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Evaluating energy security performance from 1990 to 2010 for eighteen countries

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ABSTRACT

This study provides an index for evaluating national energy security policies and performance among the United States, European Union, Australia, New Zealand, China, India, Japan, South Korea, and the ten countries comprising the Association of Southeast Asian Nations (ASEAN). Drawn from research interviews, a survey instrument, and a focused workshop, the article first argues that energy security ought to be comprised of five dimensions related to *availability*, *affordability*, *technology development*, *sustainability*, and *regulation*. The article then breaks these dimensions down into 20 components and correlates them with 20 metrics that constitute a comprehensive energy security index. We find that the top three performers of our index for all data points and times are Japan, Brunei, and the United States and the worst performers Vietnam, India, and Myanmar. Malaysia, Australia, and Brunei saw their energy security improve the most from 1990 to 2010 whereas Laos, Cambodia, and Myanmar saw it decline the most. The article concludes by calling for more research on various aspects of our index and its results.

1. Introduction

Energy security—defined as how to equitably provide available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users—has in recent years grown as a salient policy and political issue. The security of supply and the concentration of energy fuels among countries, theories about peak oil, rising prices, and energy poverty, to name only a few, have all become prominent concerns among policymakers and investors, as is energy security's close relationship with sustainable development and economic growth. Perhaps because of the variegated nature of energy security vulnerabilities, however, attempts at creating a concise definition of the concept, let alone devising metrics to measure national energy security performance, have been elusive. Trying to measure energy security by using single metrics in isolation—such as energy intensity, the rate of electrification, or electricity consumption per capita—provides an incomplete and possibly misleading assessment.

While considerable efforts have been undertaken to create individual indicators for transport, forestry, agriculture, energy efficiency, energy production, environmental sustainability, and energy use, these have yet to be synthesized into a common, usable framework [1–4]. Furthermore, many studies rely on incomplete or inconsistent definitions of energy security, centered on technical and economic aspects such as security of fossil fuel supply or end-user prices but not encompassing social and political elements such as stewardship or sound governance. In addition, many energy security studies focus only on a particular sector (e.g. industrial energy intensity), an individual country (e.g. United States), or a specific technology (e.g. "nuclear security" or "oil security"). Little effort to date has occurred trying to measure, track, or quantify energy security, and few attempts have been made to compare energy security dimensions, or the relative strength and weaknesses of different national approaches to energy security. Presumably, this is due to a lack of consensus on how best to capture these elements.

To fill this seeming void, this study presents the results of a comprehensive energy security index. The bulk of the study centers on describing the four-phase process of creating the index: first conceptualizing energy security, then devising metrics to measure it, then collecting data, and then scoring results. The final section discusses some of the study's preliminary results and calls on scholars and analysts to conduct further targeted research.

2. Research methods

The authors first selected eighteen countries to analyze—United States and the European Union (as its own entity) were chosen because they are the two of the world's most advanced energy producers and consumers; China, India, Japan, and South Korea because they are Asia's four largest energy consumers; and the ten countries comprising the Association of Southeast Asian Nations

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(ASEAN) (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam) because they have rapidly developing economies along with Australia and New Zealand because they represent a diverse mix of energy importers and exporters and are also close in proximity to ASEAN. A particular challenge here was to develop an index that reflects the region's unique energy security realities, stemming from the range of political systems and geopolitical priorities, as well as levels of governance and energy markets of the different countries observed.

Next, the authors relied on a four-phase process that first involved breaking down energy security into its constituent parts, then devising an index based on these parts (correlating them with specific metrics), collecting and consolidating data on these metrics into an index, and finally scoring performance within the index for 1990–2010.

2.1. Conceptualizing energy security components

To define energy security, we relied on semi-structured research interviews, a survey instrument, and a workshop with global energy experts. The lead author conducted 68 semi-structured research interviews over the course of February 2009 to November 2010 with senior energy security experts, including visits to the International Energy Agency, U.S. Department of Energy, United Nations Environment Program, Energy Information Administration, World Bank Group, Nuclear Energy Agency, and International Atomic Energy Agency. Participants at these institutions were asked:

(1) Which dimensions of energy security are most important?
(2) What metrics best capture these dimensions?
(3) How might these metrics be used to create a common index or scorecard to measure national performance on energy security?

