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Three blind men and an elephant: The case of energy indices to measure energy security and energy sustainability

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ABSTRACT

A large number of indices claim to quantify the performance of a country in attaining the goal of energy security and energy sustainability. The paper compares three different indices, viz., 'Energy Sustainability Index', 'International Index of Energy Security Risk' and 'Energy Architecture Performance Index' along with their variants to examine if they provide consistent results for various countries. A comparative assessment reveals that the three indices provide different country rankings, which are inconsistent. This situation is akin to three blind men groping the elephant with each one measuring a different part of the body and asserting that only their assessment is true. Further analysis reveals that countries which rank in the top of the list of different indices are insensitive to differences in construction of the index and it can be inferred that they have robust energy systems, which partly resolves the conflict. However, much more needs to be done, to examine energy security and energy sustainability of a country with other relevant tools. It may therefore be concluded that while the country ranking from the individual indices may be correct, basing the assessment of a country's performance, on the score obtained in one specific study may not be accurate.

1. Introduction

Energy is one of the primary drivers of the economy and energy security is one of the important non-military components of national security [1]. Energy security is a multidimensional concept [2] and it is interpreted differently according to the perspective of the user. It is a complex, interrelated issue involving more than just one scientific discipline [3,4] and has an inter-temporal aspect (short and long term) [5–7]. Therefore, it is not surprising to note that there is no universally accepted definition of energy security [5,8–10].

Traditionally, the concept of 'Energy Security' is related to the SoS (Security of Supply) and its physical availability [8] by ensuring freedom from risk of supply disruption. Literature [11–16], on the concept of energy security shows that although energy security is an all encompassing term, which includes economic competitiveness of energy [17], environmental sustainability [18,19] and a wide variety of geopolitical issues, the focus is on the uninterrupted physical availability of energy at an affordable price.

Considering the impact of negative externalities of energy, energy sustainability is increasingly gaining importance. The term 'Sustainable Energy' evolved from the concept of 'Sustainable Development' as used in the report of the Brundtland Commission [20]. Simply put, it is the concept of 'sustainability' applied to 'energy system'. This concept of sustainability can be viewed from the perspective of 'TNS' (The Natural Step) [21] which has developed a FSSD (Framework for Strategic Sustainable Development). The framework proposes 'Four system conditions' (scientific principles), wherein it defines a sustainable society as one in which, nature is not subject to systematically increasing:

(i) Concentrations of substances extracted from the Earth's crust
(ii) Concentrations of substances produced by society
(iii) Degradation by physical means and, in that society
(iv) The ability for humans to meet their needs is not systematically undermined

These principles of sustainability, when applied to an energy system, can be used to understand and comprehend a sustainable energy system.

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Although energy security and energy sustainability have divergent end goals, the concepts are tightly coupled in the long run. While energy security for a country can be attained independently, if it is not sustainable, it would cause irreparable damage to the environment and would deplete the fossil fuel reserves. Similarly, energy sustainability focuses on the environmental impact of energy usage but ignores the high costs associated with clean energy sources and technologies for underdeveloped economies. Therefore, both, energy security and energy sustainability are of paramount importance and should be factored in carefully.

Under these circumstances, there is a need to have a long-term vision and to look at 'SES' (Sustainable Energy Security) which aims to provide energy services for meeting the present and future developmental needs of the society without compromising on economic growth and environment. We define SES as "provisioning of uninterrupted energy services in an affordable, equitable, efficient and environmentally benign manner" [22]. This perspective accommodates both the supply-side and the demand-side of an energy system and includes the three dimensions of Sustainable Development—social, economic and environmental in its approach. This refocusing to include both, sustainability and security aspects of energy, will enable energy planners to implement policies for transitioning to energy security and energy sustainability.

The paper is organized in the following sections: Section 2 investigates the importance of energy indicators and the challenges in creating a comprehensive energy index. Section 3 reviews various aggregated energy security and sustainability indices. Section 4 gives an overview of three selected indices and the differences in their composition are then discussed in detail in Section 5. Section 6 presents the methodology of comparing various indices and the results of the comparison are presented in the subsequent section. Section 8 analyses and discusses the results in detail, before concluding in Section 9.

2. Energy indicators

Attempts have been made to quantify and measure energy security and energy sustainability through the use of various metrics, which are designed to capture certain characteristics of a country, and are aptly terms as 'indicators'. An 'Energy Indicator' is a tool which is used to assess the performance of an energy system. A collection of energy indicators can be used as a set of disaggregated measures and can reveal key relationships between energy use, energy prices and economic activity [23]. A country's energy system has complex interactions with economic, social and environmental aspects of development, which may be difficult to comprehend. Hence, an energy indicator-based approach is elegant, as it avoids the complexity of characterizing the energy system. Acknowledging the usefulness and potential of indicators to convey valuable information, the World Bank [24] regularly updates its databank to track energy indicators, amongst other indicators, for all countries.

The attractiveness of energy indicators has led to the emergence of a large number of 'simple' as well as 'aggregated' indicators. A plethora of indicators has somewhat confused the picture as aggregated indicators are complex, give conflicting results, their relative importance is unknown and they measure similar characteristics. To overcome these limitations, and to provide one number, which is easy to comprehend, attempts were made to construct an 'Index' from the set of energy indicators.

Formulation of an index, helps in quantifying the performance of a country, over time and related key trends which otherwise may not be apparent [25,26]. It also helps to identify the tradeoffs within various dimensions and clearly identifies the areas of improvement [25,26]. Various attempts have been made to construct an energy security and energy sustainability index which is meaningful and is acceptable to a majority of stakeholders. However, such a search for an index has been elusive, primarily because the concept of energy security itself is not agreed upon. Further, there is a wide disparity between energy systems of different countries.

The methodological challenges of creating a comprehensive energy security index are dealt in detail by Sovacool [26]. The paper highlights the various sources of disagreement amongst energy experts with respect to issues such as selection of respondents to conduct the survey, selection of a limited number of indicators from a large set of metrics, relative weighting of indicators, methodology for scoring, quantitative vs. qualitative methods of assessment, amongst others. Further, there are spatial issues (global/regional/local), methodological issues, data issues and complex interdependencies between various indicators which present significant hurdles in creating an index.

