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Abstract

This paper presents a quantitative assessment of Sustainable Energy Security (SES) of the energy demand sub-system for India by calculating a SES index. The demand sub-system has been evaluated for four dimensions of SES, viz., Availability, Affordability, Efficiency and (Environmental) Acceptability using selected metrics. A hierarchical structure has been used to construct indices using 'scores' (objective values of selected metrics), and 'weights' (subjective values, representing importance of each metric) which are then aggregated, to obtain a SES Index. Various sectors of the energy demand sub-system are evaluated and dimensional and sectoral indices are calculated for the years 2002, 2007 and 2012. Assessment of the obtained energy indices is undertaken and the results reveal that all (except one) sectoral indices have shown an increase during the period of assessment. The results show that from 2002 to 2012 the aggregate SES Index has increased by approximately 10% which indicates a gradual improvementin the sustainability and security of the energy demand sub-system.However, the SES index is approximately 0.7 (short of the desired target of 1.0), which implies that there is still a large scope for improvement in the performance of the India's energy demand sub-system. A sensitivity analysis of various indices reveals that the SES index is relatively robust to variation in weights allotted to different dimensions and hence provides a reliable assessment of the SES of the demand sub-system.

Keywords: Energy Security, Energy Sustainability, Energy Index,Indicators

JEL Code: P28, Q41, Q42, Q48

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This paper presents a quantitative assessment of Sustainable Energy Security (SES) of the energy demand sub-system for India by calculating a SES index. The demand sub-system has been evaluated for four dimensions of SES, viz., Availability, Affordability, Efficiency and (Environmental) Acceptability using selected metrics. A hierarchical structure has been used to construct indices using 'scores' (objective values of selected metrics), and 'weights' (subjective values, representing importance of each metric) which are then aggregated, to obtain a SES Index. Various sectors of the energy demand sub-system are evaluated and dimensional and sectoral indices are calculated for the years 2002, 2007 and 2012. Assessment of the obtained energy indices is undertaken and the results reveal that all (except one) sectoral indices have shown an increase during the period of assessment. The results show that from 2002 to 2012 the aggregate SES Index has increased by approximately 10% which indicates a gradual improvementin the sustainability and security of the energy demand sub-system.However, the SES index is approximately 0.7 (short of the desired target of 1.0), which implies that there is still a large scope for improvement in the performance of the India's energy demand sub-system. A sensitivity analysis of various indices reveals that the SES index is relatively robust to variation in weights allotted to different dimensions and hence provides a reliable assessment of the SES of the demand sub-system.

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 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. Such a structured analysis of an energy system has also been proposed by Hughes (2012).

The demand of energy services from various sectors triggers the supply of energy in an energy system. The energy system responds to this demand and fulfils it to the extent feasible. Hence the demand sub-system is critical for attaining SES for a country. The importance of the demand sub-system is also evident in India's approach to energy security, which is summarized as "*The country is energy secure when we can supply lifeline*[1] *energy to all our citizens as well as meet their effective demand for safe and convenient energy to satisfy various needs at affordable costs at all times with a prescribed confidence level considering shocks and disruptions that can be reasonably expected*" (Planning Commission, 2006). However, the concept of SES goes beyond providing 'lifeline' of energy and beyond 'citizens' to include all sectors of the economy. Based on the conceptualization of SES, the key principles which are applicable for the demand sub-system are as follows:

a) Essential demand has to be met but unrestricted demand should be discouraged
b) There should be no energy deficit or unmet latent demand
c) Clean energy carriers should be accessible
d) Retail prices of energy have to be low and prices should not be distorted
e) Emissions from use of energy have to be low
f) Energy should be used with maximum[2] efficiency

With increase in population and per capita energy consumption the aggregate energy demand of a country will continue to increase in the Business As Usual (BAU) scenario. However, it can be reduced as compared to the BAU scenario, by adopting Demand Side Management (DSM) programs, and by reducing wastage (such as by utilizing waste heat). In case of electricity, peak demand management and dynamic demand reduction do not contribute directly to reduction in aggregate energy consumption, but it avoids the setting up of additional conversion and transmission infrastructure, thereby contributing to SES.

The aim of this paper is to assess the SES for the energy demand sub-system for India. The paper commences with the methodology for calculating the SES index. The selected metrics and their targets are discussed in section 3. Scoring matrices are derived for various sectors and scores are calculated in the next section. Stakeholder responses and weighting matrices are used to derive the results in section 6. A sensitivity of the derived SES index for the demand sub-system is undertaken prior to concluding the paper in section 8.

[1] Amount of energy essential, to meet the demand for productive uses
[2] Which is technologically possible

2. METHODOLOGY

The framework for assessment and the methodology to calculate the SES index is presented in this section.

2.1 Hierarchical structure for assessment of energy system

The hierarchical structure for the assessment of SES of the energy system of a country is shown in Fig. 1. The SES of an energy system is a function of the SES of the sub-systems. Each sub-system has various components which contribute to SES. The energy supply sub-system can be assessed for eight primary energy sources: coal, oil, natural gas, biomass, nuclear, wind, solar and hydro. The energy conversion & distribution sub-system can be assessed for five energy carriers: coal, gas, oil products, biomass and electricity and the energy demand sub-system can be assessed for five main sectors of the economy: Residential, Industrial, Commercial (Services), Agriculture and Transport. These components can be further divided into sub-components for a detailed assessment. SES of domestic and imported energy for various energy sources can be assessed separately in the energy supply sub-system and SES of rural and urban consumers can be assessed in detail for the residential sector in the demand sub-system. The structure for assessment of SES is similar to the S/D (Supply/Demand) Index proposed by Scheppers et. al. (2007), but differs in many details. This hierarchical structure allows us to undertake a complete assessment of the SES of an energy system for a country or a region.

SES is a multidimensional concept and there are various dimensions, categories and indicators which can be chosen to assess the SES of an energy system. 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 energy productivity) are selected for undertaking an assessment of SES of an energy system. These dimensions enshrine the principles of SES, are distinct and indicators can be neatly grouped under respective dimensions for undertaking an assessment of SES. The dimensions are further divided into various categories and sub-categories which amplify the characteristics of SES which are being evaluated.

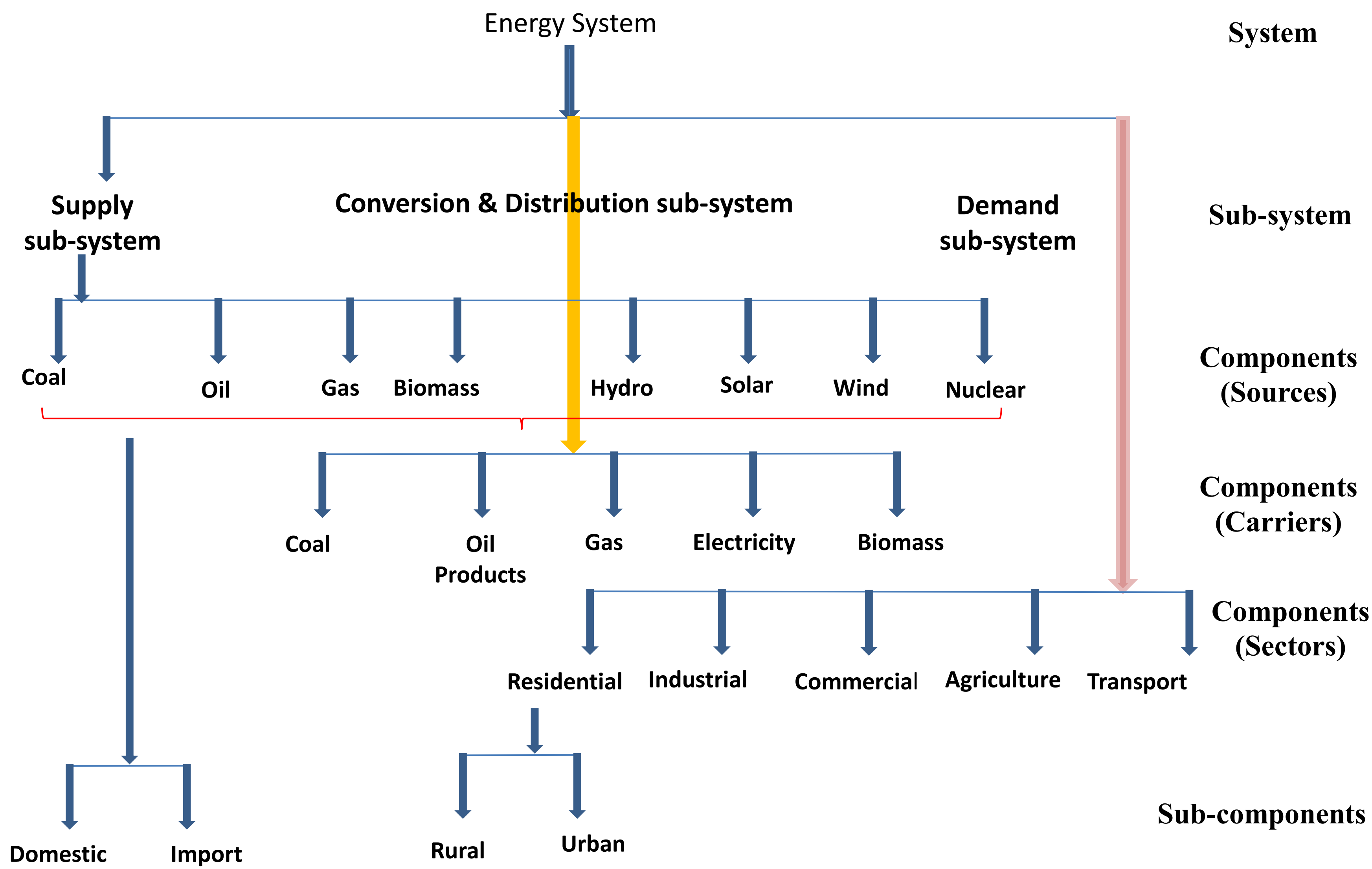

Fig. 1. Hierarchical structure for assessment of SES for an energy system

2.2 Constructing a SES index

In this paper, measurement of SES is undertaken through the use of 'Indicators'. Indicators[3] may be qualitative or quantitative. Quantitative indicators are based on data and can be used for measurement without any subjectivity. They are known as 'metrics' and are used for undertaking an assessment of the chosen characteristics of the energy system. Following the hierarchical structure for assessment of SES for an energy system, a hierarchy of energy indices can be evolved using a combination of 'weights'[4] and 'scores'[5] and a composite SES index can be aggregated using the model discussed ahead.

2.3 Model for constructing an index

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 elements of the scoring matrix and these 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.

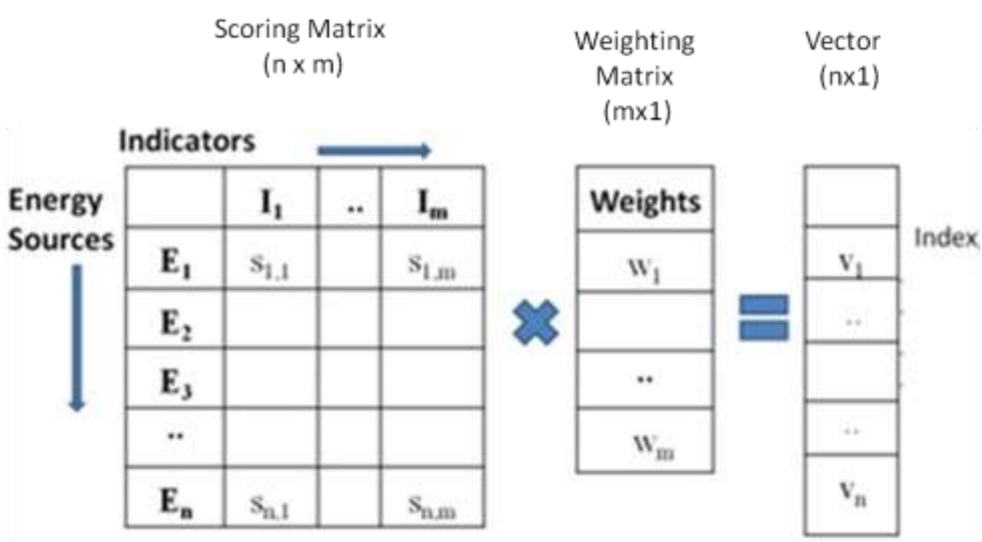

Fig. 2. Model for constructing an Index

[3]An 'Indicator' is a tool which is designed to capture certain characteristics of a system and energy indicators are used to assess the performance of an energy system
[4]Weights can be considered as importance coefficients
[5] Scores are used to measure the performance on specific characteristics

2.3.1 Scoring matrix

A scoring matrix consists of 'n' rows, for different components, to be evaluated (shown as energy sources, E_i, for supply sub-system) and 'm' columns, having different metrics, I_j. Each element of the matrix has the 'score', s(E_i, I_j), which represents the value of the indicator I_j for a particular energy source E_i. The elements of the (n x m) scoring matrix are filled using these scores which are derived from a combination of the value of the metric and the scoring rule. The weighting matrix is a column matrix, having 'm' rows and each element is assigned the values w_j. Each element of the vector, obtained by the multiplication of the scoring and the weighting matrix, is the index corresponding to the particular energy source E_i. Scores are derived from the actual value of the metrics. Metrics are collated from various data sources (if directly available), or are calculated from its components. Data imputation and other approximations may have to be undertaken to account for the missing data in certain cases. Various metrics have different units and these are normalized to make them dimensionless quantities. The normalized metrics are then scaled appropriately/inverted to attain the scores which are entered as elements of the scoring matrix.

2.3.2 Scoring rules

The 'distance to reference' approach is used to derive the scores of the selected metrics for the demand sub-system. The 'score' can be calculated using the generic eqn. (1) below.

$$n = \frac{value\ (x) - f * target(x)}{\mathrm{f}' * \mathrm{target}(x)} \qquad (1)$$

Where,

value (x) = actual value of the selected metric;

target (x) = Desired value of the metric;

f = allotted value (1/5)

f' = allotted value (4/5)

The appropriate target for each metric is decided based on a pragmatic judgment and the scoring rules are further explained in detail. There are two types of metrics: one for which a higher value is preferred (e.g. percentage of population with access to electricity) and the other, for which a lower values result in higher SES (e.g. sectoral energy intensity). The scoring rules for these metrics are different and the scores are derived using eqns. (2) and (3).

(a) For metrics where lower values are desirable

If value (x) < = target (x) : $\text{Score} = 1$

If 5* target(x) > value (x) > target (x) : $\text{Score} = \frac{(5*\text{target}-\text{x})}{4*\text{target}})$

If value (x) > = 5* target(x) : $\text{Score} = 0$ (2)

(b) For metrics where higher values are desirable

If value (x) > = target (x) : $\text{Score} = 1$

If 0.2* target(x) < value (x) < target (x) : $\text{Score} = (\frac{\text{x}-(\text{target}/5)}{(\frac{4}{5})*\text{target}})$

If value (x) < = 0.2* target(x) : $\text{Score} = 0$ (3)

For metrics where lower values are desirable, if value (x) < = target (x), the score of the metric will be 1, as the target has already been met. This is a special case, and is not encountered often as the country would generally have a shortfall from the target. If value (x)> = 5* target(x), the score is 0. Such a value of the metric signifies more than 500% reduction from the current value, and is therefore allotted a score of 0. If the value of the metric is within the range of 5* target(x) > value (x) > target (x), the score is obtained by linear scaling between 0 and 1.

For metrics where higher values are desirable, if value (x) > = target (x), the score of the metric is 1, as the target has already been met. If value (x) < = (1/5)* target(x), a score of 0 is allotted. Such a value signifies that more than 500% increase is required from the current value of the metric and it is therefore allotted a score of 0. If the value of the metric is within the range of (1/5)* target(x) < value (x) < target (x), the value of the score is obtained by linear scaling.