Responses were frequently captured with a digital audio recorder and always textually coded. To supplement qualitative research interviews that were difficult to code, a survey was administered to 74 energy experts working at 35 institutions in Asia, Europe, and North America. Fig. 1 shows some of the demographic characteristics of those that completed the survey. Lastly, we hosted a three-day workshop in Singapore in November 2009, attended by 37 participants from 17 countries to discuss the same three questions as the interviews.

To adhere to Institutional Review Board guidelines followed at the authors' university, particular responses must be listed anonymously to protect confidentiality. However, for reference purposes, Appendix A provides a complete list of all institutions consulted in interviews.

2.2. Choosing metrics and creating an energy security index

Table 1 presents the data collected from our interviews, survey, and workshop and shows the dimensions, components, and metrics of energy security most commonly identified by respondents—note how for these respondents, energy security is almost synonymous with energy sustainability, and is constituted by five overlapping dimensions and 20 final metrics.

To reflect the *availability* dimension of energy security, our index relies on four metrics: total primary energy supply per capita, average reserve-to-production ratios, self-sufficiency, and share of national renewable energy supply. Total energy supply per capita is the best commonly accepted metric for measuring the raw amount of energy supplied to a population. Reserve-to-production ratios have shortcomings—they encompass only reserves proven at this time, do not factor in fluctuations in demand or changing prices, do not tell us about the quality of the fuels being produced, are agnostic about export composition, and assume constant future production rates [5,6]—but cut to the heart of estimating the number of years for which current level of production can be

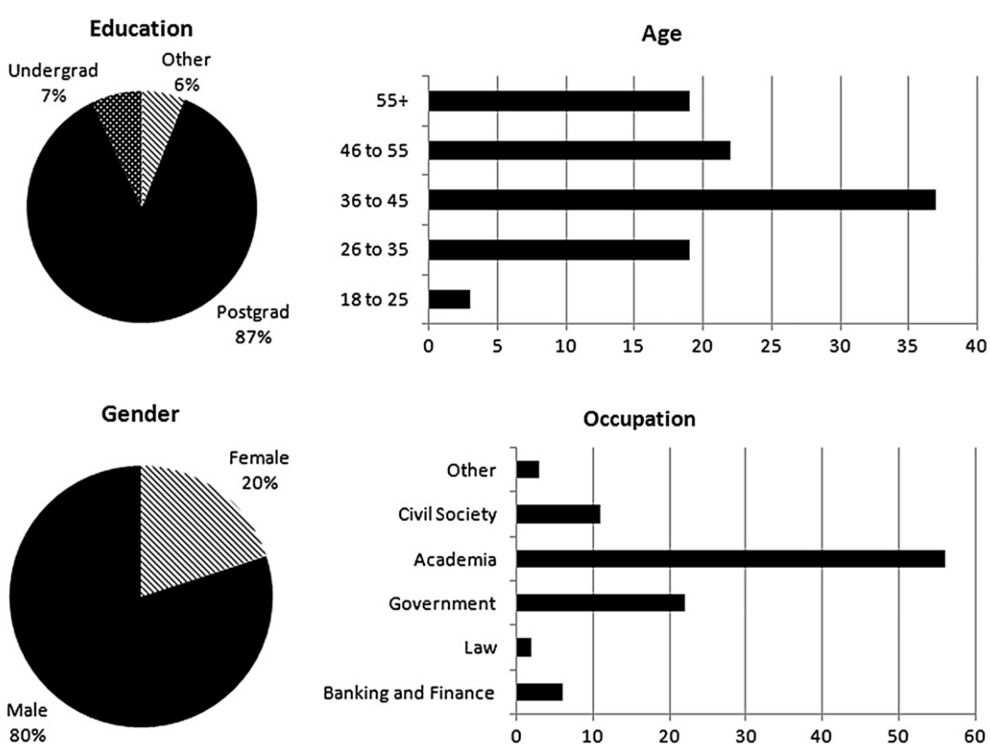

Fig. 1. Demographic details of the energy security survey ($n = 70$).