Notwithstanding the above, there are a large number of indices in literature which attempt to undertake the assessment of a country's energy security and sustainability.

3. Review of aggregated energy security indices

Considering the importance of energy-related issues in a rapidly changing world scenario, various studies have been undertaken to analyse energy security and energy sustainability from different perspectives [27–32]. The scale of these studies extends from a macro (country/regional) to a micro (island/village) level. Further, energy security has been examined for primary energy sources, notably oil [13] and its derivatives, and to a lesser extent to natural gas [33] and coal. Extending this concept to secondary sources of energy, security and sustainability of electricity conversion has also been studied [34–36].

There are a large number of energy indicators which have been used to quantify the performance of a country. Thirty indicators along with their thematic framework, guidelines and corresponding methodology were developed as EISD (Energy Indicators for Sustainable Development). This was a collaborative effort by the IAEA (International Atomic Energy Agency) in cooperation with the UNDESA (United Nations Department of Economic and Social Affairs), IEA (International Energy Agency), Eurostat and the EEA (European Environment Agency) [37]. Five indicators were used by APERC (Asia Pacific Energy Research Centre) [10], while an energy security composite indicator was suggested by the JRC (Joint Research Centre), European Union [19]. This study used five simple and three diversity indicators to create an energy security composite indicator using OWA (Ordered Weighting Averaging) methodology. Ten indicators were used by Helio International under their SEW (Sustainable Energy Watch) program [38] to quantify energy security for various countries. On the other extreme, a potential list of 320 simple and 52 complex indicators was presented by Sovacool and Mukherjee [39] which could be used to study energy security of a country. Hence, there are various sets of indicators in use, which attempt to measure different aspects of energy security in their own unique way.

In addition to the disaggregated indicators, there are a large number of energy security indices which are available in literature, such as diversity based index [40], Energy Security Index (ESI_{price} and ESI_{volume}), IEA [41], 'willingness to pay function' for security of supply proposed by Bollen [42], OVI (Oil Vulnerability Index), Gupta [43], Vulnerability index, Gnansounou [44], Geopolitical energy security measure [45], Risky external supply index [27], Economic and Socio-political risk index under project REACCESS (Risk of Energy Availability: Common Corridors for Europe Supply Security) [46], Energy affinity index [47], Energy development index, IEA

[48], Energy sustainability index, Doukas et al. [49], AESPI (Aggregated Energy Security Performance Indicator) proposed by Martchamadol and Kumar [25], amongst many others.

Most of these indices focus on certain specific aspects of energy security; primarily on the economic dimension while neglecting environmental and social aspects; on security of supply while neglecting other essential components such as demand-side management and energy efficiency; on specific fuels such as oil and gas, while relatively neglecting other energy sources such as renewable energy, nuclear and coal. A couple of them such as S/D Index by Scheepers et al. [50] and MOSES (Measuring Short-term Energy Security) [51], however, have a comprehensive scope and attempt to measure all facets of the performance of the energy system, using an energy supply chain approach.

Summarizing the discussion on energy security indices, we can conclude that there are a host of indices in which indicators are selected based on the perspective of the user. Some of the selected indicators are common to various studies, while others are carefully constructed to measure specific characteristics in cognizance of the end goal. Further, an energy security index gives little information, when read in isolation, and adds value only when read in conjunction with the entire set of indicators. Lastly, it has been acknowledged that "no set of energy indicators can be final and definitive"; "indicators must evolve over time to fit country-specific conditions, priorities and capabilities" and "more work is needed, in most countries, for a systematic and complete analysis" [37,52].

The aim of this paper is to evaluate whether various indices which rank countries based on various facets of energy security and sustainability, give consistent and reliable information. We will restrict this paper to studies which undertake a quantitative assessment of energy security and energy sustainability and have been used to rank various countries. Further, we will focus on indices which have found institutional acceptance over time. In line with these specifications, this paper evaluates three indices viz. 'Energy Sustainability Index' and its older versions developed by the WEC (World Energy Council), 'International Index of Energy Security Risk' developed by the Institute for 21st Century Energy, US Chamber of Commerce and 'Energy Architecture Performance Index' developed by the World Economic Forum in collaboration with Accenture. The issues which emerge when presented with different indices are:

(a) How do countries perform across various indices and how consistent is the ranking of the countries?
(b) What is the impact of minor methodological change in the composition of the index on the overall ranking of the countries?
(c) Can we derive certain trends in a country's performance based on different indices?
(d) What does a large variation in the ranking of a country, signify?

This paper attempts to address the above issues.

4. Comparing different indices

This section presents an overview of three indices and their variants which are compared in detail in this paper.

4.1. EAPI (Energy Architecture Performance Index)

EAPI (Energy Architecture Performance Index) is a tool to evaluate "how successfully does (the) country's energy system perform in terms of promoting economic growth and development, whilst being environmentally sustainable, secure and allowing universal access to consumers?" [53]. The global EAPI Report defines an energy architecture conceptual framework which consists 'physical elements' such as energy sources, energy carriers and energy markets; 'social elements' such as political institutions, industry and civil society, which shape the physical elements; 'energy triangle' which the energy architecture is designed to support; and 'boundary conditions', having various physical and social factors which limit the performance of the energy architecture to attain the end goal. The 'energy triangle' has at as its apex, three objectives, viz. 'economic growth and development', 'environmental sustainability' and 'energy access and security' which are the ultimate objectives of the energy system.

WEF launched a beta version of the EAPI in April 2010 [54]. This index used the data for the year 2008 and ranked various countries. The EAPI Report-2013 [55] was first launched in December 2012, ranking 105 countries using 16 indicators. The data used for the analysis was of 2011 and of earlier years. The second version was released in December 2013 [53] in which 18 indicators were used to rank 124 countries. Although data for 2012 was primarily used, some data belonged to 2010 and 2011. Apart from adding two additional indicators in EAPI-2014, the weights allotted to the indicators were also changed to accommodate new indicators and a minor modification was made to the indicator for monitoring CO_2 emissions.