The range of scores of the metrics varies between 0 and 1 and the relationship between value of the metric (as a multiple of target value) and its score is shown in Fig. 3.

2.3.3 Weighting matrix

Weights are essentially value judgments and represent a tradeoff between various competing criteria. A pair-wise comparison is undertaken for determining the weights. This process is chosen as weights gathered from the stakeholders capture the perception of a cross-section of the society and therefore represents the concerns for energy security and sustainability of a country.

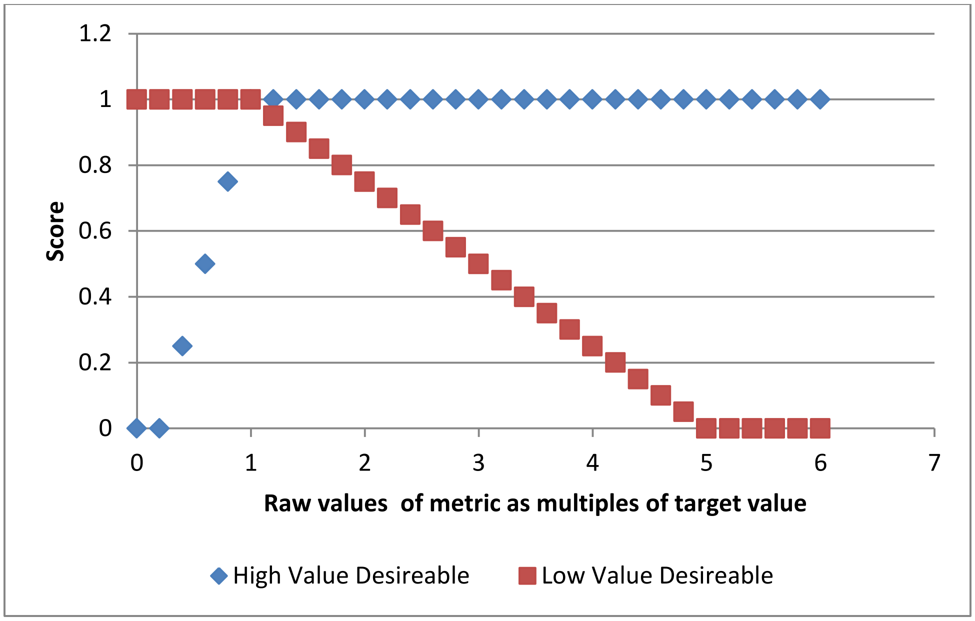

Fig. 3. Scoring rules for metrics

2.4 Energy indices for demand sub-system

Fig. 4 shows the structure for evaluation of the energy demand sub-system. Five main sectors of the economy are evaluated for SES in four dimensions. The residential sector is further sub-divided into rural and urban sub-components. Scores obtained by various metrics are evaluated and weights are allotted based on a survey of respondents. The share of final energy consumed by various sectors, $sh_{S(p)}$, is used for various components and the share of rural and urban population, sh_{RUR}, sh_{URB}, is used at sub-component level.

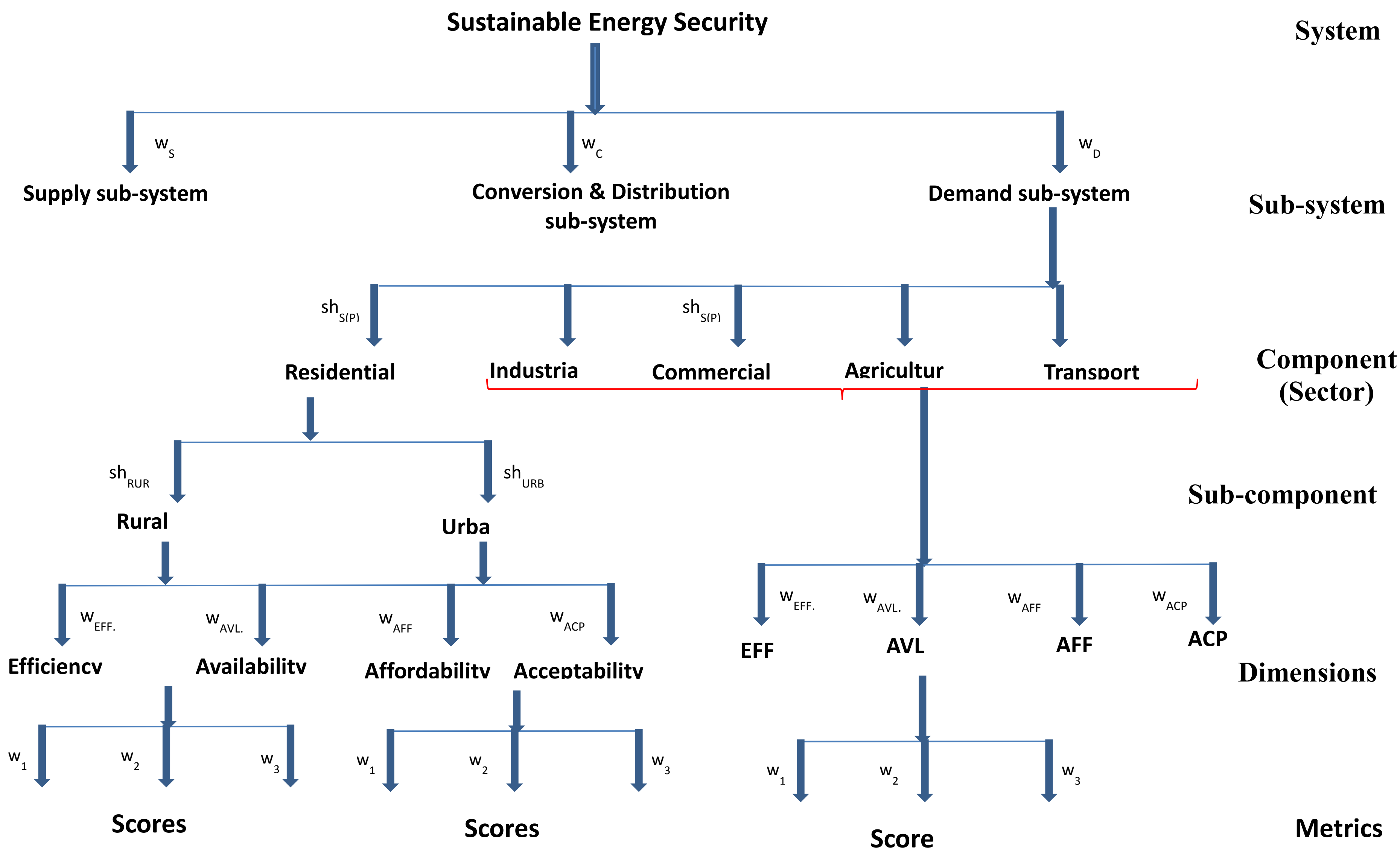

Fig. 4. Assessment of SES for energy demand sub-system

3. METRICS

Different metrics are chosen to represent different dimensions of SES. The selected metrics, grouped under categories, sub-categories and dimensions along with the variables and units for the demand sub-system are given at Appendix A.

3.1 Selected metrics

For the case of residential sector, 'availability' dimension captures energy 'adequacy' as well as 'access' to clean energy for both lighting and cooking/heating. Although oil products are available, there is very high dependence on fossil fuels for the transport sector. This is a cause of concern for SES as there are limited alternatives for shifting to non-fossil fuels in this sector. Hence, metric for the transport sector attempts to capture the dependence of the sector on fossil fuels. For the remaining sectors such as commercial and agriculture, the availability dimension is represented by adequate supply of electricity.

'Affordability' is a function of retail prices of energy and the paying ability of a household. Metrics for the 'Affordability' dimension are selected to capture the distortion in retail price of different fuels. Price distortion occurs due to the difference between the actual cost and the retail price of fuel due to taxes and subsidies. Taxes are a source of revenue for the government[6]. Subsidies, though well intended, are often untargeted as they are generally implemented across the board and are a drain on the public exchequer. Therefore, large untargeted subsides increase price distortion and are an impediment for attaining SES. The 'weighted sum of price distortion score due to subsidy' has been used as a metric for the 'Affordability' dimension. As different fuels are used for providing an energy service, the price distortion score is weighted by the share of fuel used in the sector and the weighted sum reflects the price distortion score for the sector. Affordability is also a function of the paying ability of a household and the 'share of expenditure on fuel and light in the total household expenditure' is used as a metric for the residential sector.

Sectoral emission intensity is used as a metric for 'Acceptability' dimension. CO_2 emission intensity is selected as the metric for all sectors. Lower emission intensity implies lower CO_2 emissions per unit of value added and therefore contributes to a higher SES index.

[6]While the amount of taxes levied are debatable, its quantity is not questioned in this study.

SES can be achieved only if energy demand is kept under control; however it is also important that essential energy demand is met. Both these objectives can be attained by having lower energy intensity[7]. 'Energy Intensity' has also been used as an indicator for 'essential energy demand needs' in the S/D (Supply/Demand) Index proposed by Scheppers et. al.[8]. 'Monetary Energy Intensity' is selected as a metric for the Efficiency dimension for all sectors[9], except for residential sector. Improvement in energy intensity has a cascading impact on attaining SES as it results in lowering of final energy consumption, which in turn leads to an overall reduction in emissions and lowers the total expenditure on energy. Lower energy intensity therefore contributes to a higher SES index.

3.2 Selecting targets for metrics

Selection of targets is based on the principles of SES which is briefly discussed for 'Acceptability' and 'Efficiency' dimension here and further discussed in detail for each metric in section 4.

One of the key principles of SES is that demand for energy has to be kept under control and this aspect is incorporated in the selection of targets or desirable values. There are declared as 'global targets' such as doubling the global rate of improvement in energy efficiency by 2030, adopted by Sustainable Energy for All (SE4ALL) initiative[10]; 'regional targets' such as EU wide headline targets of 20% improvement in energy efficiency by 2020[11] (these have been further disaggregated into country wide indicative targets of absolute levels of primary and final energy consumption in 2020 for EU countries); and 'country targets' such as those announced by

[7] There is a pyramid of Energy Intensity (EI) metrics which can be used. A 'top down' approach is suitable at the economy wide and sectoral level and can be used for calculating aggregated EI indicators. A 'bottom up' approach is based on detailed segregated data such as process efficiencies and specific energy consumption. Although the bottom up approach is more rigorous and gives clear understanding of energy use in the economy, a top down approach may be sufficient for a country wide perspective (Sathaye, 2010).

[8] The S/D Index uses different 'benchmark values' and 'scoring rules'. The average values of top five performing EU countries (or top two, after removing outliers) have been chosen as the benchmark values. A set of scoring rules which compares the energy intensity of various sectors to this benchmark value has then been defined to calculate the S/D Index.

[9] The 'overall energy intensity' which is the ratio of aggregate energy use to GDP, is not an ideal indicator of energy efficiency or sustainability of energy use as it depends on the structure of the economy. Sectoral energy intensity is a better indicator as it is specific to a sector, but it has its own limitations.

[10] http://www.se4all.org/our-vision/our-objectives/

[11] New energy efficiency targets have been declared for 2030. While the European Commission had proposed a target of 30%, EU countries agreed on a target of atleast 27% by 2030 at an EU summit in Oct 2014. http://ec.europa.eu/energy/en/topics/energy-efficiency

China[12] (6% reduction in the overall energy intensity, as a goal of its 12th five year plan from 2011-2015).

In case of India, there are no country wide goals for reduction of energy intensity. However the National Mission on Energy Efficiency (NMEE) aims to lower the energy intensity of high energy consuming sectors. Under the aegis of this mission, the Perform, Achieve and Trade (PAT) scheme has adopted energy saving targets for 477 Designated Consumers (DCs) in eight[13] industrial sectors under the first PAT cycle (2012-15). Targets for energy savings are determined based on the Specific Energy Consumption (SEC) for different sectors. Since, the baseline studies revealed a wide bandwidth of SEC within an industrial sector (due to non-homogeneity in production processes, technologies and vintage), a single benchmark SEC for the sector was not defined and SEC improvement norms were set for individual plants[14]. As an example, the SEC for the iron and steel industry was targeted to be reduced by an average of 4.8% (in the range of 3.04% to 8.51% for different plants). Hence, while there are targets for a few of the industrial consumers at plant level, there are no targets for reduction of overall energy intensity for India.

In the case of emission intensity, India has voluntarily agreed to adopt the Copenhagen Accord target of reduction of the overall CO_2 emission intensity by 25%, relative to 2005 levels, by 2020. While this provides an overarching target, the contribution from various sectors has not been identified.

Under these circumstances where targets have not been defined by the governments, this study selects targets based on the key principles of SES. It is to be noted that selection of targets has some subjectivity and can be questioned. However, the rationale for selection of the target is clearly explained and the selected values (which are specific to the country under analysis) have been justified. Notwithstanding the chosen values, different targets can be selected by other users and an index can be calculated by applying this framework.

[12] http://www.c2es.org/international/key-country-policies/china/energy-climate-goals-twelfth-five-year-plan#_edn1

[13] Thermal Power Plants, Fertilizer, Cement, Pulp and Paper, Textiles, Chlor-Alkali, Iron & Steel, and Aluminum

[14] Each DC is mandated to reduce its SEC by a certain value, based on its current SEC (or baseline SEC) within the SEC bandwidth for the sector.

4. SCORING MATRIX FOR VARIOUS SECTORS

The scoring matrices for five sectors are derived in this section. Scores are calculated from the raw value of the selected metric and the scoring rules which become the elements of the scoring matrix.

4.1 Residential sector

Energy is used in the residential sector primarily for meeting cooking and lighting services. Developing countries such as India, suffer from inadequate supply and lack of access to clean energy. Hence ‘Adequacy’ and ‘Access’ for lighting and cooking are the two categories under which metrics are selected for ‘Availability’ dimension.

Electricity is a clean form of energy (as compared to kerosene) for lighting and it is also used for providing other services such as cooling, heating, entertainment etc. Hence adequate supply of electricity for the residential sector is necessary for attaining SES. ‘Average per capita electricity consumption per year’ (R1) is selected as a metric for Availability dimension. The average per capita electricity consumption for households varies widely across countries. Table 1 shows India’s consumption, the world average consumption, and the countries having minimum and maximum consumption for different years.

Table 1: Average annual per capita electricity consumption for residential sector

Year	2002[15]	2007	2012[16]
	kWh/capita/yr		
India	74	108	139
World average	588	686	726
Max value	-	8351	8513
Country	-	Kuwait	Kuwait
Min value	-	14	19
Country	-	Ethiopia	Ethiopia

Source: World Energy Council, 2015

Average annual per capita electricity consumption[17] for the residential sector shows a large variation as the size of houses, ownership of appliances, habits, income levels and weather

[15] Data for 2000 is used instead of 2002
[16] Data for 2011 is used. As per the updated data, the value for India for 2013 was 0.41 and the world average was 0.28. The updated data set is however different from the earlier data set and cannot be compared directly.

conditions vary across the world[18]. Therefore a suitable target has to be selected for the specific country. Planning Commission, 2006 recommends a lifeline electricity supply of 1kWh/day/household (365 kWh per household per year or 73 kWh/capita/yr) while WEO, 2012 suggests a baseline of 250 kWh/household/year (50 kWh/capita/yr) for rural and 500 kWh/household/year (100 kWh/capita/yr) for urban consumers for energy access. WEO recognizes that electricity consumption will grow as households are electrified and adopts a baseline of 750 kWh/household/yr (150 kWh/capita/yr) by 2030. De la Rue du Can et.al., 2009 estimated that approximately 420 kWh/household/yr was used in 2000 by an average Indian household (908 kWh/household/yr for urban; 224 kWh/household/yr for rural areas). The study also estimated that the average urban Indian household will consume 2972 kWh/household/yr (approximately 595 kWh/cap/yr), while the consumption in rural household will rise to 1311 kWh/household/yr (approximately 262 kWh/cap/yr) in 2020.