Table 1
Dimensions, components, and metrics comprising an energy security index.

Dimension	Component	Metric	Unit	Definition
Availability	Security of supply	Total primary energy supply per capita	Thousand tons of oil equivalent (ktoe)	Total primary energy supply comprises the production of coal, crude oil, natural gas, nuclear fission, hydroelectric, and other renewable resources plus imports less exports, less international marine bunkers and corrected for net changes in energy stocks.
	Production	Average reserve-to-production ratio for the three primary energy fuels (coal, natural gas, and oil)	Remaining years of production	Ratio of proven recoverable reserves at the end of a given year to the production of those reserves in that year.
	Dependency	Self-sufficiency	% Energy demand by domestic production.	Percentage of total primary energy supply divided by total primary energy consumption.
	Diversification	Share of renewable energy in total primary energy supply	% of supply	Share of geothermal, solar, wind, hydroelectric, tidal, wave, biomass, municipal waste, and biofuel based energy in total primary energy supply.
Affordability	Stability	Stability of electricity prices	% Change	Percentage that retail electricity prices have changed every five years.
	Access	% Population with high quality connections to the electricity grid	% Electrification	Combined percentage of urban and rural electricity customers with reliable grid connections compared to all people in the country.
	Equity	Households dependent on traditional fuels	% of population using solid fuels	Percentage of the population that relies on solid fuels as the primary source of domestic energy for cooking and heating. Solid fuels include biomass, wood, charcoal, straw, crops, agricultural waste, dung, shrubs and coal.
	Affordability	Retail price of gasoline/petrol	Average price in US$ for 100 L of regular gasoline/petrol PPP (adjusted for Purchasing Power Parity)	Actual prices paid by final consumers for ordinary gasoline inclusive of all taxes and subsidies.
Technology development and efficiency	Innovation and research	Research intensity	% Government expenditures on research and development compared to all expenditures	Expenditures for research and development are current and capital expenditures on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development.
	Energy efficiency	Energy intensity	Energy consumption per dollar of GDP	Total primary energy consumption in British thermal units per dollar of GDP (2005 US$ PPP).
	Safety and reliability	Grid efficiency	% Electricity transmission and distribution losses	Electric power transmission and distribution losses include losses in transmission between sources of supply and points of distribution and in the distribution to consumers, including pilferage.
	Resilience	Energy resources and stockpiles	Years of energy reserves left	Reserves of coal, oil, gas and uranium divided by total final energy consumption.
Environmental sustainability	Land use	Forest cover	Forest area as percent of land area	Forest area is land under natural or planted stands of trees of at least 5 m in situ, whether productive or not, and excludes tree stands in agricultural production systems (for example, in fruit plantations and agroforestry systems) and trees in urban parks and gardens.
	Water	Water availability	% Population with access to improved water	Improved sources include household connections, public standpipes, boreholes, protected wells, and/or spring and rainwater collection. Unimproved sources include vendors, tanker trucks, and unprotected wells and springs. Reasonable access is defined as the availability of at least 20 L a person a day within 1 km of dwelling.
	Climate Change	Per capita energy-related carbon dioxide emissions	Metric tons of CO_2 per person	Annual tons of carbon dioxide emissions from fuel combustion divided by total national population.
	Pollution	Per capita sulfur dioxide emissions	Metric tons of SO_2 per person	Annual tons of sulfur dioxide emissions from fuel combustion divided by total national population.
Regulation and governance	Governance	Worldwide governance rating	Worldwide governance score	Mean score given for the six categories of accountability, political stability, government effectiveness, regulatory quality, rule of law, and corruption.
	Trade and connectivity	Energy exports	Annual value of energy exports in 2009 US$ PPP (billions)	Total value in US$ of net exports of coal (including coke and briquettes), crude petroleum, and natural gas (including liquefied natural gas).
	Competition	Per capita energy subsidies	Cost of energy subsidies per person (2009 US$ PPP)	Total government expenditures on direct and indirect energy subsidies divided by the national population
	Information	Quality of energy information	% Data complete	% of data points complete for this index out of all possible data points.