EAPI-2014 is a composite index which uses a set of 18 indicators, six each, across the three core areas, to measure the performance of global energy systems to meet the objectives of the energy system. Indicators and their relative weights are decided by an expert panel. Raw scores of each indicator are derived from various datasets. Different weights, which are made explicit, are allotted to each of the six indicators in the three 'baskets' and the weighted scores are calculated to produce three sub-indices. The score attained on each sub-index is averaged to generate an overall score, implying equal weights to the three baskets. The aggregated score, known as the EAP Index quantifies the performance of the energy system of a country, and various countries are then ranked in decreasing order.

4.2. International index of energy security risk

The International Index of Energy Security Risk is designed to measure the risk to overall energy security. It also allows comparisons of energy security risks across countries and country groups, and charts the risk changes over time. The institute for 21st Century Energy and the US Chamber of Commerce launched the 'US Energy Security Risk Index' in 2010 [56], followed by subsequent indices in 2011 [57], 2012 [58] and 2013. Buoyed by the success of this index, an 'International Index of Energy Security Risk' (abv. as ES Risk in this paper) was launched on similar lines. The first version for assessing risk in a global energy market was launched as 2012 edition [59], with data pertaining to the year 2010. The 2013 edition with a revised methodology was released in March, 2014, which primarily used the data of 2012. The 2013 edition has twenty nine indicators; one more than the 2012 edition. Apart from changes in weights to accommodate the additional indicator, certain other revisions were made such as changing the definition to measure the diversity of the power sector [60].

The index measures energy security risks in two ways: In absolute terms; and relative to a baseline average of the OECD (Organization for Economic Co-operation and Development) countries. Twenty nine individual indicators were selected under eight broad categories which represented various competing aspects of energy security. These indicators were given weights and the weighted scores were aggregated to generate the risk index for a country. The scores for various countries are reported in relation to a reference index which represents the average risks for OECD member countries. This is calibrated to a 1980 base year figure of 1000 and all subsequent figures move in relation to this number. In addition, the baseline for a cross-country comparison for each year changes and is pegged to the OECD score for that specific year. Hence, changes in the index over time will reflect both its absolute changes and those relative to the OECD baseline.

ES Risk Index conveys the notion of risk, and therefore a lower index equates to a lower risk implying higher energy security. Although the raw values are not provided, the scores are given for each indicator for the top 25 countries in detail and the total index score is provided for 75 countries. Hence, it is possible to rank the countries based on this data.

4.3. WEC (World Energy Council)-defined indices

4.3.1. AI (Assessment Index)-2009

WEC's first attempt to develop an index was in 2009 where it proposed an ‘Assessment of Energy Policies and Practices Index’ to measure the extent to which a country has the necessary attributes in place to achieve its energy policy objectives. This was called as ‘AI’ (Assessment Index) [61]. As it attempted to measure the effectiveness of national energy policy, it was not strictly an energy security index. In WEC's assessment, each country's policy effectiveness was analysed according to four areas, or supports: institutions, economy, social capacity and equity, and environment [61] (p 74). Forty six ‘policy indicators’ comprised 12 ‘building blocks’ under the four supports. ‘Energy Security’ incidentally was only one of the building blocks under the ‘economy’ support.

Raw data for various countries was normalized to a range of 0–10 and weights were used for each building block to calculate the overall AI using equal weighting. The report justified its choice of using equal weights by claiming that other methods, such as the PCA (Principal Component Analysis) and using the AHP (Analytic Hierarchy Process) to determine the weights, were considered in the initial examination, and the difference in results using different weighting methods was minimal.

The results of the AI were then grouped into five ‘country clusters’, viz. lower income net energy importers/exporters, fast growing countries, higher income net energy importers/exporters. For each country in a particular cluster, the sub-indexes and the overall AI were calculated and the countries were placed in decreasing order. For each value of the sub-index and the overall AI, countries were identified as belonging to one of the four divisions (quartile). Hence, instead of ranking, 88 countries were grouped in four quartiles. As the index measured energy policy effectiveness, a higher value of the index implied more effectiveness of a country's energy policy.

4.3.2. ESCI (Energy Sustainability Country Index)-2010

In 2010, WEC modified the AI to its revised form, the ESCI (Energy Sustainability Country Index) to assess energy and climate policies of a country. The index ranked countries in terms of their likely ability to provide a stable, affordable, and environmentally sensitive energy system [62] (p.14). This index was based on the WEC's definition of energy sustainability which had three core dimensions—energy security, social equity, and environmental impact mitigation [62] (p. 5).

The ESCI was derived from country scores against 21 key indicators which focused on two axes. The first axis, called the “energy performance” axis, covered the three dimensions of energy sustainability, viz., ‘energy security’, ‘social equity’ and ‘environmental impact mitigation’. The second axis was named “country context” axis, and included three dimensions which aided the development and implementation of effective policies, viz., ‘political’, ‘societal’, and ‘economic strength’. Seventy five percent of weight was given to ‘Energy Performance’ axis, while 25% of weight was given to ‘Contextual Performance’ axis, with the scores for each dimension carrying equal weights within their axis. Ninety one countries were divided into four (nearly) equal-sized economic groups (A, B, C, and D) by GDP per capita. Each of the countries was also identified as an importer or exporter of energy. The overall ESCI ranking of various countries was presented along with the output of a sensitivity analysis (error bars which indicated positional changes) that resulted from allowing the six dimensional weights to change randomly by up to ± 5%.

Normalised data (0–10) for various indicators was provided in an annexure. The report claimed to use the latest comparable data to evaluate key policy developments and outcomes from the past 18 months [62] (p. 13). This implies that data for 2007–08 was used for the generation of the index. To highlight the ‘Energy Performance’ aspect, countries were also ranked separately in the three dimensions of ‘energy security’, ‘social equity’ and ‘environmental impact mitigation’.

