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Sustainable energy security for India: An assessment of the energy supply sub-system

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ABSTRACT

This paper undertakes part of the assessment of the sustainable energy security (SES) for India. SES goes beyond 'energy supply' and is a function of the aggregate energy system of a country, including the 'energy demand' and 'conversion and distribution sub-system'. The supply sub-system which consists of eight primary energy sources viz. coal, oil, natural gas, biomass, hydro, solar, wind and nuclear has been evaluated for four dimensions of SES, viz., availability, affordability, efficiency and (environmental) acceptability using 16 selected metrics. The dimensional indices are calculated for domestic and imported energy sources separately for the years 2002, 2007 and 2012. Results reveal that the SES index for oil has increased by 10% but it has decreased by 6% for gas from 2002 to 2012, while changes for other energy sources are marginal. The overall supply sub-system SES index is approximately 0.75 (against an ideal value of 1.0) which reveal the shortfall from the desired value. A sensitivity analysis reveals that the SES index is relatively robust to variation in weights. The assessment provides a comprehensive way to track the performance of the energy supply sub-system and can be used to design policy interventions for improving the overall SES index for India.

1. Introduction

Sustainable Energy Security (SES) is defined as "provisioning of uninterrupted energy services in an affordable, equitable, efficient and environmentally benign manner" (Narula, 2014) and has been proposed as an end goal of the energy policy for a developing country. Energy security is a property of the energy system (Mitchell and Watson, 2013) and the physical energy system of a country can be divided into three distinct sub-systems, 'energy supply' sub-system, 'energy conversion & distribution' sub-system and 'energy demand' sub-system. The energy supply sub-system deals with primary energy, either extracted as fossil fuels (coal, crude oil, natural gas); renewable energy (solar, wind, hydro) which is harnessed directly to generate electricity; biomass and; nuclear energy which is extracted as uranium and is then converted to electricity.

Energy security is often used synonymously with security of energy supply. This perception of energy security enhances the importance of the energy supply sub-system in the energy system. World Energy Outlook- 2015 (IEA, 2015) forecasts that India will move to the centre stage of the world energy system and the change in demand for energy for the period 2014–2040 will be the highest amongst all countries. Thus the energy supply sub-system will need to grow to meet this demand and there is likely to be a large increase in import of fossil fuels and renewable energy generation from domestic resources. Tracking of the performance of the energy supply sub-system of a country based on an assessment of various competing sources of energy is therefore essential. This paper attempts to contribute to the methodological advancement for undertaking a multidimensional assessment of an energy system for a country. The generic methodology is valid for any country or region and the paper applies it for undertaking a comprehensive analysis of the Indian energy supply sub-system.

There are a set of indices in literature which attempt to undertake the assessment of a country's energy security and sustainability. A few of them are: Energy Security Index (ESI_{price} and ESI_{volume}) by IEA (2007), 'willingness to pay function' for security of supply (Bollen, 2008), Oil Vulnerability Index (Gupta, 2008), Vulnerability Index (Gnansounou, 2008), geopolitical energy security measure (Blyth and Lefevre, 2004), risky external supply index (Le Coq and Paltseva, 2009), economic and socio-political risk index under project Risk of Energy Availability: Common Corridors for Europe Supply Security (REACCESS, 2011), energy development index (IEA, 2010), energy sustainability index (Doukas et al., 2012), Aggregated Energy Security

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Performance Indicator (AESPI) (Martchamadol and Kumar, 2013), amongst 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 specific fuels, such as oil and gas, while neglecting energy sources such as renewable energy, nuclear and coal. However, a couple of them such as S/D Index (Scheepers et al., 2007), Model of Short-term Energy Security (MOSES) (Jewell, 2011) and the index developed by Sreenivas and Iyer (2014), comprehensively attempted to measure major facets of the performance of the energy system. Yao and Chang (2014) have undertaken a quantitative analysis of energy security in China using the 4 A's framework. Using a similar approach Tongsopit et al. (2016) applied the 4-As framework to measure the status of energy security of ASEAN countries. The paper examines four quantitative indicators for each A's related to availability, applicability, affordability and acceptability and examines the trends from 2005 to 2010.

The aim of this paper is to assess the SES for the energy supply sub-system for India. Eight components of the supply sub-system (primary energy sources) are evaluated for 16 metrics and their dimensional indices are calculated for the years 2002, 2007 and 2012. These are aggregated into indices for domestic and imported energy sources and further into an SES index for the energy supply sub-system. An analysis of calculated indices is undertaken and the shortcomings in the performance of the energy supply sub-system are identified. A sensitivity analysis of various dimensional indices examines the robustness of the supply sub-system SES index. The paper highlights the applicability of the SES index for tracking the performance of the energy supply system for a country and concludes with certain policy implications for India based on the comprehensive analysis of its energy supply sub-system.