Source: research interviews, energy security survey, and workshop discussion.

sustained by its reserves. It should also be noted, however, that while this metric covers three primary energy fuels, namely, petroleum, natural gas and coal, uranium reserve-to-production ratios were not recorded. Self-sufficiency serves as a useful proxy for evaluating how dependent a country is on foreign sources of fuel or energy imports. Many studies have argued that diversification, defined as “maintaining an evenly balanced variety of mutually disparate options,” to renewable energy can foster innovation and experimentation, hedge against uncertainty, and insulate national energy systems from shortfalls in supply [7–11].

To reflect *affordability*, our index relies on the four metrics of stability of electricity prices, percentage of population with access to the electricity grid, households dependent on traditional fuels, and the retail price of gasoline. The residential electricity price volatility metric uses retail electricity tariffs, or the stability of those prices over five year increments, capturing how predictable tariffs are for a given location. The percentage of population with access to the electricity grid and households dependent on traditional fuels both reflect varying elements of electricity justice, poverty, access, and equity [12–20]. The retail price of gasoline indicates taxation and subsidy levels applied to local oil prices, with lower prices presumably leading to improved energy access because greater numbers of consumers can afford them.

To reflect *technology development and efficiency*, our index relies on the four metrics of research intensity, energy intensity, grid efficiency, and energy stockpiles. Public R&D spending was used as a proxy for energy sector R&D, and therefore excludes private sector expenditures. Energy intensity provides the best comparative measure for the efficiency of national economic activity, and low energy intensity usually signifies the adoption of energy-efficient technologies, fuel switching to more efficient carriers, and changes to end-user behavior and shifting consumer preferences to low energy using products [21,22]. It is more useful for tracking changes in energy consumption over time. The energy intensity of a home is also an ideal indicator since it naturally takes into account diverse elements such as size of the house, climate, insulation level, building stock, as well as external factors such as energy carriers and regulations [23]. Grid efficiency, or electric transmission and distribution losses, is an indicator that represents how effective delivery mechanisms for energy services are. We couldn’t get data on energy stockpiles or Strategic Petroleum Reserves (SPR) for non-Organization of Economic Cooperation and Development (OECD) countries, so we instead chose a rough proxy of how many years current primary energy reserves within a country can meet levels of domestic consumption. Though imperfect, this metric helps portray countries’ resilience to future supply shocks and forward-minded development of energy infrastructure.

Environmental sustainability is reflected in the four metrics of forest cover, water availability, per capita energy-related CO_2 emissions, and per capita SO_2 emissions. In the absence of reliable land use, land use change and forestry data for the study’s years, we selected forest cover as percentage of land area to incorporate the natural environment’s role in carbon sequestration, though the metric does not distinguish among canopy types. The metric is also loosely connected to issues such as suburbanization, mining, and industrial development, which are all related in part to energy production and energy security. Access to improved water was selected to underscore the energy-water nexus [24–26], and per capita energy-related carbon dioxide emissions was chosen to show which countries are more carbon efficient when their population sizes are taken into consideration and to include an element related to climate change (though this metric does not include other greenhouse gases) [27]. Sulfur dioxide emissions were our final metric because they are a precursor to both particulate matter pollution and acid rain, key threats to public health and ecosystem vitality.

To reflect *regulation and governance*, the index employs worldwide governance ratings, energy exports, per capita energy subsidies, and quality of energy information. The World Bank’s worldwide governance rating system goes beyond state fragility to cover other aspects such as accountability, rule of law, corruption, government effectiveness and regulatory quality, giving a more comprehensive look at core governance issues. Energy exports represent the international trade aspect of energy fuels and globalization, and per capita energy subsidies reflect a degree of competition and fairness in energy markets (the idea being that subsidies distort energy markets and promote overconsumption which reduces security levels). Our sample of respondents also felt it important to include a metric in our index related to the quality or availability of energy information, so we built this into the index itself, giving countries a score based on how many data points within the index we could reliably complete.