4.3.3. ESI (Energy Sustainability Index)-2011

In 2011, the WEC modified the ESCI and renamed it as ESI (Energy Sustainability Index). The methodology and the approach however, were unchanged [63]. Data for 2009–10 was used to rank 92 countries in the overall index ranking. A sensitivity analysis (to allotted weights) also showed the range of each country's potential ranking in the index. The ranking in ‘Energy Performance’ axis was also presented separately and a comparative assessment was made of country ranking with ESCI (2010).

4.3.4. ESI - 2012

ESI 2012 followed the same framework to evaluate the aggregate effect of energy policies applied over time and provided a snapshot of the country's energy performance in a particular year. Data from 2009 to 2011 was used to calculate the 2012 Index for 94 countries. Methodological enhancements [64] (p. 119–120) were made to a couple of indicators in the ‘social equity’ and ‘environmental impact mitigation’ dimensions. Rankings for previous years, 2011 and 2010, were calculated with the new methodology to allow for a comparison in various dimensions of ‘energy performance’ and the overall index between the years. Countries continued to be divided into four economic groups as per their GDP. The ESI-2012 was then used to urge countries to adopt sustainable energy policies [65].

4.3.5. ESI – 2013

ESI-2013 followed the earlier framework to evaluate the index [66]. While attempting to highlight the energy trilemma, it introduced a ‘balance score’ for how well countries manage the trade-offs among the three core elements of sustainable energy systems—energy security, energy equity, and environmental sustainability. One hundred and twenty nine countries were ranked based on an analysis of 60 datasets using the data from 2010 to 2012. Methodological improvements were again made to certain indicators to calculate the index and an additional indicator was added in the ‘energy security’ dimension. This has raised the total number of indicators from 22 to 23, which subsequently resulted in changes in weights allotted to the indicators. To enable year-on-year comparison, the 2011 and 2012 index rankings were recalculated to reflect methodological changes in the index and ESI rankings, broken down by energy performance dimensions were shown. Based on the findings of ESI 2013, ten areas were then set out for focused attention by WEC [67], which urged stakeholders in various countries to put the agenda into action.

A summary of different indices and their major differences are shown in Table 1.

5. Differences in composition of indices

Table A.1 presents various indicators (details have been avoided intentionally), which have been used for calculation of the three indices. The indicators have been grouped under the chosen categories of 'Availability', 'Affordability', 'Efficiency' and 'Acceptability' in accordance with an adopted framework to evaluate SES (as a part of larger study). The table highlights the similarities and differences in the selected indicators and the variation in the weights allotted to them for calculation of the respective indices. The indicators which are directly comparable are listed first under each dimension and are followed by dissimilar indicators under the category. As is evident from the specific indicators presented at Table A.1, there is a large variation in the composition of the indices. Further, dimensions, number of indicators in the respective dimension, selected indicators, and the weights allotted to indicators are also different. Hence, although the end goal is to evaluate the performance of various countries in achieving energy security and sustainability, different indices actually end up measuring different facets of energy.

Addition of new indicators (undertaken during the process of development of the index), has necessitated change of allotted weights to the indicators. This along with minor methodological changes has resulted in the emergence of different variants of the indices. The indices have therefore been recalculated retrospectively using different methodologies to enable an accurate assessment of the progress of a country over time.

The nomenclature used in this paper for addressing different variants of energy security indices which use different methodologies and data is shown in Table A.2 placed at Appendix. The first column identifies the type of index. The second uses a short identifier to spot the different variants of indices which are used in this paper, while the third uses a detailed nomenclature for the same. The scheme followed is {Type of Index, Edition (Year of Methodology, Data for the year) where ambiguous}. The fourth column relates to the year of the methodology. The fifth column identifies the range of years for data and the last column shows the number of indicators which are used for constructing the index.

6. Methodology for comparison of ranking

The ten largest energy consuming countries of the world (by TPES (Total Primary Energy Supply)), according to Global Energy Statistical Yearbook 2013, Enerdata (data for 2012) are used for a detailed country wise assessment. Ranks of these countries, as evaluated by variants of the three indices, are compared. The ranking of countries are derived from index values and are summarised in Table A.3. As different studies use a different set of countries for the assessment, the normalized rank (0–1) of each country in a particular year is calculated from the absolute rank, using Eq. (1).

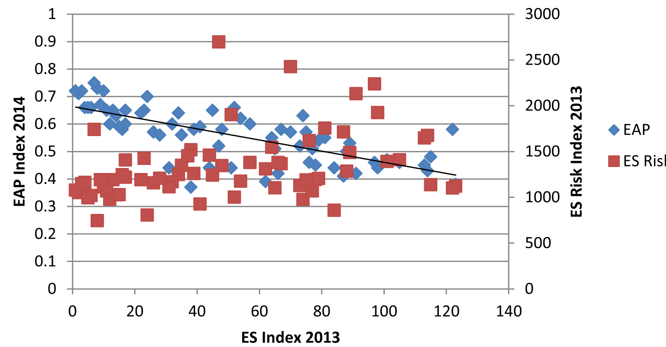

Fig. 1. Scatter plot using actual index values.

$$\text{Rank}_N = \text{Rank of a country/Total number of countries} \quad (1)$$

This makes the indices comparable over datasets having different number of countries. The score is then obtained from the normalized rank, as shown in Eq. (2).

$$\text{Score} = 1 - \text{Rank}_N \quad (2)$$

Countries can therefore attain a score in the range of 0–1 (e.g. a country ranked 5 in a list of 100 countries will have a normalized rank of 0.05 and a score of 0.95) and the scores for various countries is summarised in Table A.4. A higher score corresponds to a higher rank, which implies higher energy security and energy sustainability of that country. Various variants of the indices are then grouped together for analysing the impact of different indices on the ranking of the countries.

7. Calculation and results

7.1. Correlation analysis

Correlation of the three main indices is undertaken for a total of 67 countries which are common to the three studies. The three indices which are considered are ES Risk 2013 (13 M, 12 Y); EAPI 2014 and ESI 2013 (13 M). Correlation analysis is undertaken using both 'actual indices' and 'scores' obtained from the rank of the countries which are derieved using Eq. (1) and (2). Fig. 1 shows the scatter plot using actual indices for ES Index 2013 (on x axis) vs EAP

Table 1
Comparison of energy indices for assessment of countries.