2. Methodology

The analytical framework for the assessment of SES of an energy system, the methodology for constructing an SES index and the metrics to calculate the SES index has been proposed earlier (Narula and Reddy, 2016). The paper describes in detail the overall framework of assessment of the energy subsystem, the methodology, the justification of selection of dimensions and the metrics and the relationship of the selected metrics with SES.

The energy system is divided into three parts to facilitate the assessment of its SES and the boundaries are shown on a representative Sankey diagram in Fig. 1 (Narula and Reddy, 2016). The supply sub-system consists of all domestic and imported primary energy sources. The impact of extraction of primary energy sources is also considered for the assessment of supply sub-system and is shown as an additional block in Fig. 1. Primary energy sources are converted into secondary energy such as electricity and refined petroleum products in the conversion and distribution sub-system. The demand sub-system consists of various energy consuming sectors. The end use devices which convert the final energy to useful energy are also considered in the assessment of the energy demand sub-system. The framework for the assessment of the energy supply sub-system which is evaluated in this paper is also presented in Fig. 1 and the methodology is briefly described ahead.

The components of the supply sub-system are various primary energy sources which are assessed separately for domestic supply and imports. For hydro, solar, wind and biomass there are no sub-components as these energy sources are primarily domestic in nature. Renewable primary energy sources such as hydro, solar, and wind as well as nuclear (uranium), are assessed for their potential to supply electricity.

Four different dimensions — ‘Availability’ (related to adequacy and access), ‘Affordability’ (related to prices and paying ability), ‘Environmental Acceptability’ (related to resource extraction and waste production) and ‘Efficiency’ (related to productivity in the use of energy resources) are used for the assessment of SES of an energy system. These dimensions enshrine the principles of SES and are equally applicable to all sub-systems. However, they have different interpretations for different sub-systems. For the energy supply sub-system, ‘availability’ implies adequacy of domestic energy reserves, adequacy of primary energy supply and ease of energy imports. High availability lowers the risk of energy supply disruption. Lower cost of energy, lower volatility in the price of imported energy and a lower energy import bill for a country implies higher affordability of energy supply sub-system which increases the SES. ‘Efficiency’ dimension for the energy supply sub-system includes extraction efficiency of primary energy sources and a higher extraction efficiency (recovery factor) is desirable. Acceptability of a particular energy source is high if there is lower use of resources such as water and land and if there is reduced waste generation such as air emissions from primary energy extraction. Suitable metrics are then selected for each dimension for undertaking a comprehensive assessment of SES of the energy supply sub-system.

As shown in Fig. 1, weights are allotted to metrics and dimensions. The shares of domestic (sh_{DOM}) and energy imports (sh_{IMP}) for various energy sources and their shares in the primary energy supply ($sh_{E(i)}$) are obtained from energy balances.

Measurement of SES can be undertaken through the use of ‘metrics’ which reflect the characteristics of the energy system. Following the hierarchical structure for assessment of SES for an energy system, energy indices can be evolved using a combination of ‘weights’ and ‘scores’ and a SES index for the energy supply sub-system can be aggregated. The model for creating an SES index consists of a scoring matrix and a weighting matrix, which are multiplied together to form a vector, elements of which can be considered as an ‘index’. ‘Scores’ are used to measure the performance of specific characteristics of energy sources and are objective values which are obtained from statistical data and scoring rules for various metrics. On the other hand, ‘weights’ represent the subjective component and can be interpreted as a measure of relative importance of the metric. The generic model for constructing an index for the assessment is shown in Fig. 2.

Metrics are collated from various data sources (if directly available), or are calculated from its components. Data imputation and other approximations are undertaken to account for the missing data in certain cases. Various metrics have different units and these are normalized to make them dimensionless. The normalized metrics are then scaled appropriately/inverted to attain the scores which are elements of the scoring matrix.

Min-max normalization followed by scale inversion is used for the supply sub-system. Value (x) of each energy source for a particular metric is collected and is benchmarked against pragmatically (user) defined minimum and maximum values. The allotted score for a metric is 0, if the value of the metric is below the lower threshold (minimum), and is 1, if it is above the upper threshold (maximum), respectively. If the value of the metric for a country is within these two limits, the normalized score of the country is linearly interpolated. A similar methodology has also been used in calculating the S/D index (Scheepers et al., 2007) and in MOSES (Jewell, 2011), where well defined scoring rules are formulated for each metric after defining the minimum and maximum values.

In order to calculate the normalized value, ‘n’, Eq. (1) is used, which transforms the values to a relative scale of 0–1.

$$n = \frac{x - \min(x)}{\max(x) - \min(x)} \tag{1}$$

The selected metrics can be grouped into two categories, viz., metrics which have a positive impact and those which have a negative impact on SES. Positive impact metrics are those, where a high value of the metric contributes to high SES index; while for negative impact metric, a high value of the metric contributes to lowering of SES index. While the normalized values of the positive impact metrics are unchanged, the normalised values of negative impact metrics have to