These 20 metrics in aggregate demonstrate the necessity of having a multidimensional and comprehensive index. To some, our metrics may look disjointed and unrelated to each other, or too closely related to energy or environmental sustainability. But as Table 1 above shows, each metric is tied to a particular dimension and component of energy security derived from our interviews, survey, and/or workshop. It is also intuitive why one needs a broad set of indicators rather than a few utilized in isolation. Relying on total primary energy supply per capita by itself, for example, does nothing to measure how efficient energy is used within a country or how clean or equitably distributed it is. Reserve-to-production ratios by themselves do not account for issues of global trade (think how much coal Indonesia produces that it never uses or oil that Singapore refines but does not consume, and instead exports globally), self-sufficiency says nothing about how clean or sustainable that sufficiency is, and diversification to renewable resources of energy does not say how reliable or intermittent they are, or how much that diversification might cost in terms of reduced reliability or increased tariffs for customers. Electricity price volatility and the affordability of petroleum, furthermore, can be tied more to the introduction of new subsidies, or trends in international markets, than individual actions within a country; high prices can also be good if they reflect other things, like the inclusion of externalities into energy prices or the cross-subsidization of energy efficiency programs and mandates. A country’s electrification rate in isolation reveals nothing about the quantity (hours of availability in a day), quality (rated voltage and frequency), or household use of electricity (a light bulb to a wide range of end-uses). The percentage of households dependent on traditional fuels such as biomass does also not describe how much that fuel costs them in terms of money, time, or debilitating health disorders, and will also differ by latitude, with high-latitude locations needing more fuel for heating [15], and high biomass consumption by itself could signify affluence as well as poverty, with larger and wealthier homes using more of it [17]. Electricity is not always a substitute for traditional fuels, with many homes in developing countries, including those in Asia, reliant on both [12–14], which is why an index (like ours) including both biomass and electrification is essential. Research intensity figures for some developing countries may not account for the percentage of those expenditures lost to corruption and graft, which is why also having a metric associated with corruption (the worldwide governance rating we use) is necessary. The point is that utilizing our 20 metrics as part of a consolidated index is instrumental in ensuring as many of the-dimensions and complexities of energy security are captured as possible.

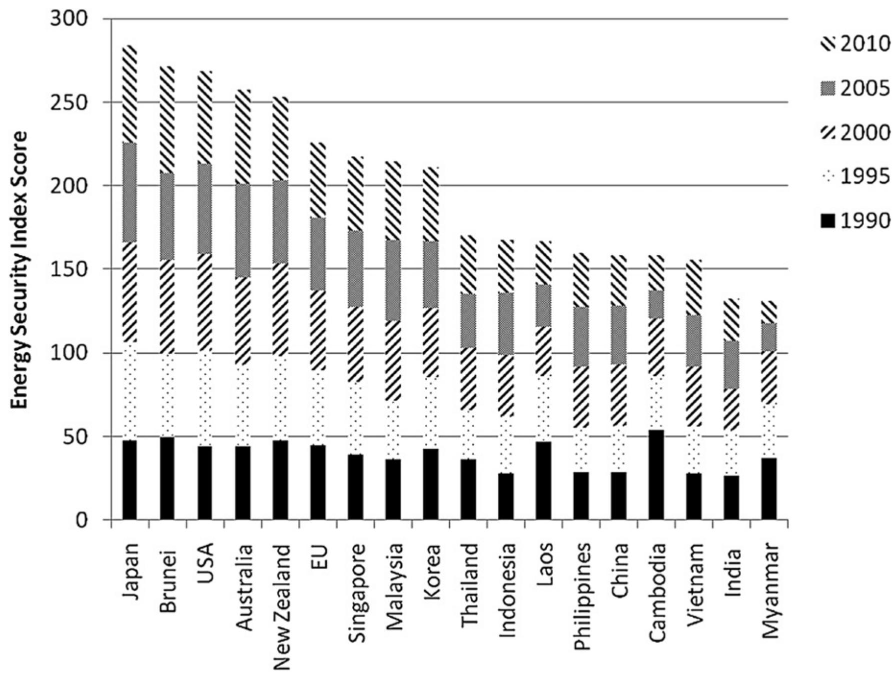

Fig. 2. Average energy security performance for eighteen countries.