	EAP index	ES risk index	ESI – 2013
End goal	To measure the performance of global energy systems to meet the objectives of providing a secure, affordable and environmentally sustainable energy supply	To measure the risk to overall energy security	To rank countries in terms of their likely ability to provide a stable, affordable and environmentally sensitive energy system
Dimensions	3	4	6
Core dimensions	'Economic growth and development', 'environmental sustainability' and 'energy access and security'.	Geopolitical, economic, reliability, and environmental factors	**Energy performance:** Energy security, social equity, and environmental impact mitigation **Contextual performance:** Political, societal and economic strength
Indicators	18	29	23

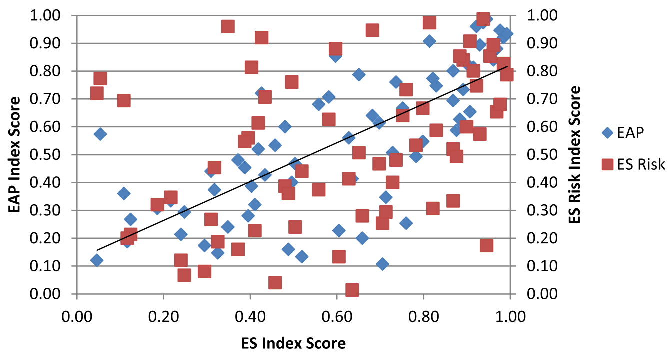

Fig. 2. Scatter plot using scores obtained from country ranks.

Table 2
Pearson's correlation coefficient for three indices.

	EAPI and ESI	ES risk and ESI	EAPI and ES risk
Index values	−0.72	0.35	−0.41
Scores	0.74	0.5	0.37

Index 2014 (on the left hand *y* axis) and for ES Index 2013 vs ES Risk Index 2013 (on the right hand *y* axis).

As is evident from Fig. 1, the EAPI and ESI show a strong negative correlation. A negative value is expected as ESI uses the ranks of countries as indexes (Best country has rank 1, implying that country which have lower ranks have higher index values), while the best performing country has highest EAP Index. Further, the ES Risk Index and ESI show a moderate positive correlation. A positive value is expected as higher values for both ESI and EAPI imply poor energy security and energy sustainability.

Fig. 2 shows the scatter plot for ES Index 2013 (on *x* axis) vs EAP Index 2014 (on the left hand *y* axis) and for ES Index 2013 vs ES Risk Index 2013 (on the right hand *y* axis). Scores derived from country ranks are used for this analysis. As is expected, both the EAP Index and ES Risk Index show a positive correlation with ES Index.

The Pearson's correlation coefficient, which is a numerical indictor of the correlation, is calculated for various indices using both ‘actual index values’ and ‘scores’ are shown in Table 2.

The above analysis indicates that EAPI and ESI show a strong correlation and a convergence in their assessment of countries. On the other hand, ES Risk and ESI as well as EAPI and ES Risk show a weaker correlation in their assessment.

Some of the selected countries which show divergence in the results of assessment of energy security and sustainability are shown in Table 3. The table clearly reveals that there may be a large variation in the assessment by various indexes and therefore deserves a closer look.

7.2. *Effect of different indices on country rankings*

Fig. 3 plots the score obtained by three different indices viz. ES Risk 2013 (using the methodology of 2013), EAPI 2014 (using the methodology of 2014) and ESI 2013 (using the methodology of 2013), all of which use data from 2010 to 2012. Fig. 3 shows a large variation in the scores for some countries such as Korea, Japan, China, India and Brazil, while results for other countries such as US, Germany, Canada are fairly consistent across various indices. It is seen that India which ranks above Russia, China, Japan, Brazil, South Korea in the ES Risk 2013 index, ranks only above China in the EAPI 2014 and is relegated to the last position in ESI 2013. On the other hand, Canada is ranked first both in ES Risk index - 2013 and ESI 2013 and ranks second in EAPI 2014. This cross–index comparison clearly demonstrates that results from separate indices are inconsistent for some countries.

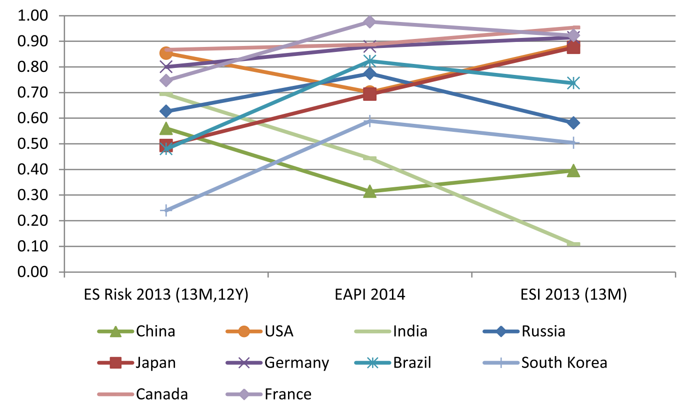

Fig. 3. Variation in country scores for different indices.

7.3. *Effect of different methodologies on country rankings*

To analyse if the ranking of countries is consistent within the same index, we compare the score of countries using the same index, but with different methodologies.

Table 4 compares the score obtained by ESI using different methodologies viz. 2013, 2012 and 2011 with the data set of 2009–10. As highlighted in Section 4, there are a few minor changes in the methodology for calculation of ESI in 2013, 2012 and 2011. The intent in selecting these variants of the indices is to highlight the impact of using different methodologies on ranking of countries.

The rank of various countries has been compiled from various reports [56–58,60]. In accordance with our adopted methodology, we normalize the absolute ranks and calculate the score. The range of scores obtained by three indices which is shown in the last column of Table 4, clearly shows the impact of slight variation in methodology on the ranking of countries. We can conclude from the above analysis that methodological considerations play an important role and even minor variations in selection and weighting of indicators can change a country's relative ranking in the world.

Table 3
Assessment of selected countries which show major divergence.