As electricity consumption differs widely, different target values are taken for rural and urban areas. Using an average value also accommodates the large variation[19] across households having different incomes. A target of 600 kWh/capita/yr and 260 kWh/capita/yr has been selected for the Indian urban and rural household, respectively. While this choice of targets is inspired by the LBNL study, a bottom up analysis of energy consumed by lighting and other appliances used in a household also yields results in the same range. While there are higher forecasts[20] of electricity consumption by other studies, a lower target is selected following the principle of SES that the demand of energy has to be kept under control.

Cooking needs are met by different fuels which are used in varying quantities amongst rural and urban households. Households in rural areas consumed between 300-500 MJ/capita/month, while those in urban areas consumed between 275-450 MJ/capita/month in 2009-10 (Patil and Chattopadhyay, 2013). This demand was met by various fuels and the 'energy ladder' concept was validated as households used more convenient and cleaner fuels with

[17] All calculations are based on an average of 5 members per household

[18] While the average all India electricity consumption in electrified households for 2009 in India was 96 kWh/capita/yr for rural areas, it was 288 kWh/cap/yr for urban areas (NSSO, 2012b). This is in the same range as that reported by international agencies.

[19] As reported by various household level surveys, use of electricity in households varies as per the household income (it is reported for different income quintiles) and the level of urbanization. For e.g. the consumption of electricity in urban areas (average for all India) varies between 76.3 to 964.4 kWh/capita/yr for lowest (MCPE 1) to highest (MCPE 12) income groups, while the average of all income deciles is 310 kWh/capita/yr. (NSSO,2014)

[20] The electricity consumption of 731 kWh/cap/yr (3656 kWh/household/yr) was estimated for 2030 by a detailed bottom up analysis undertaken by World Bank in 2008.

increasing income levels. For attaining SES, a country needs to shift from traditional to modern forms of cooking. It is widely accepted that LPG is a clean and convenient fuel for cooking. 'Average per capita LPG consumption per year' (R2) is selected as the metric for cooking adequacy. The Integrated Energy Policy report proposes a transition to LPG for a majority of households and sets a minimum target of 6 kg of LPG per household per month (equates to 14.4 kg/capita/yr). The average LPG consumption in developing countries is 22 kg/capita/yr (OECD, 2011). D'Sa and Murthy, 2004 reported that the average annual use of LPG per connection across India was approximately 115 kg for the year 2003. This equates to 23.00 kg/capita/yr. Although there is a variation[21] between per capita consumption of LPG in rural and urban areas, it is small and is neglected for this study. Based on the above assessment, a target of 24 kg/capita/yr is adopted for R2. A higher value of R2 is preferred as it contributes to higher SES.

'Energy Access' is measured by two metrics, '% of population with access to electricity' (R3) and '% of population using LPG for cooking' (R4). The target value for both R3 and R4 is 100% implying that all households in rural as well as urban India should use electricity for lighting and LPG for cooking. A higher value of R3 and R4 is preferred for higher SES.

Affordability of energy can be measured by the ability of a household to pay for energy. 'Percentage of expenditure on fuel and light by households' (R5) is chosen as a metric to measure the paying ability of the household. While this value varies across income deciles and rural/urban households, the average value of R5 is in the range of 6.5-10.5% for the past 25 years for India (Narula, 2014). A target value of 7% is taken as the average value for R5 for rural as well as urban areas. A lower value of R5 is desirable as it contributes to greater affordability and increases SES.

Price distortion due to subsidies is measured separately for cooking and lighting. The 'weighted sum of price distortion score for cooking' (R6) and 'weighted sum of price distortion score for lighting' (R7) have been selected as other metrics for the 'Affordability' dimension. Amongst the various fuels used for cooking in households, LPG and kerosene are subsidized. Other fuels[22] such as biomass, coal and dung cake are collected free of cost or are purchased at market prices and therefore there is no price distortion due to subsidy in these fuels. The Price Distortion Score (PDS) due to subsidies is calculated by accounting for fiscal subsidies as well as

[21] The aggregate annual average use of LPG per connection of 115.12 kg is disaggregated into 101.4 kg for rural areas and 119.3 kg for urban areas.
[22] Electricity accounts for a very small share for cooking and hence is not accounted.

under recoveries to Oil Marketing Companies (OMCs) for LPG and kerosene. The actual price is arrived at by adding the subsidy to the retail (sale) price on per unit basis. The Price Distortion Score (PDS) is then calculated using eqn (4) below.

$$PDS = \{\frac{\text{Actual Price – Retail Price}}{\text{Actual Price}}\} \qquad (4)$$

The PDS is in the range of 0 to 1, where 0 represents 0% subsidy i.e. retail price is same as actual price and 1 represents 100% subsidy (when retail price is zero or energy is provided free of cost). The weighted sum of PDS (WSPDS) for cooking (PDS of each energy fuel is multiplied by its share in the final energy mix for cooking) is then calculated using eqn (5).

$$\text{WSPDS}=\sum sh_{C(i)} \text{ x } PDS_{C(i)} \qquad (5)$$

Where, $sh_{C(i)}$ is theshare of fuel (i) used for cooking (LPG, Kerosene, biomass etc.) in residential sector, and $PDS_{C(i)}$ is Price Distortion Score for the corresponding type of fuel (i)

Eqn (6) is used to calculate R6. The value of R6 is 1 when there is no subsidy for any type of fuel (i) used for cooking and will be between 0 and 1 for all other cases.

$$R6 = 1 – \text{Abs (WSPDS)} \qquad (6)$$

Similarly, the 'weighted sum of price distortion score for lighting' (R7) is calculated. There are two main sources of lighting: kerosene and electricity, both of which are subsidized and their PDS is calculated using eqn (4). In the case of electricity, the (all India) average generation cost for electricity is used as the 'actual price' and the average electricity tariff to the sector is used as the 'retail price'. The price of electricity is different for different sectors as electricity is cross-subsidized in India. The range of PDS for electricity is between -1 to 0 for industrial and commercial consumers as the retail price of electricity is higher than the actual price and is between 0 to 1, for residential and agricultural consumers, as the electricity is subsidized for these sectors. The weighted sum of PDS (WSPDS) for lighting and value of R7 is calculated using eqns similar to (5)–(6).

Untargeted fossil fuel subsidies encourage wasteful consumption and are unsustainable as they stress fiscal budgets in a constrained macroeconomic environment (Dasgupta, 2013). Therefore the target should be to eliminate subsidies[23] and cross subsidies and to pass on the actual cost of fuel to a majority of consumers as it might help reduce the wasteful consumption

[23]IEA's estimates indicate that fossil-fuel consumption subsidies worldwide amounted to $548 billion in 2013, with subsidies to oil products representing over half of the total. Those subsidies were over four-times the value of subsidies to renewable energy and more than four times the amount invested globally in improving energy efficiency. http://www.worldenergyoutlook.org/resources/energysubsidies/

of fossil fuels. Phasing out inefficient fossil fuel subsides and its rationalization has been recommended by the leaders of the 20 major economies of the world (G20 Leaders' Declaration, 2012) and a gradual phase-out of subsidies has been recommended for India (IISD, 2012). It is rightly argued that elimination of fossil fuel subsidies enhances energy security, reduces emission of GHG and brings immediate economic gains (Dasgupta, 2013). IEA, 2013 also highlights the role of (partial) phase-out fossil fuel subsidies in keeping the '2 °C target alive' in climate change negotiations. Hence the target value for both R6 and R7 is taken as 1, which implies no distortion in price due to subsidies and a higher value (close to 1), would help in increasing the SES of a country.

'Annual CO_2 emissions per household' (R8) is selected as the metric for Acceptability. Table 2 shows the average annual CO_2 emissions per household for the world, India and the countries having minimum and maximum values for different years.

Table 2: AnnualCO_2 emissions (tCO_2/household/yr) from residential sector

	2002	2007	2012[24]
India	0.33	0.35	0.30
World Avg	1.12	1.06	0.99
Max value	-	6.26	5.21
Country		Iran	Iran
Min value	-	0.05	0.03
Country		Ethiopia	Congo DR

Source: World Energy Council, 2015

India had voluntarily agreed to cut its carbon intensity by 25% below 2005 levels by 2020 in the run up to Copenhagen meet in 2009. If this commitment is applied uniformly across all sectors, the target for R8 would be 0.255 tons CO_2 per household per year (the value of R8 for 2005 was 0.34 tons CO_2 per household). With this target, the carbon intensity for the residential sector for India will be similar to 2011 levels for countries like Brazil (0.28) and Indonesia (0.27)

[24] Data is for the year 2011

which were ranked within the top 20 countries. A lower value of R8 is desirable which implies that there are lower emissions from households[25].

Three metrics are selected to represent the 'Efficiency' dimension for the residential sector. End use efficiency for lighting can be measured by 'average lighting efficacy' (R9), end use efficiency for cooking can be measured by 'average cook stove efficiency' (R10) and appliance efficiency can be represented by the 'weighted sum of appliance efficiency score' (R11). Eqns (7), (8) and (9) are used to calculate the value of R9, R10 and R11 respectively.

$$R9 = \sum sh_{F(i),L} \text{ x } EFC_{F(i),L} \quad (7)$$

$$R10 = \sum sh_{F(i),C} \text{ x } EFF_{F(i),C} \quad (8)$$

$$R11 = \sum sh_{A} \text{ x } AES \quad (9)$$

Where,

$sh_{F(i),L}$ is theshare of type of fuel F(i) used for lighting,

$sh_{F(i),C}$ is theshare of type of fuel F(i) used for cooking,

$sh_{A}$is theshare of appliances using electricity in the household,

$EFC_{F(i),L}$ is the average efficacy of different lighting devices using F(i)

$EFF_{F(i),C}$is the average efficiency of different cook stoves using F(i)

AES is the Appliance Efficiency Score

There are different kinds of end use devices for converting electricity to light such as incandescent bulbs, Compact Florescent Lamps (CFL) and LED bulbs and kerosene lamps are also used for lighting. Eqn (7) can be written in an expanded form as Eqn (10)

$$R9 = sh_{Electricity, L} \text{ x (Average Efficacy)}_{bulb} + sh_{Kerosene, L} \text{ x (Average Efficacy)}_{Kerosene\ lamp} \quad (10)$$

The efficacy of an incandescent bulb of 60-100 W is 14.5-17.5 lumen/watt and a LED bulb has an efficacy of 40-100 lumen/watt. While a bottom up aggregation (which takes into account the share of CFL, LED, tube light, etc. used in the residential sector), should be used for an accurate assessment, the data in this disaggregated form is not available and a value of 15 lumen/watt is used as the average efficacy for lighting provided by electric bulbs. The average

[25] Low emissions may result from low energy use or from use of cleaner sources of energy in the household. The share of different types of energy sources and their quantities consumed can together explain the low value of R8.

efficacy of a kerosene lamp[26] is taken as 0.15 lumen/watt. It is desirable that all residential consumers shift to electricity as the primary energy source for lighting which is also evident in selection of target for R3. If all consumers use the most efficient LED bulbs (100 lumen/watt), the value of R9 will be 100. However, such a shift will be extremely expensive and is not feasible as there will always be a mix of different bulbs which will be used by households. To account for this mix, a target of 30 lumen/watt is taken as the desirable value for R9. Such a target implies that if only incandescent and LED bulbs are used for lighting then the share of LED bulbs may be 33% (assuming an average of 60 lumen/watt) and the share of incandescent bulbs may be 66% (assuming an average of 15 lumen/watt).

R10 can be calculated using Eq. (8). The average efficiency of different cook stoves using fuel F(i) is multiplied by the share of type of fuel used for cooking. The average efficiency of an LPG stove is 60% and it is selected as the target for R10. A higher value of R10 implies higher SES.

R11 can be calculated using Eq. (9) where AES is Appliance Efficiency Score. Four main types of appliances[27] are taken for analysis in the residential sector: TV, Refrigerator, Fan and air conditioner. Air coolers, water heaters and other appliances such as microwave ovens, computers etc. contribute to a small share of electricity consumed and are hence not included in the analysis.

AES is calculated using Eqs. (2) - (3), where value (x) is the efficiency level of the appliance (different appliances have different units for measuring efficiency) and target (x) is the efficiency level which is adopted from the Super-efficient Appliances (SEA)[28] program. The target levels for different appliances[29] are as follows. TV: 36 watts; Refrigerator: 128 kWh/yr; Fan: 35 watts and AC: 4.9 EER[30]. A higher value for EER for AC indicates higher efficiency and

[26] A normal kerosene wick lantern delivers 975-1560 lumen hr/lit kerosene. An average of 1500 lumhr/lit kerosene = 1500*60*60/36.6MJ, equals 0.15 lumen-sec/J (where, 36.6 MJ is the energy content in 1 lt of kerosene) and equals 0.15 lumen/watt

[27] Lighting appliances such as bulbs and tube lights are not included

[28] The Superefficient Equipment and Appliance Deployment (SEAD) Initiative was launched within the Clean Energy Ministerial (CEM)'s Global Energy Efficiency Challenge in July 2010. SEAD, a task within the International Partnership for Energy Efficiency Cooperation (IPEEC), attempts to tap potential energy savings by accelerating market transformation of energy-efficient equipment and appliances. http://www.ipeec.org/SEAD.html

[29] The 5 Star rating (India) was given to various appliances for 2010 at the following levels. TV: 62 watts; Refrigerator: 411 kWh/yr; Fan: 51 watts and AC: 3.1 EER.

[30] The Energy Efficiency Ratio (EER) for an AC is the ratio of the cooling capacity to the power input and it is a dimensionless quantity. For example, if a 1 TR (3500 W) AC consumes 1000 watts, then the EER of the Air conditioners is 3.5 W/W. A higher ratio implies higher cooling at lower power and hence higher efficiency.

is desirable (AES will be calculated using Eq. 3) and a lower values is desirable for all other appliances (AES will be calculated using Eq. 2). The obtained values of AES will be in the range of (0-1) and when multiplied by the share of appliances, it will give a weighted sum of AES, or the average appliance efficiency (R11). The target value of AES has been selected as 1, which implies that the most energy efficient (technically feasible) appliances are used. The summary of selected targets and the desired values for higher SES for the residential sector is shown in Table 3.

Table 3: Selected targets and desired values for residential sector

Metric	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
Target Values	260 (R) 600 (U)	24	100	100	7	1	1	0.255	30	60	1
Desired Values	High	High	High	High	Low	High	High	Low	High	High	High

4.2 Industrial sector

The selected targets for the industrial sector are summarized in Table 4.The metric for the ‘Availability’ dimension is ‘number of hours of electricity in a day’ (I1). This value varies across different states of India and reliable data is not available for I1. Hence this value is estimated using data from specific studies. The target for I1 is 24 hours which implies that electricity should be available for 24 hours in a day and the performance of SES for this sector is evaluated against this target. Higher value of I1 leads to higher SES.

Table 4: Selected targets and desired values for residential sector

Metric	I1	I2	I3	I4
Target Values	24	1	0.12	0.05
Desired Values	High	High	Low	Low

Metric I2 is calculated for the sector in a similar manner as that of the residential sector. The target value for I2 is 1, which implies that there should be no distortion in energy prices due to subsidies. A high value of I2 (closer to 1) is desirable for attaining SES.

Table 5: CO_2 intensity ($kgCO_2/\$05_p$) of industrial sector

Year	2002	2007	2012[31]
India	0.48	0.46	0.51
World average	0.36	0.34	0.33
Max value	-	0.99	0.69
Country	-	Ukraine	Ukraine
Min value	-	0.02	0.02
Country	-	Chad	Chad

Source: World Energy Council, 2015

Table 5 shows the values of metric I3 for India, world average and the maximum and minimum values. India's CO_2 emission intensity for the industrial sector is higher than the world average which implies that there is a scope for de-carbonisation of the sector which is heavily dependent on coal. If the 25% reduction in emission intensity (from 2005 levels) is applied to this sector, it implies a target value of 0.32 $kgCO_2/\$05_p$ (I3 in 2005 was 0.43 $kgCO_2/\$05_p$). However a target of 0.12 $kgCO_2/\$05_p$ is selected [32] which represents a reduction of approximately 75%, from the current levels. Considering that the emission intensity of Hungary and Philippines was 0.12 $kgCO_2/\$05_p$ in 2011, such a target is considered achievable. It is to be noted that there are other developing countries like Paraguay and Sri Lanka which have even lower emission intensity of 0.03 $kgCO_2/\$05_p$ and 0.05 $kgCO_2/\$05_p$ respectively and therefore the selected target is feasible. A lower value of I3 leads to higher SES.

