy generation from 2002 to 2009 [15].

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 follow up scheme known as the Carbon Emission Reduction Target [61]. A set of domestic policies and programs reflect UK's significant efforts targeting CO_2 emissions 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 have motivated energy-efficiency and emission-reduction measures leading to the UK's gradually improving energy security performance. The general approach has been to use a "Regulatory State Paradigm" where government provides a regulatory framework that tackles market barriers and moves toward a defined general direction, at the same time allowing the market to select the specific means to reach the end [62].

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 countries in Cluster 1, the UK has relied on regulations and market-based incentives targeting energy efficiency, carbon emissions and renewable energy, while focusing less on the affordability aspect of energy security. Not surprisingly, the UK has seen its real electricity prices grow by over 300% from 1970 to 2007, doubling the average growth rate of all selected OECD countries. From 2004 to 2012, domestic electricity prices increased by over 75 percent and gas prices rose by more than 122 percent [63], with gas prices rising 15 percent alone from 2011 to 2012 [64]. Unfortunately, looking to the future, Deutsche Bank has projected that, with expected energy price rises of 25 percent by 2015, a quarter of the country could fall into "fuel poverty," a situation where they spend more than 10 percent of their income on energy services [64]. As the Department for Energy and Climate Change was forced to admit, "For several years, prices have been the most influential factor in movements in fuel poverty. Prices have risen at a rate well above that of income" [65].

7.2. Belgium

Over the period from 1970 to 2010, 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 comparing with other OECD countries in our sample. But Belgium has shown little improvement in the diversification of its transportation fuels, and has increased its electricity use per capita and SO_2 emissions.

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 has imported 100% of its primary energy since its last coal mine was closed in 1993 [66,67]. 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 [67].

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 1970s to the 1990s, 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 [66]. Continuing to diminish the market power of dominant players, Belgium exchanges electricity 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 notable, as well as the rise in natural gas and nuclear power [67]. From 1990 to 2003, carbon emissions from coal dropped by more than 40%. In the 1970s and 1980s, 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 directly emitting air pollutants and carbon dioxide [66].

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 was 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 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 cleaner electricity generation [68,69]. 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 created an energy service company (FEDESCO) with government capital from the Kyoto Fund to promote energy efficiency in public buildings [66,67]. 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.

Besides its 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, it is in various stages of implementing the EU Directive of Building Codes [66,70]. 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 electricity consumption per capita.

However, Belgium's practices on energy security measures are highly constrained by 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 [68]. Oil continues serving as the major energy source (over half of total primary energy supply 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. The dynamics between the federal and the regional governments only 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 successful domestic implementation of EU directives on energy efficiency measures and its experience in the electricity market integration with neighboring countries, which has reduced its electricity rates. The other Cluster 2 countries can also learn from Belgium's policy experience of reducing carbon emissions.

7.3. France

Compared to the *z*-scores of other countries in our sample, France improved only on four of our 10 metrics. In absolute terms, oil dependence decreased from 98 percent to just 94.4 percent from 1970 to 2010. 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 2880 kWh per capita to 7300 kWh per capita. Retail electricity and gasoline prices both more than doubled in real terms as well. And natural gas import dependence increased almost threefold from 35 percent to 98 percent, although France's reliance on natural gas is more limited than in most EU countries.

France's performance on energy and economic efficiency is weaker than the other countries in Cluster 3. It has slipped in terms of energy intensity (per GDP), electricity use (per capita), and on-road fuel economy compared to the average among our sample of 22 countries. 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 percent of known recoverable uranium reserves [71].

But a large part of the French energy security dilemma 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 radiance and identity [72,73]. 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 social convention of state intervention to subsidize and protect certain industrial enterprises. Such expertise was a prerequisite to participate in policy discussions, and was rarely questioned [74,75].

France thus embarked on an extremely centralized energy policy, run by state elites, oriented toward 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 percent in 1960 to 4 percent in 1970 and then less than one percent per year after 1973 [76]. 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" [77].

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 very low level of greenhouse gas emissions per unit of GDP [78]. 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 percent in 1973 to 51.5 percent in 1995 [76] and in 2008 nuclear energy accounted for 40 percent of total primary energy supply [79]. For the mid-2000s France also boasted the most renewable energy production of any European Union country, and it spent more than all other European countries on energy research.