	ES risk index		ESI		EAPI		Interpretation
	Raw value	Ranking (out of 75)	Raw value	Ranking (out of 129)	Raw value	Ranking (out of 124)	
Singapore	2697	75	47	47	0.52	44	ES risk index assessment is an outlier
Kazakhstan	1100	17	122	122	0.58	32	ESI assessment is an outlier
Bangladesh	1122	21	123	123	0.38	66	Large variation in assessment
Norway	1740	62	7	7	0.75	1	ES risk index assessment is an outlier

Table 4
Variation in country scores for same index using different methodologies.

Countries	ESI 2011 (13 M)			ESI 2011 (12 M)			ESI 2011 (11 M)			Range
	Rank	$Rank_N$	Score	Rank	$Rank_N$	Score	Rank	$Rank_N$	Score	
Total no. of countries	129			94			92			
China	74	0.57	0.43	71	0.76	0.24	32	0.34	0.66	0.42
USA	16	0.12	0.88	12	0.13	0.87	16	0.17	0.83	0.05
India	115	0.89	0.11	89	0.95	0.05	71	0.76	0.24	0.19
Russia	60	0.47	0.53	27	0.29	0.71	23	0.24	0.76	0.23
Japan	13	0.10	0.90	11	0.12	0.88	6	0.06	0.94	0.06
Germany	10	0.08	0.92	10	0.11	0.89	4	0.04	0.96	0.07
Brazil	43	0.33	0.67	45	0.48	0.52	17	0.18	0.82	0.30
South Korea	55	0.43	0.57	37	0.39	0.61	52	0.55	0.45	0.18
Canada	8	0.06	0.94	1	0.01	0.99	5	0.05	0.95	0.05
France	7	0.05	0.95	7	0.07	0.93	3	0.03	0.97	0.04

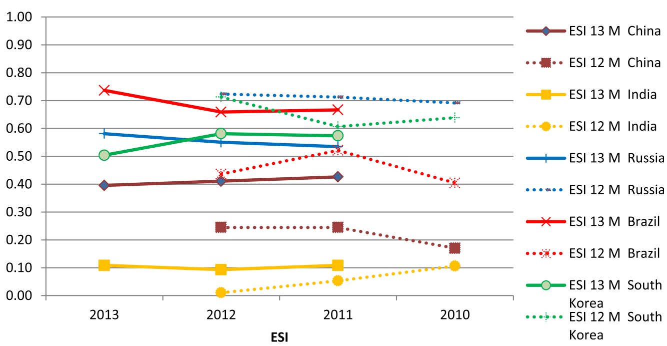

Fig. 4. Trends in performance of different countries.

7.4. Assessment of trends in country performance

Fig. 4 shows the trends in performance of different countries for ESI using 2012 and 2013 methodologies over a period of four years. Comparison is made only for five countries which shows a large range of scores (as identified in Table 4). The aim is to assess the impact of different methodologies on evaluating the trends in the performance of the country.

The first three columns of Fig. 4 show the score of countries obtained by ESI for the years 2013, 2012 and 2011 using the 2013 methodology and the last three columns in dotted lines show the scores for the years 2012, 2011 and 2010 using the 2012 methodology.

Although there are large variations in absolute scores of countries such as Brazil and China, the direction of the movement of the score is fairly consistent. If we neglect minor variations, the trends for different countries as evaluated by both the methodologies over a period of four years, show that while energy security and sustainability for India and China are decreasing, it is increasing for Russia and the trends are inconsistent for Brazil and South Korea (increases over some and decreases over other time periods).

7.5. Assessment of variation in country scores

Fig. 5 plots the variation in score obtained using 14 different variants of three indices. The spread of the scores obtained for top 10 energy consuming countries and their median value is shown in Fig. 5. Although the data used for calculation of country ranks is for various years from 2009 to 2012, the wide variation in the range of scores for certain countries is clearly evident.

Table 5 shows the minimum value, maximum value, median value and the Standard Deviation (SD) of the population (14 different variants). The comparative ranking of countries derived from the median values of the scores is as follows: Canada, France, Germany, Japan, USA, Russia, Brazil, South Korea, China and India.

The results can also be analysed by clubbing countries into three groups based on the interpretation of the above statistics. The top grouping is obtained by France, Canada and Germany which have a low SD and a high median value of the scores. The next group of countries consists of USA, Japan and Russia, which, although have a relatively higher median value, also has a high SD. The last group of countries which has a high SD and lie around the middle of the country rankings (or lower) consists of Brazil, South Korea, China and India.

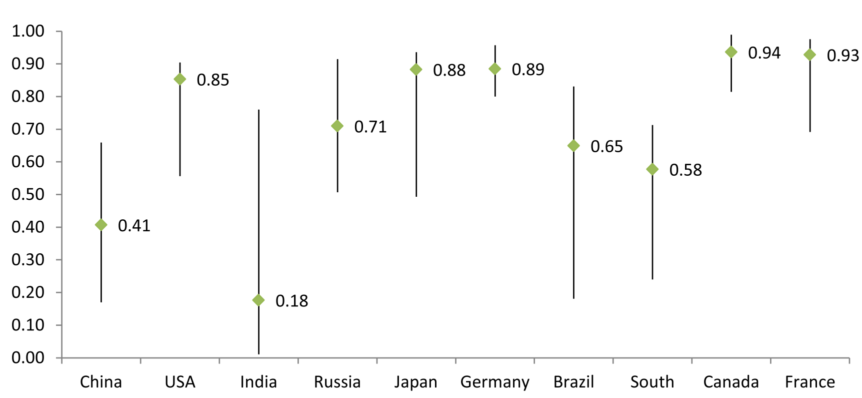

Fig. 5. Range and median of country scores for different indices.

Table 5
Range, median and standard deviation of country scores.