Table 6 shows the values of metric I4 for India, world average and the countries having maximum and minimum values. India's energy intensity for the industrial sector is higher than the world's average. The selected target for metric I4 is 0.05 $kgoe/\$05_p$ which is also the value for Switzerland (2011) and Hong Kong (2011). These countries are in the list of top ten energy efficient countries and as advanced industrialized economies, set a role model for other countries. Although this target represents a reduction in energy intensity by approximately 70%,

[31] Value for 2011 is used. As per the updated data, the value for India for 2013 was 0.41 and the world average was 0.28. The latest data set is however different from the earlier data set and cannot be compared directly.

[32] Planning commission, 2006 has estimated that in the Baseline Inclusive Growth (BIG) scenario, India's emissions intensity falls from 0.43 kg of CO_2/ \$ GDP $_{2007\text{-}PPP}$, in 2007, to 0.33 kg of CO_2/ \$ GDP $_{2007\text{-}PPP}$ by 2030, a reduction of 22 percent. However, with low carbon policies (Low Carbon, Inclusive Growth (LCIG) scenario), it can be reduced to 0.25 CO_2/ \$ GDP $_{2007\text{-}PPP}$ by 2030, a cumulative reduction of 42 percent.

such a target is achievable by adoption of aggressive energy efficient practices in the Indian industry. A lower value of I4 leads to higher SES.

Table 6: Monetary energy intensity (kgoe/$05p) of industrial sector

Year	2002	2007	2012[33]
India	0.2	0.16	0.17
World average	-	0.14	0.14
Max value	-	0.5	0.37
Country	-	Ukraine	Ukraine
Min value	-	0.002	0.002
Country	-	Libya	Cameroon

Source: World Energy Council, 2015

4.3 Services sector

The selected targets for the services sector are summarized in Table 7.

Table 7: Selected targets and desired values for industrial sector

Metric	S1	S2	S3	S4
Target Values	24	1	0.002	0.006
Desired Values	High	High	Low	Low

S1 is similar to I1 and this value is estimated as exact data is unavailable. The adopted target for S1 is 24 hours and a higher value of S1 is desirable. S2 is calculated in a manner similar to the residential sector and its target is 1, which implies that there should be no distortion in prices of fuel due to subsidies.

Table 8 shows the values of metric S3 for India, average for all countries of the world and the countries having maximum and minimum values. India's CO_2 intensity for the services sector is lower than the world average as the services sector is highly productive. Further, it continues to show a declining trend implying that further improvements are possible. The value for metric S3 in 2005 was 0.011 $kgCO_2/\$05_p$. A 25% reduction in this value implies a target value of 0.008

[33]Value for 2011 is used. As per the updated data, the value for India for 2013 was 0.13 and the world average was 0.12. The latest data set is however different from the earlier data set and cannot be compared directly.

$kgCO_2/\$05_p$. However a target of 0.005 $kgCO_2/\$05_p$ is selected for S3. This target represents a reduction of approximately 55% from 2011 levels and is considered achievable, considering that the emission intensity of one of the best performing country was 0.002 $kgCO_2/\$05_p$ (Brazil, 2011).

Table 8:CO_2 intensity ($kgCO_2/\$05_p$) of services sector

Year	2002	2007	2012[34]
India	0.015	0.010	0.009
World average	0.027	0.023	0.021
Max value	-	0.069	0.089
Country	-	Slovakia	Kazakhstan
Min value	-	0.001	0.002
Country	-	Peru	Brazil

Source: World Energy Council, 2015

Table 9 shows the values of metric S4 for India, world average and the countries having maximum and minimum values. India's energy intensity for the services sector is approximately half as that of the world average. The selected target for metric S4 is 0.006 $kgoe/\$05_p$ which represent a 45% reduction from 2011 levels. Mexico, which is a country in a similar development stage, had the same value in 2011 and it was ranked in top 5 countries of the world.

Table 9: Energy intensity ($kgoe/\$05_p$) of services sector

Year	2002	2007	2012[35]
India	0.016	0.012	0.011
World average	-	0.021	0.02
Max value	-	0.04	0.044
Country	-	Russia	Kazakhstan
Min value	-	0.002	0.003
Country	-	Kenya	Kenya

Source: World Energy Council, 2015

[34] Value for 2011 is used. As per the latest updated data, the value for India for 2013 was 0.007 and the world average was 0.017. The latest data set is however different from the earlier data set and cannot be compared directly.
[35] Value for 2011 is used. As per the latest updated data, the value for India for 2013 was 0.007 and the world average was 0.017. The latest data set is however different from the earlier data set and cannot be compared directly.

4.4 Agriculture sector

The selected targets for the agriculture sector are summarized in Table 10.

Table 10: Selected targets and desires values for agriculture sector

Metric	A1	A2	A3	A4
Tgt Values	100%	1	0.011	0.006
Desired Values	High	High	Low	Low

Energy is primarily used in the agricultural sector for pumping water and tilling land. While tractors and animals are used for tilling, electricity and diesel are used for pumping of water. Electricity is the first choice for users as it is cheaper (and relatively cleaner). However, often there is no electricity connection, electricity is erratic, is provided at odd hours and for a limited time. Therefore the agricultural sector relies on diesel pump sets for irrigation. For attaining SES for the sector, a large portion of the energy demand for pumping applications should be met by electricity. '% share of electrified pump sets' (A1) is therefore used as a measure of adequate supply of energy in the agriculture sector. The target value selected for this metric is 100% which implies that it is desirable that all pump sets are electrified. A2 is calculated for the sector in a similar manner as that of the residential sector. Based on a similar reasoning, its target value is 1 and a high value of A2 is desirable for attaining SES.

Table 11 shows the values of metric A3 for India, world average and the countries having maximum and minimum values. India's CO_2 intensity for the agricultural sector is much lower than the world average and the country already ranks in top five countries of the world. The primary reason is that agriculture in India is dependent on animal and human power, uses little commercial energy and hence has lower emissions. As further large reductions in the sector are not possible, a target value of 0.011 $kgCO_2/\$05_p$ is taken for A3. This was also the value of A3 for India in 1990.

Table 11: CO_2 intensity ($kgCO_2/\$05_p$) of agriculture sector[36]

Year	2002	2007	2012[37]
India	0.025	0.029	0.012
World average	0.116	0.105	0.097
Max value	-	0.680	0.659
Country	-	Denmark	Denmark
Min value	-	0.003	0.006
Country	-	Algeria	Algeria

Source: World Energy Council, 2015

Table 12 shows the values of metric A4 for India, world average and the countries having maximum and minimum values. India's energy intensity for the agriculture sector is approximately half as that of the world average. The selected target for metric A4 is 0.010 kgoe/$\$05_p$ which is also the value for Philippines in 2011 and close to that of Pakistan (0.008 kgoe/$\$05_p$ in 2011). Both countries have similar agricultural practices and the reduction in energy intensity to achieve the target is approximately 45%, which is considered achievable.

Table 12: Energy intensity (kgoe/$\$05_p$) of agriculture sector

Year	2002	2007	2012[38]
India	0.022	0.023	0.018
World average	-	0.046	0.043
Max value	-	0.303	0.302
Country	-	Denmark	Denmark
Min value	-	0.001	0.001
Country	-	Cameroon	Cameroon

Source: World Energy Council, 2015

[36] Value of A2 for 2002 and 2007 was 0.025. However a value of 0.012 was reported for 2011. This drastic fall in value is unexplainable and is therefore attributed to data error. However, the values are used for calculation.

[37] Value for 2011 is used. As per the updated data, the value for India for 2013 was 0.041 and the world average was 0.088. The latest data set is however significantly different from the earlier data set and cannot be compared.

[38] Value for 2011 is used. As per the updated data, the value for India for 2013 was 0.032 and the world average was 0.039. The latest data set is however different from the earlier data set and cannot be compared directly.

4.5 Transport Sector

The selected targets for the transport sector are shown in Table 13.

Table 13: Selected targets for agriculture sector

Metric	T1	T2	T3	T4
Tgt Values	90	1	0.02	0.014
Desired Values	Low	High	Low	Low

The percentage share of fossil fuel used for transportation' (T1) is chosen as the metric of availability for the transport sector. A low value of T1 is desirable as it indicates that other energy sources[39] are also used in the sector. EU has a target of reducing the % share of liquid fuel in transport sector to 90% by 2020 and this is the selected target value for T1[40].

T2 is calculated for the sector in a similar manner as for other sectors and its target value is 1. A high value of T2 is desirable for attaining SES.

Table 14:CO_2 intensity ($kgCO_2/\$05_p$**) of transport sector**

Year	2002	2007	2012[41]
India	0.05	0.04	0.042
World average	0.1	0.09	0.08
Max value	-	0.18	0.19
Country	-	Jordan	Saudi Arabia
Min value	-	0.02	0.02
Country	-	Hong Kong	Hong Kong

Source: World Energy Council, 2015

Table 14 shows the values of metric T3 for India, world average and the maximum and minimum values. India's CO_2 intensity for the transport sector is approximately half of the world average and the country ranks in top ten countries of the world. The primary reason is that there is lower density/ownership of motor vehicles, as compared to the world. Relatively, a larger share of transport is human powered (cycle rickshaws, hand pulled carts, bicycles) and animal

[39]Alternatives to use of oil are electricity, natural gas, coal and biofuels.

[40] The average value of T1 across the world for 2012 was 92.86%. The value of T1 for Brazil was 82%, in 2012 as its transport sector uses biofuels extensively (IEA, 2015).

[41] Value for 2011 is used. As per the updated data, the value for India for 2013 was 0.04 and the world average was 0.07. The latest data set is different from the earlier data set and cannot be compared.

powered (horse carts) leading to low emission intensity. While a reduction of emission intensity by 25%, will lead to a target of 0.03 $kgCO_2/\$05_p$, (T3 was 0.04 $kgCO_2/\$05_p$ for India in 2005), India can be ambitious and can adopt a target of 0.02 $kgCO_2/\$05_p$ which is the lowest emission intensity for the transport sector and is exhibited by Hong Kong.

Table 15: Energy intensity (kgoe/$\$05_p$) of transport sector

Year	2002	2007	2012[42]
India	0.016	0.014	0.015
World average	0.039	0.036	0.034
Max value	-	0.062	0.083
Country	-	Luxembourg	Libya
Min value	-	0.003	0.003
Country	-	Chad	Chad

Source: World Energy Council, 2015

Table 15 shows the values of metric T4 for India, world average and the maximum and minimum values. India's energy intensity for the transport sector is less than half as that of the world average. The selected target for metric T4 is 0.014 kgoe/$\$05_p$. This value is chosen as it is forecasted that demand for motorized transport will grow in India due to large scale urbanization and the value of T4 is likely to increase. A lower value of T4 is desirable as it leads to higher SES.

5. CALCULATION OF SCORES

The actual values of selected metrics for different years are collated from various data sources, and the scores are calculated for each sector according to the adopted methodology. The values and the corresponding scores are presented in this section and detailed calculations for some metrics are shown at Appendix B. The scores for various metrics have been calculated and are shown in Table 16. The scoring matrices can be filled using these scores and can be further used for the calculation of various indices.

[42] Value for 2011 is used. As per the latest updated data, the value for India for 2013 was 0.013 and the world average was 0.029. The latest data set is however different from the earlier data set and cannot be compared directly.

Table 16: Actual values and scores for various dimensions

Dimension	Sub-component	Metric	Target	Unit	Value			Score		
					2002	2007	2012	2002	2007	2012
Residential Sector										
Availability	Rural	R1	260	kWh/cap/yr	84.6	84.6	107.08	0.16	0.16	0.26
		R2	24	Kg/cap/yr	2.88	2.88	4.55	0.00	0.00	0.00
		R3	100	%	43.5	60.2	55.3	0.29	0.50	0.44
		R4	100	%	5.7	9.1	11.4	0.00	0.00	0.00
	Urban	R1	600	kWh/cap/yr	267.84	267.84	310.05	0.31	0.31	0.40
		R2	24	Kg/cap/yr	21.72	21.72	23.11	0.88	0.88	0.95
		R3	100	%	87.6	93.8	92.7	0.85	0.92	0.91
		R4	100	%	48	61.8	65	0.35	0.52	0.56
Affordability	Rural	R5	7	%	8.80	9.72	9.24	0.45	0.90	0.92
		R6	1	-	0.98	0.96	0.94	0.98	0.96	0.94
		R7	1	-	0.62	0.49	0.52	0.62	0.49	0.52
	Urban	R5	7	%	8.94	8.54	7.6	0.93	0.95	0.98
		R6	1	-	0.78	0.68	0.65	0.78	0.68	0.65
		R7	1	-	0.57	0.58	0.63	0.57	0.58	0.63
Acceptability		R8	0.255	tCO_2/household/yr	0.33	0.35	0.30	0.93	0.91	0.96
Efficiency	Rural	R9	30	lm/W	6.62	9.09	8.36	0.03	0.13	0.10
		R10	60%	%	0.18	0.21	0.20	0.12	0.18	0.18
		R11	1	-	0.23	0.34	0.46	0.23	0.34	0.46
	Urban	R9	30	lm/W	13.16	14.08	13.92	0.30	0.34	0.33
		R10	60%	%	42.02%	48.01%	48.18%	0.63	0.75	0.75
		R11	1	-	0.23	0.34	0.46	0.23	0.34	0.46
Industry Sector										
Availability	NA	I1	24	hr.	22.6	22.2	22.4	0.93	0.91	0.92
Affordability		I2	1	-	0.99	0.98	0.98	0.99	0.98	0.98
Acceptability		I3	0.12	kCO2/$05p	0.48	0.46	0.51	0.25	0.29	0.19

Efficiency		I4	0.05	koe/$05p	0.2	0.16	0.17	0.25	0.45	0.40
Services Sector										
Availability	**NA**	S1	24	hrs.	23.9	23.9	23.9	1.00	0.99	0.99
Affordability		S2	1	-	0.95	0.93	0.95	0.95	0.93	0.95
Acceptability		S3	0.005	kCO2/$05p	0.015	0.01	0.009	0.50	0.75	0.80
Efficiency		S4	0.009	koe/$05p	0.016	0.012	0.011	0.81	0.92	0.94
Agriculture Sector										
Availability	**NA**	A1	100	%	75[43]	79	83	0.69	0.74	0.79
Affordability		A2	1	-	0.58	0.54	0.60	0.58	0.54	0.60
Acceptability		A3	0.011	kCO2/$05p	0.025	0.029	0.029	0.68	0.59	0.59
Efficiency		A4	0.006	koe/$05p	0.022	0.023	0.018	0.33	0.29	0.50
Transport Sector										
Availability	**NA**	T1	82	%	96.07	96.02	95.78	0.96	0.96	0.96
Affordability		T2	1	-	0.99	0.87	0.87	0.99	0.87	0.87
Acceptability		T3	0.02	kCO2/$05p	0.05	0.04	0.042	0.63	0.75	0.73
Efficiency		T4	0.014	koe/$05p	0.016	0.014	0.015	0.96	1.00	0.98

Source: R1, R2: Values for R1 and R2 for 2002 are not available. Hence values for 2007 are used. 2007 (NSSO, 2010); 2012 (NSSO, 2014); R3, R4: 2002 (Census of India 2001, 2001); 2007 (data of NSS 64 Round (July 07- June 08) retrieved from TEDDY, 2010); 2011 (Census of India 2011, 2011); R8:World Energy Council, 2015; R9,10,11: Calculations shown in Appendix B
I1 and I2: Calculations shown in Appendix B; I3 and I4: World Energy Council, 2015
S1 and S2: Calculations shown in Appendix B; I3 and I4: World Energy Council, 2015
A2: Calculations shown in Appendix B; A3 and A4: World Energy Council, 2015
T1: IEA, 2015; T2: Calculations shown in Appendix B;T3 and T4: World Energy Council, 2015)

[43] Data is not available.