The relative slowness of energy security progress 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 merely on minor points [74]. 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 who challenged national policy ever had access to real power [80]. To protect its nuclear industry, France resisted restructuring efforts that would have introduced more competition in the electricity sector [81,82]. The transport sector is carbon intensive, responsible for more than one-third of all emissions in 2008 [79]. The implication is that a lack of debate and discussion could sustain the path dependency of its existing energy configuration for the foreseeable future.

7.4. Sweden

Over the 1970–2010 period, Sweden's overall z-score index declined slightly (from −0.20 in 1970 to −0.33 in 2010), indicating that it has slipped in its energy security standing relative to the other 21 countries. 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 8048 kWh to 15,066 kWh, which approximated the mean among OECD countries 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 for on-road fuel economy and the control of electricity prices.

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 about 16,000 MW of hydropower capacity. Although Sweden received about 40 percent of its energy from these types of renewable resources in 2005, 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 10 reactors is also powered exclusively by imports. Sweden has neither plans for nor ongoing domestic uranium production activities [83]. Coal, like natural gas, is a minor fuel and contributes less than 5% of total primary energy supply [84].

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 [85]. 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 [86]. Energy efficiency measures were implemented and oil-fired power stations replaced by nuclear plants [87]. 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 an increase of only 25% in total primary energy supply over the same period [54].

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 [88,89]. However, this did not mark an outright rejection of nuclear power. According to the World Nuclear Association [89], 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, Barseback 1 and 2, before the 2010 deadline [90].

Since the 1970s, the country has used fiscal policy to drive environmentally sound energy use, first through taxes on oil products [84,91] 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 [92]. These levies tilted the economics in favor of wood fuels and biofuels for electricity which saw a greater than three-fold increase in supply between 1990 and 2000 [93]. 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 oil fuel 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 has energy-intensive industries like paper and pulp processing, steel manufacturing, and chemicals production for which energy represents a sizable share of production costs [94]. 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 [92].

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 [95]. A 2030 target for fleet-wide independence from fossil fuels has also been designated, though its achievement seems 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 [96]. 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.

8. Conclusion

This study has presented an energy security index comprised of four dimensions (energy availability, affordability, energy efficiency, and environmental stewardship) and 10 indicators, based on the status of energy conditions in 22 OECD countries from 1970 to 2010. 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 on more than six indicators 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, and major reforms in energy markets and aggressive EU policies geared toward energy efficiency and climate sustainability, our index reveals that the energy security of most countries has degraded.

Second, despite the degradation of energy security, a great disparity exists between countries. Some clear leaders, such as the UK and Belgium (described in this article) as well as Denmark and Japan (described in Sovacool and Brown [28]) stand above the rest and offer many lessons. In some of these countries, public policy was complimented by private practice, as in the UK where market privatization and liberalization in the 1980s and 1990s boosted efficiency improvements in the energy market. 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 mechanism, but a variety of mechanisms.

Third, our analysis of OECD countries suggests that countries have similarities and differences in energy security trends that align with the four dimensions, implying that the countries can be categorized based on distinct energy security strategies and resource endowments. Although the sheer diversity of countries, markets, and technological portfolios 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 study highlights how different dimensions of energy security can tradeoff with each other. One of the reasons Sweden suffers in the index because its gas import dependence has gone from zero in 1970 (when it used no gas) to 105 percent in 2010, showing a tension between diversification (introduction of a new fuel source) and dependence. France has been able to achieve its greenhouse gas mitigation priorities only at the expense of rising prices and growing dependence on imported natural gas. Higher prices of gasoline, diesel, and electricity in the United Kingdom (and high road taxes) have contributed to improved fuel economy for vehicles and better energy efficiency for buildings, but have made energy less affordable for households, especially those on the verge of fuel poverty. Belgium has reduced its dependence on foreign sources of natural gas but as a result has seen a rise in sulfur dioxide emissions. The implication here is that unless planners and policymakers learn to anticipate, and manage, tradeoffs, gains in one area of energy security can occur only at the expense and erosion of another.

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