	Min	Max	Median	SD
China	0.17	0.66	0.41	0.1408
USA	0.56	0.90	0.85	0.0929
India	0.01	0.76	0.18	0.2686
Russia	0.51	0.91	0.71	0.1090
Japan	0.49	0.94	0.88	0.1545
Germany	0.80	0.96	0.89	0.0529
Brazil	0.18	0.83	0.65	0.1845
South Korea	0.24	0.71	0.58	0.1449
Canada	0.81	0.99	0.94	0.0563
France	0.69	0.98	0.93	0.0927

8. Discussion

The above results can be interpreted to answer the questions raised in Section 3. Countries obtain different scores by using different indices and the country rankings are inconsistent for certain countries. This inconsistency in scores leads us to the conclusion that the ranking of the country varies widely across different indices, even for data which is derived from a common set of years. This is primarily due to differences in the construction of different indices which use different indicators with different weights.

However, trends derived for a particular country from various indices using different methodologies are fairly consistent and show the performance of a country over time. Further, the performance of a country does not show significant changes over a short time period of four years. Hence we can conclude that the process of ranking countries can be undertaken at larger time intervals (rather than yearly), particularly when the datasets overlap, without any significant loss of information.

Table 5 reveals that China, Russia, India, Brazil and South Korea show a large variation in the country scores. This implies that these countries are very sensitive to the selection and to the weights allotted to indicators. Hence the ranking of such countries is relatively unreliable, and the performance of these countries is poor. On the other hand, countries which are consistently ranked high by all studies have a smaller range of scores. Hence, it can be concluded that the performance of such countries is insensitive to variation in methodologies, selection of indicators and their relative weighting. This translates to a robust performance of the energy system for the country.

Numerical ranking of countries based on a relative comparison, inherently assumes homogeneity between the characteristics of the energy system of all countries. However, it is well known that there is heterogeneity in terms of resource endowment (importer/exporter status), economic profiles (GDP), size of energy system (small/large), geographic and weather conditions (affecting per capita consumption), stages of industrialization (affecting demand), etc. amongst countries. Notwithstanding the above, countries with different characteristics have been grouped together for a relative comparison. As the characteristics of a country are very different, clubbing countries together for ranking is questionable. Realizing the non-homogeneity amongst countries, WEC [61] clubs similar countries into five clusters based on their GDP and net energy importer/exporter status for evaluating AI, while ESCI [62] highlights the status of countries (as per four economic groups and importer/exporter status) along with their overall ranking.

Further, it is better to avoid numerical ranking, as it comes out with one specific number, which is interpreted to be an accurate assessment. A better option is to club countries which fall within a range of scores, together. Such an approach, which presents the results of country rankings into four quartiles (top 25%, 25–50%, 50–75% and bottom 25%), is used for presenting the results of AI [61]. A similar approach is taken in evaluation of MOSES, which groups the performance of different countries which have similar combinations of risks and resilience factors together, without assigning a particular rank [51]. This trade-off to abandon precise values of country rankings accommodates uncertainties in measurement and inherently acknowledges the limitations of undertaking a comprehensive quantitative evaluation of energy security and sustainability. It therefore allows for a better understanding and interpretation of a country's performance without laying emphasis on the numeric values or ordering of the country ranking.

The case of India deserves a special mention here. The country shows the highest standard deviation of 0.2686, whereas the average standard deviation of the 10 countries is 0.1297. While other countries with high standard deviation have one or two data points which are outliers (Brazil (9); South Korea (1); China (13); Japan (1,2,3); South Korea (1, 2, 3, 9); numbers in brackets indicate index identifier as per Table A.2), India's scores are more evenly spread across the entire range. A detailed look at A4 also reveals that the score of India attained by index variants 1, 2, 3 is high (range 0.69–0.76); by 4, 5, 14 is in the middle level (range 0.44–0.50); and by index variants 6, 7, 8, 9, 10, 11, 12, 13 is very low (range 0.01–0.24). This large discrepancy in scores therefore needs to be examined in greater detail (such as by considering country relevant indicators, appropriate weighting etc.), but is beyond the scope of this paper.

9. Conclusion

It is evident that different indices capture different characteristics of the country's performance in attaining energy security and energy sustainability. Hence they all give different perspectives as deemed important by the agency which is constructing the index. The situation is akin to three blind men assessing what an elephant is like [68]. As each one feels a different part, they end up in complete disagreement. Therefore, while one's subjective experience is true it may not be the totality of truth. Similarly, although the ranking from each of the variants of the index is correct, they only give a part of the picture and not the whole picture. Hence, it may be concluded that basing the assessment of a country's performance in attaining energy security and sustainability, on the score obtained in one specific study may not be accurate.

Therefore, we need to start 'listening' to different perspectives and need to collaborate to 'see' the full elephant. While accepting this reality, if we attempt to see beyond this disagreement in the country rankings, we can conclude that countries which perform consistently better in the ranking have energy systems which perform robustly. These countries are in the top bracket of performers and the ranking of these countries can be considered reliable, irrespective of the index. However, the same is not true for countries which show poor performance. It is observed that the ranking of these countries has a large spread across different indices which imply high sensitivity to the selection and weighting of the indicators. Hence, indices for these countries do not give reliable information and further analysis is required for assessing the energy security and energy sustainability of these countries.

We also need 'more men' to 'see' other parts of the elephant to describe the hidden facets. Hence 'energy security' which is the proverbial 'elephant', needs to be examined with different tools such as newly constructed indices which focus on other key aspects of the country's energy system. Unlike the story of the blind men and the elephant, we may never have a sighted man who may walk past and may see the elephant all at once, but if we accept the fact that we are 'blind', we can learn to collaborate and resolve our conflicts to draw a complete picture which looks somewhat like the actual elephant.

Appendix A

Table A.1
Indicators and weights used for various indexes.