6. STAKEHOLDER RESPONSES AND WEIGHTING MATRIX

The response of seven stakeholders was captured in an interview and weights for different metrics are derived using the methodology presented in section 2.

(a) Weights for different metrics for residential sector:

The (n x n) judgment matrix, [*A*] for availability dimension of the residential sector is shown for the seven respondents at Appendix C. A consolidated matrix, which represents the preferences of all seven stakeholders, is also shown. Each element of the consolidated matrix (b_{ij}) is obtained as a geometric mean of the elements (a_{ij}) of the judgment matrices filled by the seven respondents using Eqn (11).

$$b_{ij} = (a_{1ij} \cdot a_{2ij} \cdots a_{kij})^{\frac{1}{k}}, \qquad (11)$$

where, k = number of respondents.

The iterations for calculation of the normalized principal eigenvector [W] and checking of the consistency of the judgment is shown in Appendix C. Weights are allotted to the metrics (R1-R4) after the consistency is checked and is found within limits. Weights for other metrics for the residential sector and dimensional weights are calculated in a similar way. As respondents have different perceptions of the relative importance of weights, they allocate different values for the pair wise comparison, which results in different normalized principal eigenvector [W]. This diversity in perception of the stakeholders is used to generalize the weights of different metrics across the entire population. The minimum and the maximum weights for different metrics are shown in Table 17 and are further used for undertaking a sensitivity analysis. The consolidated weights which are used to form the weighting matrices for calculation of various indices are also presented.

Table 17: Weights obtained for different metrics for residential sector

Dimension	Metric	Min weight (%)	Max weight (%)	Consolidated Weight (%)
Availability	R1	8	57	28.5
	R2	10	43	23.9
	R3	11	38	22.8
	R4	6	51	24.8
Affordability	R5	33	74	62.1
	R6	11	33	18.8
	R7	9	34	19.1
Acceptability	R8	-	-	100
Efficiency	R9	9	65	24.4
	R10	23	65	47.6
	R11	11	46	27.9

(b) Dimensional weights:

Respondents were also interviewed for evaluating their perceptions on the relative importance of various dimensions. The process for deriving the consolidated dimensional weights is the same as above and the weights obtained for different dimensions are summarized in Table 18. For sectors other than residential, only one metric is used for each dimension and hence each metric is allotted the consolidated dimensional weight.

Table 18: Weights obtained for different dimensions

Dimension	Min weight (%)	Max weight (%)	Consolidated Weight (%)
Availability	10	37	27.4
Affordability	9	57	26.9
Acceptability	9	51	20
Efficiency	11	38	25.6

It was observed that the consolidated weights obtained for different dimensions tend to converge towards equal weights as the number of respondents increases. The consolidated weights are then used to fill the weighting matrix and the range of weights is used for undertaking the sensitivity analysis.

7. RESULTS:

The scoring matrix is multiplied by the weighting matrix to obtain various indices and the calculations for each sector are shown in Appendix D The dimensional indices calculated for different sectors[44] for different years are shown graphically in Figs. 5(a)-(d).

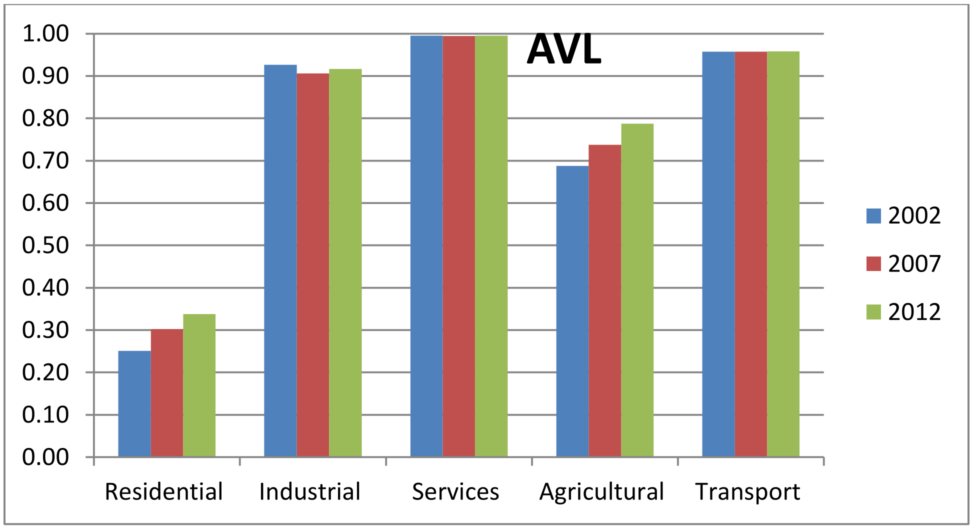

Fig. 5a. Availability Index for various sectors

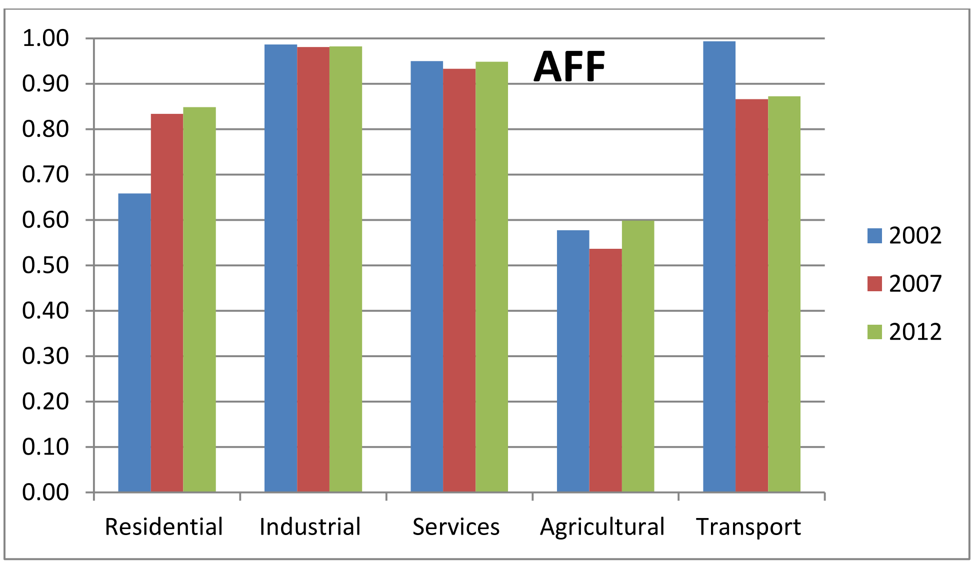

Fig. 5b. Affordability Index for various sectors

[44] The dimensional indices for the residential sector have been aggregated using the dimensional indices of rural and urban areas and the share of rural and urban population.

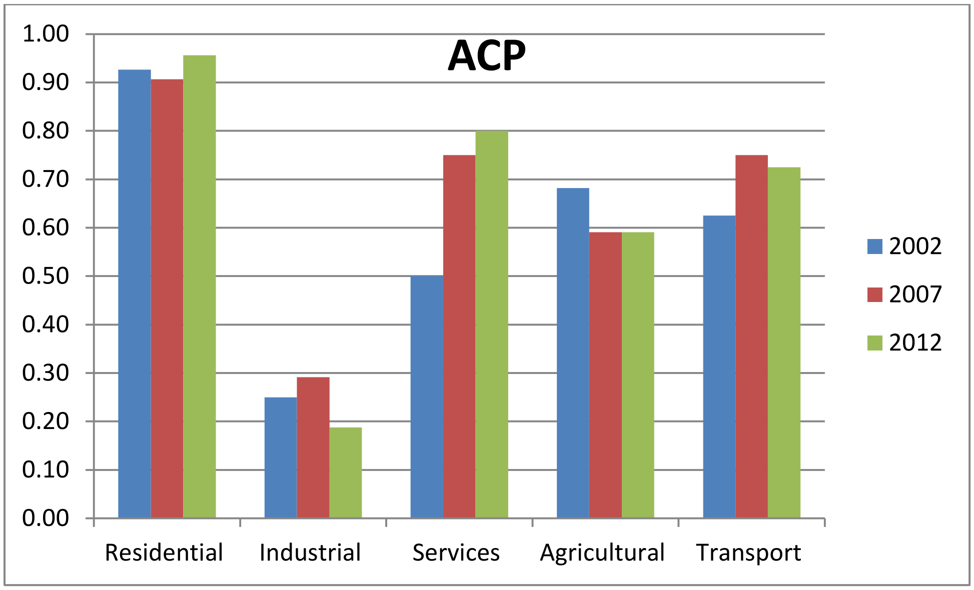

Fig. 5c. Acceptability Index for various sectors

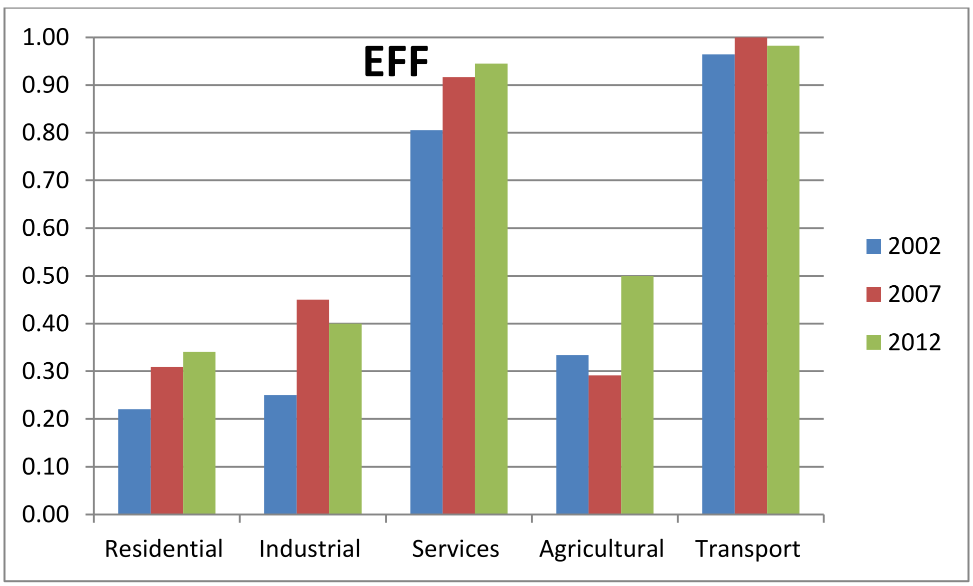

Fig. 5d. Efficiency Index for various sectors

Dimensional indices for different sectors reveal that availability index for residential sector, affordability index for the agricultural sector and acceptability index of the industrial sector is low. Efficiency index of residential, industrial and agricultural sectors also needs large improvements.

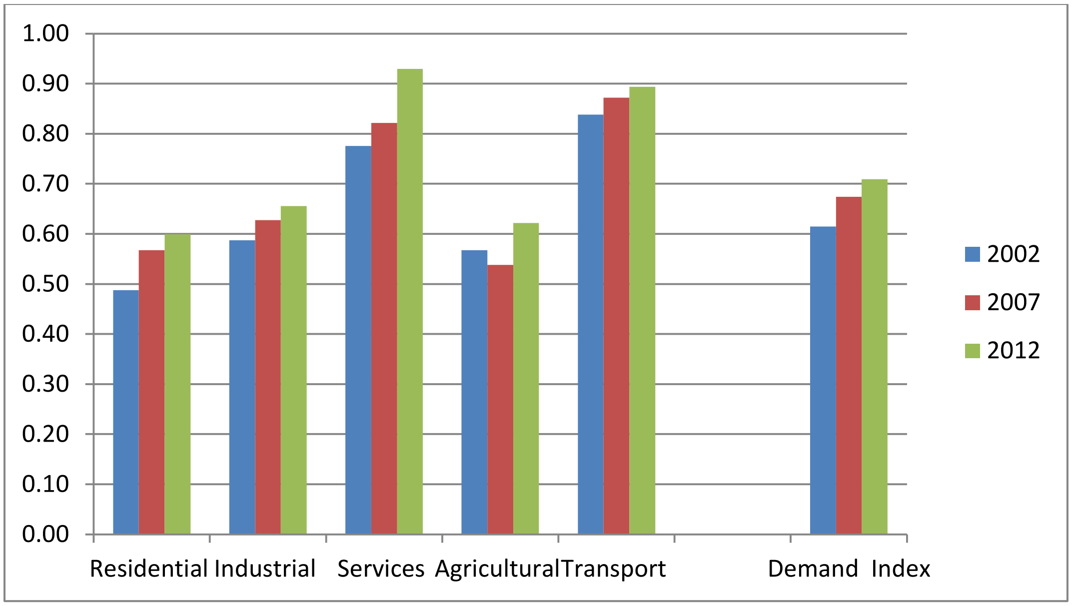

Fig. 6. SES Index for different sectors and demand sub-system SES index

The SES index for different sectors and the demand sub-system SES index is shown in Fig. 6 graphically. Results reveal that the SES Index for the demand sub-system for India has increased by approximately 10% from 2002 to 2012. It is also observed that except a drop in the SES index for agriculture sector from 2002 to 2007 all indices have shown an increase from 2002 to 2007 and from 2007 to 2012. This implies that the performance of the energy demand sub-system is showing a gradual improvement and various policies which have been implemented over the last decade might have led to an increase in SES of the demand sub-system. The demand sub-system SES index is approximately 0.7 which is well short of the desired target of 1.0. This implies that there is still a large scope for improvement in the performance of the India's energy demand sub-system.

8. SENSITIVITY ANALYSIS

8.1 Sensitivity to variation in weights

(a) Sensitivity of dimensional indices

Four metrics are used for the 'Availability' dimension for Residential sector (R1 - R4). 12 scenarios (placed at Appendix E) are created by allotting different weights to these four metrics. Fig. 7a shows the range of weights allotted to metrics R1 to R4 (based on minimum and maximum weights obtained from respondent interview). The range of availability index obtained by multiplying the scores (for rural areas in residential sector for the year 2012) with different weights (as pre-decided for various scenarios) is also shown. The consolidated weights (shown as AVG) and the corresponding availability index are also shown.

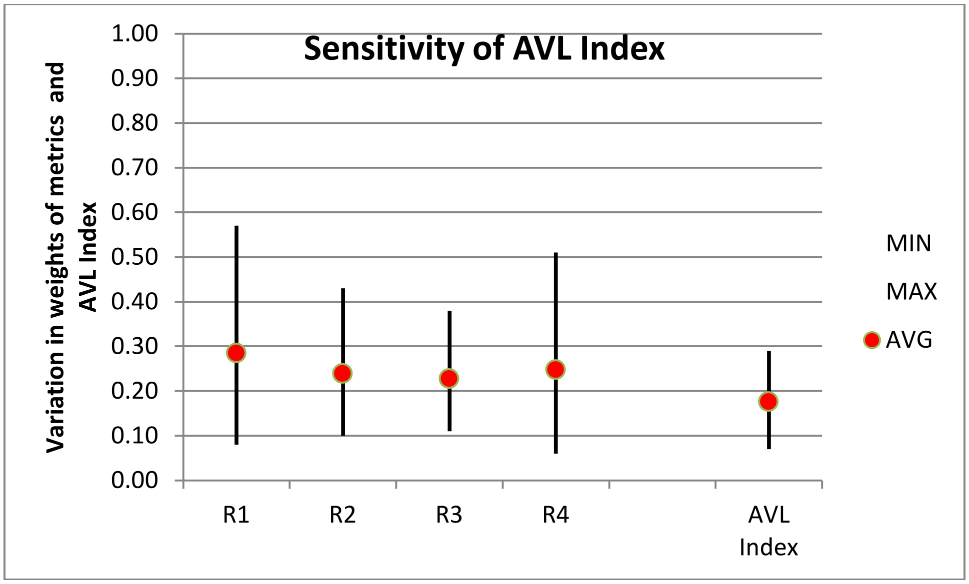

Fig. 7a. Sensitivity of availability index to variation in weights of R1-R4

Three metrics are used for the 'Affordability' dimension for Residential sector (R5-R7) and 'Efficiency' (R9-R11) dimension. Six scenarios (placed at Appendix E) are created by allotting different weights to these metrics. Fig. 7b and 7c shows the range of weights of R5-R7 and R9-R11 and the consolidated weights. The dimensional indices along with its range, obtained by multiplying the scoring matrix with weights for different scenarios are also shown.