2.3. Collecting and synthesizing data

The penultimate phase involved collecting data for our 20 metrics for the period 1990–2010 in five-year increments. We relied primarily on energy databases and reports from the International Energy Agency, U.S. Energy Information Administration, World Health Organization, World Bank, and United Nations. As these sources did not provide complete coverage for all countries over the years in question, we reviewed academic articles and reports for missing pieces of data. Energy ministries in the relevant countries were contacted via email, fax, and telephone to fill remaining data gaps. Appendix B presents the results of our data collection for all 18 countries for 1990, 1995, 2000, 2005, and 2010.

We stopped collecting data at the end of March 2011 from our sources [28–86]; any updated data we received after that point have not been included in our index. Whenever a range of values was given for a particular metric, we took the average. The mix of countries constituting the European Union has also shifted over our 20-year period, not to mention that some data sources look at "Europe" rather than the European Union as an entity – the definition of which varied.[1] Notwithstanding, the EU's appearance in our study is more a reference point than an exact study of shifts in the EU's energy security. Furthermore, despite our five-sequenced data collection strategy, a surprising number of data points in Appendix B are still unavailable.

After collecting and coding our raw data, we then set to make all 20 metrics in our index unidirectional, so that higher values corresponded with better energy security scores (the idea being that it would be easier to identify common trends). We thus inverted or transformed eight of our metrics: price stability,[2] households dependent on traditional fuels, retail gasoline prices,[3] energy intensity, grid inefficiency, per capita CO_2 and SO_2 emissions, and per capita energy subsidies.

2.4. Scoring country performance

The final phase of our research concerned scoring country performance among the 20 metrics over the 20-year period. Rather than measure performance using some type of abstract or absolute method, we instead made our scoring *empirical* and *relative*: empirical in that scores were based on real-world performance of countries observed within a particular metric for a given year, and relative in that we took the best and worst scores for those countries and used those to create our range of scoring points. This involved converting all of our data points to a score between 0 and 100.

More specifically, we first created a scoring range for a metric for a given year by subtracting the minimum value (the worst performer) from the maximum value (the best performer). Some values were negative, we discarded these and converted them to zero. We then took each data point, subtracted the minimum value, and divided by the range. What resulted was a score for each country anywhere between 0 and 100.[4] The idea was to avoid a scoring system based on arbitrary value judgments and instead

[1] The mix of countries constituting the European Union did not remain consistent over our 20-year period; 1990 included East Germany, twelve extra countries were included post 2004 and five others added recently in 2008.

[2] Negative price movements received a 100 regardless of magnitude, while the peak price gains for each period were scored as 0. Positive percentage values for the metric were converted to real numbers with their inverses used as the basis for assigning score values.

[3] Endpoints for the 0–100 range were then drawn from extreme transformed values in each period. Since Gesellschaft für Technische Zusammenarbeit (GTZ) uses black-market exchange rates for countries with parallel currency rates, Myanmar prices were converted from USD equivalents, as expressed in the GTZ fuel price reports, back to local currency using the black-market rate, while all other countries were converted using historical official exchange rates from Oanda or the Federal Reserve Economic Data (FRED) database.

[4] For example, in Appendix B (for 1990) the total primary energy supply per capita data ranges from a low of 0.3 for Myanmar to a high of 7.7 for the United States. Our range of scores was 7.7 minus 0.3, or 7.4. The United States scores a 100 (7.4 out of 7.4), Singapore a 47.3 (3.5 out of 7.4), Myanmar a 0 (0 out of 7.4).