SES dimension	EAPI 2013	Wt	ES risk 2013	Wt	ESI 2013	Wt
Total indicators	18		29		23 (only 12 used for energy performance are comparable)	
Availability (Diversity)	Energy import dependence (net % energy use)	0.066/0.04125	Total energy import exposure	0.04	Ratio of total energy production to consumption	0.04175
	Diversity of total primary energy supply (Herfindahl index)	0.066	Electricity diversity	0.05	Diversity of electricity generation	0.04175
	Diversification of import counterparts (Herfindahl index)	0/0.04125	GDP per capita	0.04	Days of oil and oil product stocks	0.04175
	Electrification rate (% of population)	0.066	Security of world oil, gas, coal reserves	0.02 each		
	Percentage of population using solid fuels for cooking (%)	0.066	Security of world oil, gas, coal production	0.03, 0.03, 0.02		
	Quality of electricity supply (1–7)	0.066	Petroleum, gas, coal import exposure	0.03, 0.03, 0.02		
			Energy consumption per capita	0.04		
			Transportation energy per capita	0.03		
			World oil refinery utilization	0.02		
Affordability	Cost of energy imports (% GDP)	0.04125	Fossil fuel import expenditures per GDP	0.05	Net fuel imports/exports as a percentage of GDP	0.04175
	Degree of artificial distortion to gasoline pricing (index)	0.04125			Affordability of retail gasoline	0.125
	Electricity prices for industry	0.0825	Retail electricity prices	0.06	Affordability and quality of electricity relative to access	0.125
	Degree of artificial distortion to diesel pricing (index)	0.04125	Energy expenditure volatility	0.04	Five year CAGR of the ratio of TPEC to GDP	0.04175
	Value of energy exports(% GDP)	0.04125	Crude oil price volatility	0.05		
			Crude oil prices	0.07		
			Energy expenditures per capita	0.03		
Acceptability	Alternative and nuclear energy (% of total energy use)	0.066	Non-CO_2 emitting share of electricity generation	0.02		
			Energy-related carbon dioxide emissions intensity	0.02	CO_2 intensity	0.0625
	CO_2 emissions from electricity production	0.066	CO_2 emissions trend	0.02	CO_2 emissions from electricity generation	0.0625
	Methane emissions in energy sector	0.04125	Energy-related carbon dioxide emissions per capita	0.02	Effect of air and water pollution	0.0625
	Nitrous oxide emissions in energy sector	0.04125				
	PM10, country level	0.066				
Efficiency	Energy intensity	0.0825	Energy intensity	0.07	Total primary energy intensity	0.0625
	Average fuel economy for passenger cars	0.066	Transportation energy intensity	0.04		
			Petroleum intensity	0.03	Distribution losses as a percentage of generation	0.04175
			Energy expenditure intensity	0.04		
Total weight		1.00[a]		1.0		1.00[a]

[a] Total Weight may not add to 1.00 due to rounding off.

Table A.2
Variants of indices used for country wise ranking.

Index	Short identifier	Nomenclature	Methodology	Data	No. of indicators
ES risk	(1)	ES risk 2013 (13 M, 12 Y)	2013	2012	29
	(2)	ES risk 2013 (13 M, 10 Y)	2013	2010	29
	(3)	ES risk 2012 (12 M, 10 Y)	2012	2010	28
EAPI	(4)	EAPI 2014	2014	2010–12	18
	(5)	EAPI 2013	2013	2009–11	16
ESI	(6)	ESI 2013 (13 M)	2013	2010–12	23
	(7)	ESI 2012 (13 M)	2013	2009–11	23
	(8)	ESI 2012 (12 M)	2012	2009–11	22
	(9)	EP[a] 2012 (12 M)	2012	2009–11	22
	(10)	ESI 2011 (13 M)	2013	2009–10	22
	(11)	ESI 2011 (12 M)	2012	2009–10	22
	(12)	ESI 2011 (11 M)	2011	2009–10	22
	(13)	ESI 2010 (12 M)	2012	2008–09	22
	(14)	ESCI 2010 (10 M)	2010	2008–09	22

[a] EP considers only 'Energy Performance' axis and is a component of ESI.

Table A.3
Ranking of countries for various variants of indexes.

Index identifier (as per Table A.2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total countries	75	75	75	124	105	129	129	94	94	129	94	92	94	91
China	33	33	28	85	74	78	76	71	59	74	71	32	78	52
USA	11	11	12	37	55	15	16	12	27	16	12	16	9	15
India	23	18	18	69	62	115	117	93	87	115	89	71	84	50
Russia	28	37	22	28	27	54	58	26	8	60	27	23	29	25
Japan	38	34	34	38	25	16	14	8	7	13	11	6	11	7
Germany	15	15	14	15	14	11	8	11	11	10	10	4	18	5
Brazil	39	27	39	22	21	34	44	53	77	43	45	17	56	23
South Korea	57	50	51	51	38	64	54	27	61	55	37	52	34	36
Canada	10	10	13	14	23	6	10	3	1	8	1	5	2	6
France	19	17	16	3	3	10	9	9	29	7	7	3	6	3

Table A.4
Scores obtained by countries for various variants of indexes.

Index identifier (as per Table A.2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
China	0.56	0.56	0.63	0.31	0.40	0.40	0.41	0.24	0.37	0.43	0.24	0.66	0.17	0.43
USA	0.85	0.85	0.84	0.70	0.56	0.88	0.88	0.87	0.71	0.88	0.87	0.83	0.90	0.84
India	0.69	0.76	0.76	0.44	0.50	0.11	0.09	0.01	0.07	0.11	0.05	0.24	0.11	0.45
Russia	0.63	0.51	0.71	0.77	0.78	0.58	0.55	0.72	0.91	0.53	0.71	0.76	0.69	0.73
Japan	0.49	0.55	0.55	0.69	0.80	0.88	0.89	0.91	0.93	0.90	0.88	0.94	0.88	0.92
Germany	0.80	0.80	0.81	0.88	0.89	0.91	0.94	0.88	0.88	0.92	0.89	0.96	0.81	0.95
Brazil	0.48	0.64	0.48	0.82	0.83	0.74	0.66	0.44	0.18	0.67	0.52	0.82	0.40	0.75
South Korea	0.24	0.33	0.32	0.59	0.69	0.50	0.58	0.71	0.35	0.57	0.61	0.45	0.64	0.60
Canada	0.87	0.87	0.83	0.89	0.81	0.95	0.92	0.97	0.99	0.94	0.99	0.95	0.98	0.93
France	0.75	0.77	0.79	0.98	0.98	0.92	0.93	0.90	0.69	0.95	0.93	0.97	0.94	0.97

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