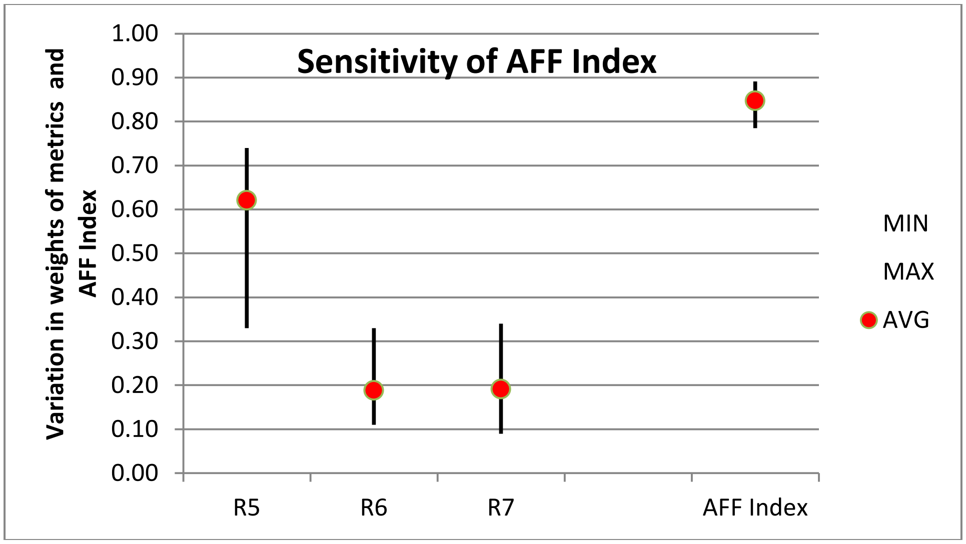

Fig. 7b. Sensitivity of affordability index

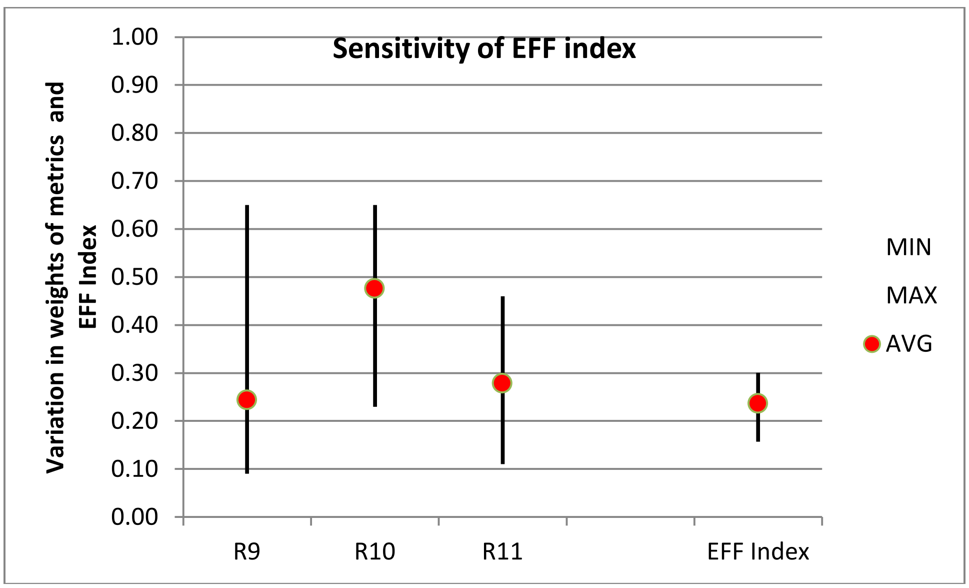

Fig. 7c. Sensitivity of efficiency index

The percentage variation in weights allotted to different metrics by the respondents is shown in fig.8a and the sensitivity of dimensional indices to variation in weights allotted to metrics (based on different scenarios) is shown in fig.8b respectively. The % variation is shown as deviation from the consolidated weights (Fig. 8a) and from the dimensional index obtained from using corresponding consolidated weights (Fig 8b).

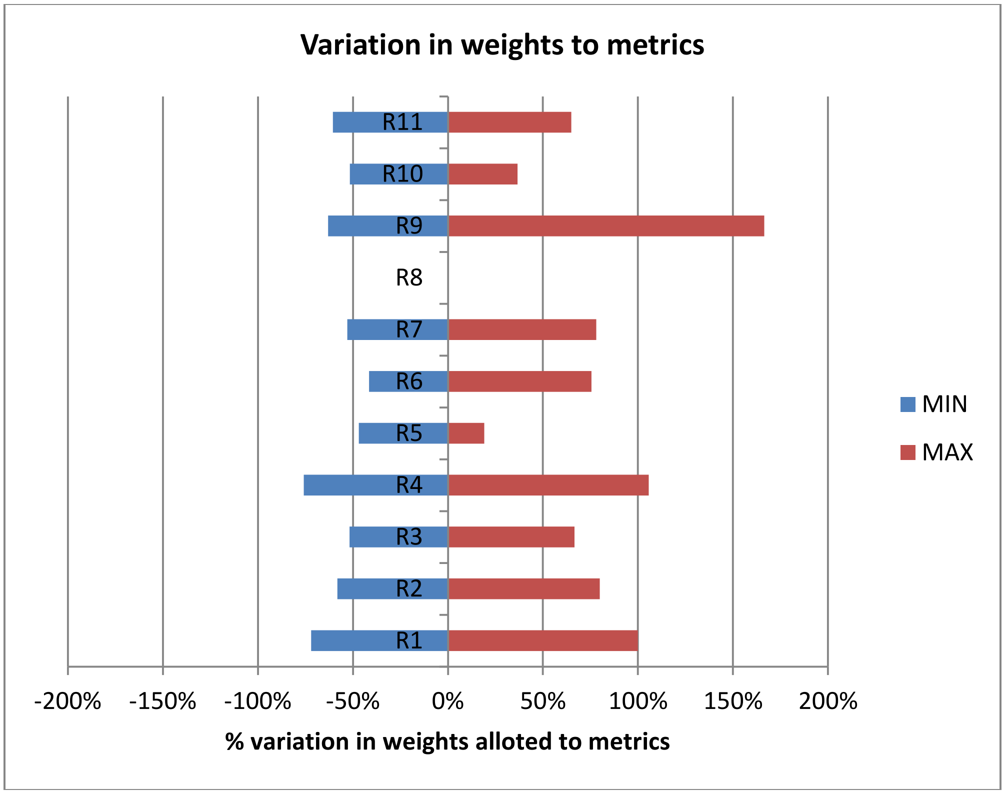

Fig. 8a. Variation in weights allotted to different metrics

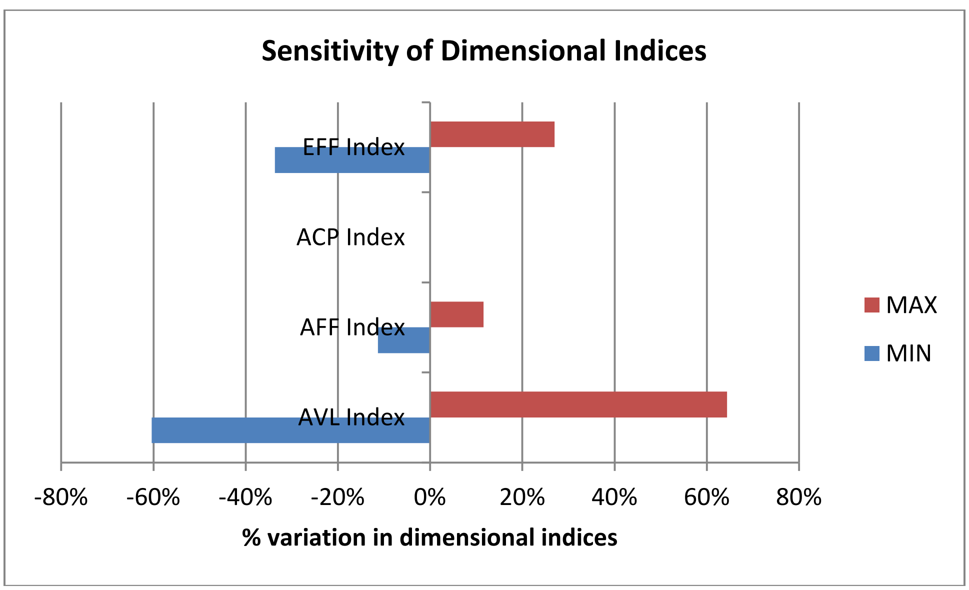

Fig. 8b. Sensitivity of dimensional indices to variation in metric weights

The results of sensitivity to variation in weights can be mathematically analyzed as follows. The set of Eqns. (12) shows the mathematical formulation of Availability Index (AI) for different scenarios (Sc1 –Sc 12) for the residential sector.

AI (Sc1) = $w1S1 + w2\,S2 + w3S3 + (1 - w1 - w2 - w3)S4$

AI (Sc2) = $w1S1 + w2\,S2 + (1 - w1 - w2 - w4)S3 + w4S4$

…..

AI (Sc4) = $w1S1 + (1 - w1 - w3 - w4)S2 + w3S3 + w4S4$

……

……

AI (Sc10) = $(1 - w2 - w3 - w4)S1 + w2S2 + w3S3 + w4S4$

….

(12)

Where

Sc1- Sc 12 are different scenarios;

w1 - w4 are different weights for metrics R1-R4; and

S1 - S4 are scores for metrics R1-R4.

As the sensitivity of AI to weights is to be analysed, a partial derivative of AI w.r.t different weights is undertaken in Eq. set (13).

$$\frac{\partial AI(Sc1)}{\partial w1} = S1 - S4$$

$$\frac{\partial AI(Sc2)}{\partial w1} = S1 - S3$$

$$\frac{\partial AI(Sc4)}{\partial w1} = S1 - S2$$

$$\frac{\partial AI(Sc10)}{\partial w1} = 0$$

(13)

Similarly, partial derivatives of AI w.r.t w2, w3 and w4 will yield (S_x-S_y), where x,y vary between 1-4. Eq (14) shows the calculation of percentage variation of the Availability Index.

$$\%\,variation\,(AI) = \frac{AI\,(Scx) - AI\,(Consolidated)}{AI(Consolidated)} * 100 \quad (14)$$

Where

Sc_x are various scenarios (x=1 to 12);

AI (Sc_x) is the AI calculated for different scenarios; and

AI (Consolidated) is the AI calculated using consolidated weights

$$\%\ variation \propto 1/AI(Consolidated) \qquad (15)$$

Eq. (14) leads to Eq. (15) and it is observed that the percentage variation in AI is inversely proportional to the value of AI obtained by using consolidated weights.

Generalizing the above two inferences, it can be concluded that the sensitivity of the dimensional index to weights is directly proportional to the differential between the scores of the metrics and is inversely proportional to the value of the dimensional index calculated using consolidated weights. Table 19 shows the differential between the scores of metrics used for various dimensions, the dimensional index calculated using consolidated weights and their ratio for three dimensions.

Table 19: Sensitivity analysis of dimensional indices

Dimension	Differential between scores of metrics used for the dimension (S_x-S_y) (1)	Dimensional index using consolidated weights (2)	Ratio (3) = (1)/(2)	Observed sensitivity of dimensional indices (from Fig.8b)
AVL	0.44	0.15	2.93	High
AFF	0.42	0.85	0.49	Low
EFF	0.36	0.25	1.44	Medium

As seen from Table 19 and Fig. 8b, the sensitivity of dimensional indices corresponds to the ratio and confirms the validity of the mathematical interpretation. It can therefore be concluded that while different weights allotted to different metrics will yield different dimensional indices, the dimensional indices are more sensitive to variation in weights if the range of scores for metrics for a particular dimension, is large. Secondly, a lower dimensional index (due to low scores of various metrics) leads to higher sensitivity of the dimensional index. Hence if the country has unbalanced and low scores, the sensitivity of the dimensional index to variation in weights allotted to the metric is high.

(b) Variation in weights of dimensions

The four dimensions and 12 scenarios[45] (provided in Appendix E) are created by allotting different sets of weights to different dimensions. The range of weights and the variation in SES index for the demand sub-system (for the year 2012) are shown in fig. 9.

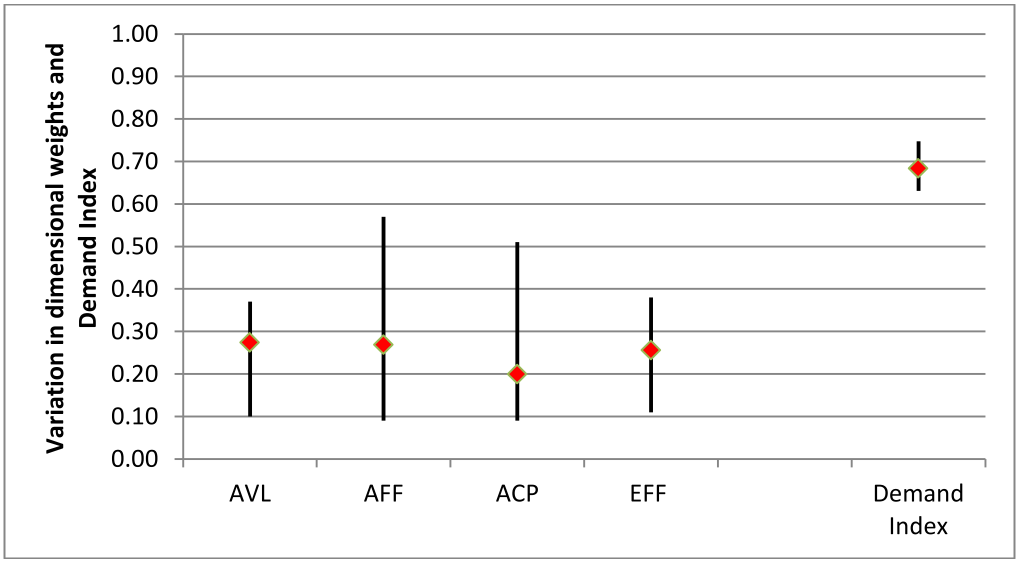

Fig. 9. Variation in dimensional weights and demand index

The results show that despite the large variation in dimensional weights (-67% to +155% from the consolidated weights), the percentage change in the demand index is within +/- 10 percent[46]. This implies that the demand sub-system SES index is relatively[47] robust to variation in weights allotted to different dimensions.

8.2 Sensitivity of SES Index to variation in scoring rules and to threshold values

For the current assessment the scoring rules shown in Eqns. (2) and (3) are used. Suppose the rules are modified as shown in Eqs. (16)-(17):

(a) <u>For metrics where lower values are desirable</u>

If value (x) < = target (x) : $\text{Score} = 1$

If 2* target(x) > value (x) > target (x) : $\text{Score} = \frac{(2*\text{target}-\text{x})}{1*\text{target}})$

[45]Some of the scenarios are not evaluated as the dimensional weights fall beyond the range of weights allotted by the participants.