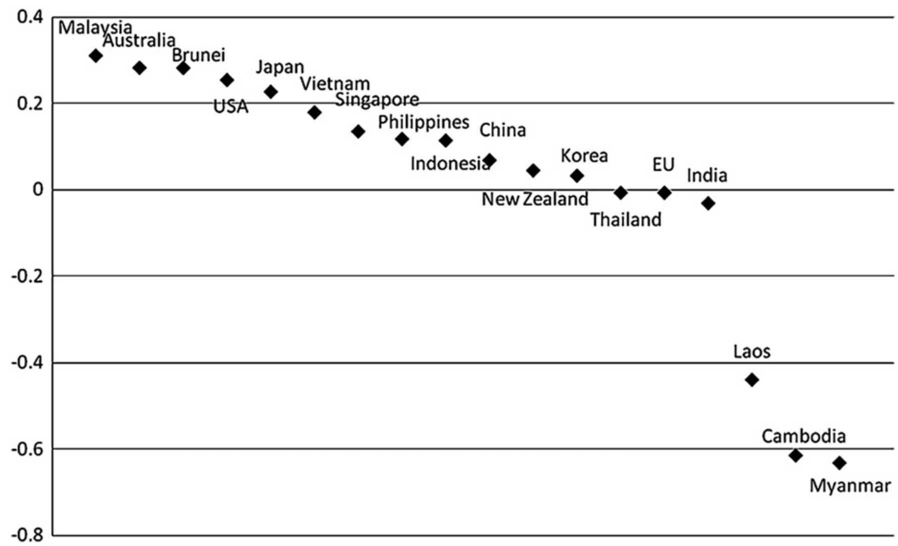

Fig. 3. Energy security improvement for eighteen countries (% change from 1990 to 2010).

rely on one that rooted in actual performance.[5] Appendix C presents these scores for all 18 countries over the 20-year period. Due to the sliding and comparative nature of our scoring system, sometimes best and worst performance was related not with improvement, but with overall deterioration in some metrics. For example, the highest self-sufficiency performer, Brunei, was above 8% in 2005 but below 6% in 2010, meaning the overall range used to score other countries was smaller (and their resulting scores higher than if Brunei's self-sufficiency had increased rather than decreased).

3. Results, discussion, and future research

Though we are limited by space—and feel it appropriate that most of this paper focuses on research methods and data collection since that constituted the most time-consuming aspect of our project—we are able to offer a few preliminary results that should be very helpful at informing both energy policy and scholarship.

The first is that if one takes the mean score for each year and metric, and aggregates them, one gets a decent sense for who is most and worst energy secure among our sample of countries. The top three performers are Japan (284), Brunei, (271), and the United States (168) whereas the worst three performers are Vietnam (155), India (132), and Myanmar (131). Fig. 2 presents these results disaggregated by year. Interestingly, the best possible score a country could have gotten—if it excelled in every category, for every year—was 500, indicating clearly that even the "best" performers still had aspects of their energy security that were unfavorable.

The second is that if one measures not absolute performance over the 20 years, but instead who has improved the most (or least) among our various metrics, then a different picture emerges. Fig. 3 depicts the overall percentage change (positive and negative) for all 18 countries from 1990 to 2010. Malaysia (31%), Australia (28%), and Brunei (28%) were the three countries who improved their energy security the most; Laos (−44%), Cambodia (−61%), and Myanmar (−63%) the three that saw their relative energy security decline the most.

Plentiful areas of future research, based on these preliminary results, would be most fruitful to explore. One would be examining in detail what caused Japan and Brunei (top overall performers) and Malaysia (most improved) to score the way they did, as well as what eroded energy security in India and Myanmar (bottom overall performers) and, again, Myanmar (least improved). This could elucidate a common set of best practices, if any exist, that other countries concerned about energy security could adopt, and worst practices they could avoid.

Another would be assigning different weights to either metrics (security of supply is perhaps weighted more heavily than water or climate change, or vice versa) or years (more recent years are given stronger weights) to see how it alters the positioning of countries.