[46] From the demand index which is obtained when consolidated weights are used

[47] The conclusion obtained in section 8.1 (a) are also valid for this result.

If value (x) > = 2* target(x) : Score = 0 (16)

(b) For metrics where higher values are desirable

If value (x) > = target (x) : Score = 1

If 0.5* target(x) < value (x) < target (x) : Score = $\left(\frac{x-(target/2)}{(\frac{1}{2})*target}\right)$

If value (x) < = 0.5* target(x) : Score = 0 (17)

Comparisons of original and new scores for metrics where the desired values are lower or higher are shown in Table 20 and are graphically plotted in Fig 10.

Table 20: Comparison of scores using different scoring rules

Low values			**High values**		
X (Target)	Org. Score	New Score	X (Target)	Org. Score	New Score
0.5	1	1	0.0	0	0
1.0	1	1	0.2	0	0
1.5	0.875	0.5	0.4	0.25	0
2.0	0.75	0	0.6	0.5	0.2
3.0	0.5	0	0.8	0.75	0.6
5.0	0	0	1	1.0	1.0

It is observed from Table 20 and Fig. 10 that the score obtained for a particular value of x using the new scoring rules is lower than the original score. While this would lower the absolute value of each dimensional index, SES index for the sector and sub-system SES index, this effect will be uniform across all time periods. The scoring rules therefore do not change the results when used for comparison across various years for a particular country. Similarly, a change in the target value for each metric uniformly affects the scores of different metrics across all periods and hence does not dilute the usefulness of the indices for measuring the SES index over time.

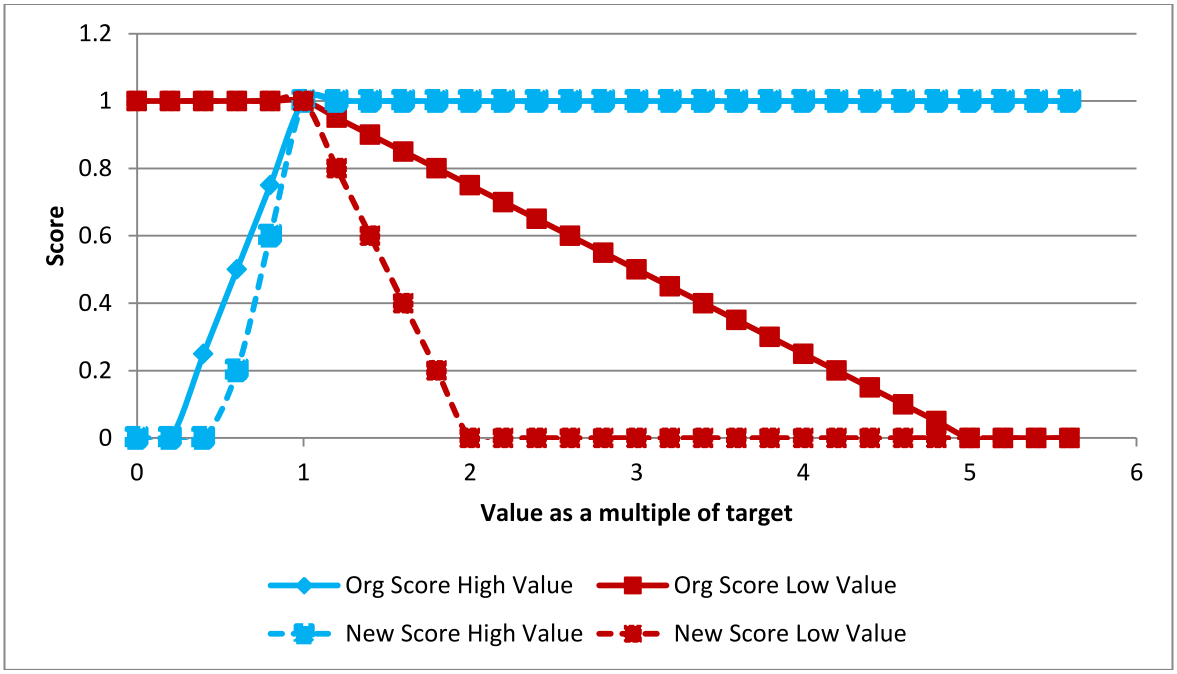

Fig. 10. Comparison of old and new scores using different scoring rules

However, the choice of scoring rules does affect the results in a different way. While the scores obtained from the old and the new scoring rules continue to lie between 0 and 1, the range of input values, which yield a non-zero score, is compressed. This can be explained with the help of an example. Suppose the target for a particular metric is 3, for which a lower value is desirable. If the actual value of this metric is 9, the original score for this metric is 0.5. However, the new score of this metric will be 0. Similarly, if the actual value of this metric is 6, the original score for this metric is 0.75. But, the new score of this metric will be also 0. Therefore, it is observed that while the old scoring rules resulted in scores of 0.5 and 0.75 for a metric value of 9 and 6 respectively, the new scoring rules yield a score of 0 for both the values. Hence using the new scoring rules would lead to a lower resolution in the index and the information of the actual value of the metric may get lost. The scoring rule given in Eqns (2) and (3) is therefore preferred and is used for the assessment.

9. CONCLUSION

This paper has undertaken an assessment of the SES for the energy demand sub-system for India. The dimensional and sectoral indices have been calculated for different years and the SES Index for the demand sub-system has been aggregated. This quantitative assessment reveals key characteristics of the performance of the Indian energy demand sub-system over time. Results illustrate that almost all indices show an improvement from 2002 to 2012 and the overall SES Index for the demand sub-system has shown a gradual increase over the years. Nevertheless, there is a large scope for improvement as the overall SES Index for the demand sub-system is about 70% of the targeted value. Sensitivity analysis reveals that the SES Index is robust to variation in weights and the results of the SES index can be used with reasonable confidence. Analysis of results also gives new insights into the performance of the energy demand sub-system which can be used to design policy interventions for improving the overall SES Index for India.

REFERENCES

1) Census of India 2001, 2001. Office of the Registrar General, India, Govt. of India, New Delhi.
2) Census of India 2011, 2011. Office of the Registrar General & Census Commissioner, Ministry of Home Affairs, Govt. of India, New Delhi.
3) Central Electricity Authority (CEA), Ministry of Power, Government of India, New Delhi.
4) Chunekar, A., Kadav, K., Singh, D., Sant, G., Potential Savings from Selected Super-Efficient Electric Appliances in India,2011. Prayas Energy Group, Pune.
5) D'Sa, A., Murthy, K.V.N., 2004. Report on the use of LPG as a domestic cooking fuel option in India, International Energy Initiative, Bangalore. pp.17-19.
6) Dasgupta, D., 2013. Fossil Fuel Subsidies: Three Questions, Evidence and Way Forward. Ministry of Finance, Government of India. http://finmin.nic.in/workingpaper/FossilFueSubsdies.pdf
7) De la Rue du Can, S., Letschert, V., Mc Neil, M., Zhou, N., Sathaye, J., 2009. *Residential and Transport Energy Use in India: Past Trend and Future Outlook*, Lawrence Berkeley National Laboratory. Environmental Energy Technologies Division. Oak Ridge. p.24.
8) G20 Leaders Declaration, 18-19 June 2012, Los Cabos, Mexico. http://www.g20.utoronto.ca/2012/2012-0619-loscabos.html
9) Harish, S.M., and Tongia, R., 2014. Do rural residential electricity consumers cross subsidize their urban counterparts? Exploring the inequity in supply in the Indian power sector. Working paper 04-14, Brookings Institution India Center, New Delhi.

10) Hughes, L., 2012. A generic framework for the description and analysis of energy security in an energy system. Energy Policy, 42, 221-231.
11) http://www.cea.nic.in/ http://www.moef.nic.in/downloads/public-information/Residentialpowerconsumption.pdf
12) IEA, 2012. World Energy Outlook – Methodology for Energy Access Analysis 2012, OECD/IEA, Paris. http://www.worldenergyoutlook.org/media/weowebsite/energymodel/documentation/energyaccess_methodology_2012_FINAL.pdf
13) IEA, 2013, Redrawing the energy climate map –World energy outlook special report, Executive Summary, OECD/IEA 2013, Paris. http://www.iea.org/media/freepublications/weo/WEO2013_Climate_Excerpt_ES_WEB.pdf
14) IEA, 2015. World Energy Balance – Sankey Diagram. http://www.iea.org/Sankey/index.html
15) IISD, 2012. A citizen's guide to energy subsidies in India, Global Subsidies Initiative, The International Institute For Sustainable Development, Geneva.
16) Ministry of Petroleum & Natural Gas, 2013. Indian Petroleum & Natural Gas Statistics (2011-12), Economic Division, Ministry of Petroleum & Natural Gas, Government of India, New Delhi. Pp. 61-64.
17) Mitchell, C., Watson, J., 2013. New Challenges in Energy Security, in: Mitchell, C., Watson, J., and Whiting, J. (Eds.), New Challenges in Energy Security. Basingstoke: Palgrave Macmillan, New York, pp.238–257.
18) Narula, K., 2014. Is Sustainable Energy Security of India increasing or decreasing? International Journal of Sustainable Energy, 33 (6),1054-1075. DOI: 10.1080/14786451.2013.811411.
19) NSSO, 2003. Household Consumer Expenditure and Employment - Unemployment Situation in India, 2001 – 2002 [Report No. 481], NSS 57th Round(July 2001 – June 2002).National Sample Survey Organisation, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.
20) NSSO, 2010. Household Consumer Expenditure in India, 2007-08 [Report No. 530], NSS 64th round (July 2007 - June 2008). National Sample Survey Organization, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.

21) NSSO, 2012a. Energy Sources of Indian Households for Cooking and Lighting, [Report No. 542], NSS 66th round (July 2009 - June 2010). National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.
22) NSSO, 2012b. Household Consumption of various goods and services in India, [Report No. 541], NSS 66th round (July 2009 - June 2010). National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.
23) NSSO, 2014. Household Consumption of various goods and services in India, 2011-12 [Report No. 558], NSS 68th round (July 2011 - June 2012). National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.
24) OECD, Energy and Development Methodology, OECD/IEA 2011, Paris. p.5. http://www.iea.org/media/weowebsite/energymodel/Poverty_Methodology.pdf
25) Patil, K., Chattopadhyay, A., Household Energy Use and CO_2 Emission: Differentials and Determinant in India. Paper presented at XXVII IUSSP International Population Conference, 26-31 Aug 2013 at Busan, Republic of Korea. http://iussp.org/sites/default/files/event_call_for_papers/Household%20Energy%20Use%20and%20CO2%20Emission.pdf.
26) Planning Commission, 2002. Annual Report (2001-02) on the Working of
27) Planning Commission, 2006. Integrated Energy Policy: Report of the expert committee, Govt. of India, Planning Commission, New Delhi.
28) Planning Commission, 2011. Annual Report 2011-12 on the Working of
29) PPAC, 2015. Petroleum Planning & Analysis Cell, Ministry of Petroleum & Natural Gas, Government of India. http://ppac.org.in/content/149_1_PricesPetroleum.aspx
30) Ravindranath, N.H., and Ramakrishna; 1997; Energy options for cooking in India, Energy policy 25 (1):63-75
31) Sathaye, J,. 2010. Energy Efficiency Indicators Methodology Booklet.Lawrence Berkeley National Laboratory. LBNL Paper LBNL-3702E.
32) Scheepers M, Seebregts AJ, De Jong, JJ and Maters JM. EU Standards for Security of Supply. Hague: Energy Research Center (ECN)/ Clingendael International Energy Programme, 2007.
33) State Electricity Boards & Electricity Departments. Power & Energy Division, Planning Commission, Government of India.

34) State Power Utilities & Electricity Departments. Power & Energy Division, Planning Commission, Government of India.

35) TEDDY, 2006. TERI Energy Data Directory & Yearbook (TEDDY) 2005/06, The Energy and Resources Institute, New Delhi.

36) TEDDY, 2010. TERI Energy Data Directory & Yearbook (TEDDY) 2010, The Energy and Resources Institute, New Delhi.

37) The World Bank, 2008. Residential consumption of electricity in India, Background paper, India: Strategies for Low Carbon Growth

38) World Energy Council, 2015. Energy efficiency indicators (Data provided by Enerdata, 2015). http://www.wec-indicators.enerdata.eu/

Appendix A: Metrics for demand sub-system for various sectors

Dimension/ Category Residential	Sub-category	Name	Metric	Variables	Unit
AVL Adequate supply	Lighting	R 1	Average per capita electricity consumption per year	Final electricity consumed annually in residential sector/total population	kWh/capita /yr
	Cooking	R 2	Average per capita LPG consumption per year	Monthly per capita quantity of LPG consumed (average, all-India, across all households) x 12	Kg/capita/yr
Access	Access to electricity for lighting	R3	% of population with access to electricity	% households using electricity for lighting	%
	Access to clean cooking fuel	R 4	% of population using LPG/PNG for cooking	% households using LPG/PNG for cooking	%
AFF Paying ability	Expenditure on cooking and lighting	R 5	% of expenditure on fuel and light by households	{Average monthly per capita expenditure (Rs.) on fuel and light (All India) / total expenditure (Rs.) } (by households) x 100	%
Retail Prices	Price distortion in energy sources for cooking	R 6	Weighted sum of price distortion score due to subsidies for cooking	$R6 = 1 - Abs(WSPDS_C)$ Where $WSPDS_C = \sum sh_{C(i)} \times PDS_{C(i)}$ $PDS = \{\frac{\text{Actual Price} - \text{Retail Price}}{\text{Actual Price}}\}$ $sh_{C(i)}$: share of type of energy (i) in the final energy used for cooking in residential sector	-
Retail Prices	Price distortion in energy sources for lighting	R 7	Weighted sum of price distortion score due to subsidies for lighting	$1 - Abs(WSPDS_L)$ Where $WSPDS_L = \sum sh_{L(i)} \times PDS_{L(i)}$ $PDS = \{\frac{\text{Actual Price} - \text{Retail Price}}{\text{Actual Price}}\}$ $sh_{L(i)}$:share of type of energy (i) in the final energy used for lighting in residential sector	-
ACP	Emissions intensity	R 8	Annual CO_2 emissions per household	Total CO_2 emissions from residential sector/total no. of households	tCO_2/household

EFF End use efficiency	End use efficiency for lighting	R 9	Average lighting efficacy[48]	$\sum sh_{F(i),L} \times EFC_{F(i),L}$, where $sh_{F(i),L}$:share of type of energy F(i) used for lighting $EFC_{F(i),L}$:average efficacy of different lighting devices using F(i)	Lumens/ watt
	End use efficiency for cooking	R 10	Average cook stove efficiency	$\sum sh_{F(i),C} \times EFF_{F(i),C}$, where $sh_{F(i),C}$:share of type of energy F(i) used for cooking, $EFF_{F(i),C}$:average efficiency of different cook stoves using F(i)	%
	End use efficiency for appliances	R 11	Average appliance efficiency	$\sum sh_{A(i)} \times AES_{F(i)}$, where sh_A :share of appliances using electricity in the household, AES is the Appliance Efficiency Score[49]	-
Industrial					
AVL	Adequate supply	**I1**	Number of hours of electricity in a day	Number of hours of electricity in a day	hrs
AFF Retail Prices	Price distortion in energy sources	**I2**	Weighted sum of price distortion score due to subsidies in energy sources used in sector	I2 = 1 - Abs(WSPDS), where WSPDS=$\sum sh_{F(i)} \times PDS_{F(i)}$, $PDS = \left\{\frac{\text{Actual Price} - \text{Retail Price}}{\text{Actual Price}}\right\}$ for energy source F(i) ; $sh_{F(i)}$: share of type of energy (i) in the final energy used in the sector	-
ACP	Emissions intensity	**I3**	CO_2 emission intensityof industrial sector	(Total CO_2 emissions from industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kgCO2/ $05p
EFF	Monetary energy intensity	**I4**	Energy intensity of industrial sector	(Total energy input to industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kgoe/$05p

[48]Efficacy, is the ratio of power input to light output i.e. emitted flux (lumens) divided by power draw (watts)

[49] AES is calculated using Eqn (2) – (3), where value (x) is the efficiency level of the appliance (different appliances have different units for measuring efficiency) and target (x) is the efficiency level of the Super Efficient Appliances (SEA) in 2010.