Still another would be isolating the factors that caused energy security performance, both in absolute terms (Fig. 2) or temporal terms (Fig. 3), to improve or degrade. Perhaps for some countries it would be the introduction of a new policy or technology, for others it might be changes in pricing or shifts in consumer attitudes, for still others major historical events. Determining these factors, and exploring both quantitatively and qualitative how they might contribute to "improved" or "degraded" energy security, could reveal previously unseen relationships between "external" events beyond a country, "internal" events within a country, and its overall energy security.

Yet another would be correlating the results of our index with other indices, such as the World Development Indicators, progress on Millennium Development Goals, or even credit ratings to see which of these have strong relationships with energy security.

Other research could look more closely at the tradeoffs involved with different aspects of energy security. As some of the metrics in our index, such as per capita carbon dioxide emissions or access to water, improve, others, such as price stability or subsidies, may worsen. Improvement in other dimensions, such as sustainability or governance, may also see availability and affordability worsen. Discovering such tradeoffs would be an instrumental part of designing synergistic energy security strategies that improve *all* elements of energy security simultaneously.

A final project could examine not the least or most energy secure country, or most or least improved, but the speed of change, both positive and negative, that a country's energy security

[5] This means our scores for any given category shift year to year, and metric to metric, entirely dependent on the best and worst performance of actual countries, something we feel captures the inherently comparative nature of energy security performance.

undergoes. This could help analysts help see which elements of energy security can be "fixed" or "tweaked" relatively quickly compared to those that may necessitate a more long-term commitment.

4. Conclusions and policy implications

Regardless of these areas of future research—which we hope others will investigate—our index is first and foremost an attempt to start a robust dialog on how to not only conceive of and measure energy security, but assess performance and find best and worst practices. A consensus seemingly exists among the experts we interviewed, surveyed, and hosted at our workshop about which dimensions of energy security are most important, and for how these can be integrated into a comprehensive index. Though preliminary, our results suggest at least three conclusions.

First, energy security is more multifaceted than many policy-makers or even scholars may realize. Our study strongly suggests that energy security analysis must extend beyond traditional themes such as security of fossil fuel supplies and the efficacy of energy markets to incorporate emergent areas of importance including energy efficiency, engendering stable and clear price signals, providing affordably priced energy services, and enhancing the sustainability of energy technologies. Researching and developing new and innovative energy systems, ensuring equitable access to energy services, and improving transparency and participation in energy decision-making are all salient aspects of a nation's energy security because enhanced knowledge improves decision-making and energy governance. National energy approaches and policies may therefore need recalibrated to accommodate this broadening of the concept of energy security itself.

Second, energy security performance among the 18 countries we collected data from has decidedly worsened from 1990 to 2010. This conclusion is somewhat counter intuitive given advancements in technology and policy over the past two decades, notably greater diversification of energy supply to include renewable energy and investments in energy efficiency, stronger consensus about the necessity of dealing with climate change, and arguably better integrated markets for natural gas and oil. No country improved in all 20 of our metrics for all time periods, and sixteen countries saw their performance on more than *half* of their energy security metrics deteriorate over the period analyzed; the exceptions were Japan and Brunei, and they still saw more than 40 percent of their metrics worsen. Our index worryingly suggests that countries are struggling to improve their energy security relative to each other.

Third, if this is true, the next questions become: what further research is needed, and what should policymakers do about it? The index developed in this study could arguably be applied for future evaluations on energy security in every country around the world, since it was designed with input from a wide group of stakeholders and also has metrics that cross sectors, types of economies and energy markets, and energy fuels—from electrification rates and fuelwood for the least developed countries to the state of diversification with renewable electricity and energy innovation and research for the most industrialized. Undertaking such a study, however, promises to be a monumental exercise in terms of data collection and conditions and limitations may emerge that require the index to be tweaked for particular contexts. Furthermore, even if all results and data were correct and appropriate, and a final index created for the globe, the policy measures available to different countries wishing to improve their energy security also vary greatly, as well as the political conditions that make them possible, or constrain them. These questions of policy and politics will remain no matter how refined our understanding of energy security threats facing individual countries and regions becomes.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.energy.2011.08.040.

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