Services					
AVL	Adequate supply	**S1**	Number of hours of electricity in a day	Number of hours of electricity in a day	hrs
AFF Retail Prices	Price distortion in energy sources	**S2**	Weighted sum of price distortion score due to subsidies in energy sources used in sector	S2 = 1 - Abs(WSPDS), where WSPDS=$\sum sh_{F(i)} \times PDS_{F(i)}$, $PDS = \left\{\frac{\text{Actual Price} - \text{Retail Price}}{\text{Actual Price}}\right\}$ for energy source F(i) ; $sh_{F(i)}$: share of type of energy (i) in the final energy used in the sector	-
ACP	Emission intensity	**S3**	CO_2 emission intensity of services sector	(Total CO_2 emissions from industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kCO2/$05p
EFF	Monetary energy intensity	**S4**	Energy intensity of service sector	(Total energy input to industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kgoe/$05p
Agriculture					
AVL	Adequate supply	**A1**	% share of electrified pump sets in sector	% share of electrified pump sets in sector	%
AFF Retail Prices	Price distortion in energy sources	**A2**	Weighted sum of price distortion score due to subsidies in energy sources used in sector	S2 = 1 - Abs(WSPDS), where WSPDS=$\sum sh_{F(i)} \times PDS_{F(i)}$, $PDS = \left\{\frac{\text{Actual Price} - \text{Retail Price}}{\text{Actual Price}}\right\}$ for energy source F(i) ; $sh_{F(i)}$: share of type of energy (i) in the final energy used in the sector	-
ACP	Emission intensity	**A3**	CO_2 emission intensity of agriculture sector	(Total CO_2 emissions from industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kCO2/$05p
EFF	Monetary energy intensity	**A4**	Energy intensity of agriculture sector	(Total energy input to industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kgoe/$05p
Transport					
AVL	Dependence on one type of primary energy source	**T1**	Dependence of the sector to fossil fuels	% share of fossil fuels used for transportation	%

AFF	Retail Prices -Price distortion in energy	**T2**	Weighted sum of price distortion score due to subsidies in energy sources used in sector	S2 = 1 - Abs(WSPDS), where WSPDS=$\sum sh_{F(i)}$ x PDS $_{F(i)}$, $PDS = \left\{\frac{\text{Actual Price} - \text{Retail Price}}{\text{Actual Price}}\right\}$ for energy source F(i) ; $sh_{F(i)}$: share of type of energy (i) in the final energy used in the sector	-
ACP	Emission intensity	**T3**	CO_2 emission intensity of transport sector	(Total CO_2 emissions from industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kCO2/$05p
EFF	Monetary energy intensity	**T4**	Energy intensity of transport sector	(Total energy input to industrial sector)/ (Total Value added) at ppp (in US Dollars, 2005 prices)	kgoe/$05p

Appendix B: Calculations for scores of metrics

Table B1: Price Distortion Score (PDS) for different fuels

Product	Price as on	Actual Price	Retail price	PDS
Diesel	01.04.2002	16.59	16.59	0
	01.04.2007	36.56	30.25	0.17
	01.04.2012	51.08	40.91	0.20
LPG	01.04.2002	380.47	250.45	0.34
	01.04.2007	531.38	294.75	0.45
	01.04.2012	737.90	399.27	0.46
Petrol	01.04.2002	26.54	26.54	0
	01.04.2007	48.12	42.85	0.11
	01.04.2012	65.64	65.64	0
Kerosene	01.04.2002	13.12	8.98	0.32
	01.04.2007	26.14	9.09	0.65
	01.04.2012	42.04	14.82	0.65

Source: 01.04.2002 and 01.04.2007: PPAC; 01.04.2012: Ministry of Petroleum & Natural Gas, 2013

Table B2: Price Distortion Score (PDS) for electricity for different sectors

Sector	Years	Actual Price (Paise/KWh)	Retail price (Paise/KWh)	PDS
Residential	2001-2002	349.9	195.6	0.44
	2006-2007	404	241	0.40
	2011-2012	487	320	0.34
Industrial	2001-2002	349.9	378.7	-0.08
	2006-2007	404	420	-0.04
	2011-2012	487	497	-0.02
Services	2001-2002	349.9	426.3	-0.22
	2006-2007	404	492	-0.22
	2011-2012	487	581	-0.19
Agriculture	2001-2002	349.9	41.6	0.88
	2006-2007	404	77	0.81
	2011-2012	487	153	0.69
Transport	2001-2002	349.9	449.2	-0.28
	2006-2007	404	442	-0.09
	2011-2012	487	539	-0.11

Source: 2001-02: Planning Commission, 2002[50]; 2006-07 and 2011-12[51]: Planning Commission, 2011

[50]Values shown are provisional for 2001-02
[5151] Values shown are provisional for 2011-12

Table B3: R6 for residential sector

Sub-component	Type of fuel	PDS for different years			Share for different years		
		2002	2007	2012	2002	2007	2012
Rural	LPG	0.34	0.45	0.46	5.70	9.1	11.4
	Kerosene	0.32	0.65	0.65	1.60	0.6	0.7
	Biomass	0	0	0	77.20	77.6	74.8
	Coal	0	0	0	1.10	0.8	0.8
	Dung Cake	0	0	0	12.80	7.4	10.9
	No Arrangement	0	0	0	1.60	4.5	1.4
	WSPDS				0.02	0.04	0.06
	R6				0.98	0.96	0.94
Urban	LPG	0.34	0.45	0.46	48	61.8	65
	Kerosene	0.32	0.65	0.65	19.2	7.6	7.5
	Biomass	0	0	0	24.8	20.1	21.5
	Coal	0	0	0	4.6	2.1	2.9
	Dung Cake	0	0	0	2	1.4	1.7
	No Arrangement	0	0	0	1.4	7.1	1.4
	WSPDS				0.22	0.32	0.35
	R6				0.78	0.68	0.65

Source: PDS from Table 1and 2; Share: 2002: Census of India, 2001;2007: NSSO, 2010; 2012: Census of India,2011

Table B4: R7 for residential sector

Sub-component	Type of fuel	PDS for different years			Share for different years		
		2002	2007	2012	2002	2007	2012
Rural	Electricity	0.44	0.40	0.34	43.5	60.2	55.3
	Kerosene	0.32	0.65	0.65	55.6	38.6	43.2
	Other arrangement	1	1	1	0.9	1.2	1.5
	WSPDS				0.38	0.51	0.48
	R7				0.62	0.49	0.52
Urban	Electricity	0.44	0.40	0.34	87.6	93.8	92.7
	Kerosene	0.32	0.65	0.65	11.6	5.1	6.5
	Other arrangement	1	1	1	0.8	1.1	0.8
	WSPDS				0.43	0.42	0.37
	R7				0.57	0.58	0.63

Source: Same as Table B3

Calculation of Efficiency metrics

$R9 = sh_{Electricity, L} \times (\text{Average Efficacy})_{bulb} + sh_{Kerosene, L} \times (\text{Average Efficacy})_{Kerosene\ lamp}$

Assumption: $(\text{Average Efficacy})_{Kerosene\ lamp} = 0.15$

$(\text{Average Efficacy})_{bulb} = 15$

Table B5: Average efficiency of end use equipment

Data Source	Coke, coal and charcoal	Firewood/ crop residue	LPG	Dung cake	Kerosene	Elec.	Bio-gas	Others
(1)	10	13-16	60	8	36-40	71	55	
(2)	23.2	15.7	60.4	11.1	40.4-60.4	71.3	-	
(3)	20	15	60	10	40			50

Sources: (1) TEDDY, 2010; (2) Ravindranath and Ramakrishna,1997; (3) Assumed for calculations

Table B6:R9 for residential sector

Sub-component	Year	% Share of fuel used for lighting in rural areas			
		Kerosene	Electricity	Others/ No arrangement	R9
Rural	2002	55.6	43.6	0.9	6.62
	2007	38.6	60.2	1.2	9.09
	2012	43.2	55.3	1.5	8.36
Urban	2002	11.6	87.6	0.8	13.16
	2007	5.1	93.8	1.1	14.08
	2012	6.5	92.7	0.8	13.92

Source: Same as Table B3

$R10 = \sum sh_{F(i),C} \times EFF_{F(i),C}$

Table B7: R10 for residential sector

Sub-component	Year	Share of fuel used for cooking in rural residential areas						R 10 (%)
		Coke, coal and charcoal	firewood and chips	LPG	Dung cake	Kerosene	Others/No arrangement	
Rural	2002	1.1	77.2	5.7	12.8	1.6	1.6	17.94
	2007	0.8	77.6	9.1	7.4	0.6	4.5	20.55
	2012	0.8	74.8	11.4	10.9	0.7	1.4	20.43
Urban	2002	4.6	24.8	48	2	19.2	1.4	42.02
	2007	2.1	20.1	61.8	1.4	7.6	7.1	48.01
	2012	2.9	21.5	65	1.7	7.5	1.4	48.18

Source: Same as Table B3

$R11 = \sum sh_A \times AES$

Table B8: Share of appliances in the household (%) **(sh_A)**

	2002[52]	2007[53]	2012[54]
TV	20.80	20.80	21.18
Refrigerator	26.74	26.74	25.41
Fan	34.97	34.97	35.60
AC	7.77	7.77	7.91
Others	9.71	9.71	9.89
Total	100.00	100.00	100.00

Estimated from Data Source: The World Bank, 2008

Table B9: AES and R11 for residential sector

Appliance	Unit	Target	Average power consumption			Appliance Efficiency Score (calculated from Eq. (2-3)		
			2002[55]	2007	2012[56]	2002	2007	2012
TV	kWh/yr	36	150	162.5	175	0.21	0.12	0.03
Refrigerator	kWh/yr	128	494	455	416	0.29	0.36	0.44
Fan	watts	35	145	108	71	0.21	0.48	0.74
AC	EER	4.9	1.62	2.22	2.82	0.16	0.32	0.47
R11						**0.23**	**0.34**	**0.46**

Source: Target: Adopted from SEAD program, Chunekaret.al., 2011, 2002: De la Rue du Can et.al. , 2009;2007: Data N.A., Average of 2002 and 2012 is used; 2012: Chunekaret.al., 2011

[52]Data for 2002 is N.A, Estimate for 2007 is used
[53] Values are estimated using data for 2006
[54] Values are estimated using data for 2011
[55] Data for 2000, Unit Energy Consumption (UEC) is used. For calculation of EER, it is assumed that 2160 W is used for 1 TR AC
[56] Data for 2010, Weighted UEC is used; For calculation of EER, it is assumed that 1242 W is used for 1 TR AC

Table B10: Price Distortion Score (PDS) for various sectors (I2, S2, A2, T2)

Sector	Type of fuel	PDS			Share		
		2002	2007	2012	2002	2007	2012
Industry	Electricity	-0.08	-0.04	-0.02	0.17	0.2	0.2
	Diesel	0	0.17	0.20	0.2	0.16	0.11
	LPG	0.34	0.45	0.46	0	0	0
	Petrol	0	0.11	0	0	0	0
	Kerosene	0.32	0.65	0.65	0	0	0
	Biomass	0	0	0	0.3	0.24	0.18
	Coal	0	0	0	0.32	0.38	0.46
	Natural Gas	0	0	0	0.01	0.02	0.05
	SUM				1.00	1.00	1.00
	WSPDS				-0.01	0.02	0.02
	I2				0.99	0.98	0.98
Services	Electricity	-0.22	-0.22	-0.19	0.23	0.31	0.35
	Diesel	0	0.17	0.20	0	0	0.08
	LPG	0.34	0.45	0.46	0	0	0
	Petrol	0	0.11	0	0	0	0
	Kerosene	0.32	0.65	0.65	0	0	0
	Biomass	0	0	0	0.5	0.45	0.35
	Coal	0	0	0	0.28	0.23	0.22
	Natural Gas	0	0	0	0	0	0
	WSPDS				-0.05	-0.07	-0.05
	S2				0.95	0.93	0.95
Agriculture	Electricity	0.88	0.81	0.69	0.48	0.46	0.42
	Diesel	0	0.17	0.20	0.52	0.53	0.57
	LPG	0.34	0.45	0.46	0	0	0
	Petrol	0	0.11	0	0	0	0
	Kerosene	0.32	0.65	0.65	0	0	0
	Biomass	0	0	0	0	0	0
	Coal	0	0	0	0	0	0
	Natural Gas	0	0	0	0.01	0.01	0.01
	WSPDS				0.42	0.46	0.40
	A2				0.58	0.54	0.60
Transport	Electricity	-0.28	-0.09	-0.11	0.02	0.02	0.02
	Diesel	0	0.17	0.20	0.82	0.66	0.65
	LPG	0.34	0.45	0.46	0.00	0.00	0.00
	Petrol	0	0.11	0	0.21	0.19	0.20
	Kerosene	0.32	0.65	0.65	0.00	0.00	0.00
	Other	0	0	0	-0.13	.02	.04
	Natural Gas	0	0	0	0.01	0.02	0.02
	ATF	0	0	0	0.07	0.08	0.07
	WSPDS				-0.01	0.13	0.13
	T2				0.99	0.87	0.87

Source: PDS from Table 1and 2; Shares: IEA, 2015

Calculation of Availability metrics

Table B11: Survey undertaken on load shedding in industry sector

Industry			
Load shedding per week (No. of hours, range)	Average No. of hours of load shedding per week (assumed)	Average No. of hours of electricity available per day	% of firms
Less than 1 hr	0	24	37
1-5 hrs	3.5	23.5	15
6 -10 hrs	7	23	16
11-20 hrs	14	22	6
21 - 30 hrs	28	20	5
31 - 40 hrs	35	19	18
Above 40 hrs	42	18	3
Weighted Average	-		**22.4**

Note: The 'number of hours of electricity in a day' for the industrial sector (I1) is obtained as a weighted average. The 'Average No. of hours of electricity available per day' is multiplied with the '% of firms' to obtain a weighted average for 2011-12 using data collected by a survey.

Table B 12: Calculation of Availability metrics (I1and S1)

	2001-02	2006-07	2011-12
Overall power deficit (%)[57]	7.5	9.6	8.5
Average no. of hours of electricity not available in Industry[58]	1.4	1.8	1.6[59]
Average no. of hours of electricity not available in Services sector[60]	0.1	0.1	0.1[61]
I1	22.6	22.2	22.4
S1	23.9	23.9	23.9

Source: Overall power deficit: CEA, various years
Note: Average no. of hours of electricity not available in Industry: Table 15
Average no. of hours of electricity not available in Services sector : Harish and Tongia, 2014

[57]Overall power deficit for India is taken.
[58]Values for 2001-02 and 2006-07 for are derived from values 2011-12 values by assuming that the overall power deficit is shared by all the sectors in the same ratio as for 2011-12.
[59] Non-availability of electricity for industry for 2011-12 is calculated from weighted average obtained in Table 15.
[60]Values for 2001-02 and 2006-07 for are derived from values 2011-12 values by assuming that the overall power deficit is shared by all the sectors in the same ratio as for 2011-12.
[61] Median values for urban Bangalore is used for estimation of data for services sector based on data collected on feeders on 26 Sep 2012. The observed mean value for availability of electricity was 22.3 hours with a SD of 3.8 for that day.The collected data also showed a median value of 23.7hrs and 24.0 hrs for data collected on 15 April 2013 and 26 Dec 2012 respectively.

Appendix C: Calculation of weights from respondent survey

Following is a brief profile of the stakeholders who were interviewed.

1. Amit Bhandari is a Fellow, at Gateway House: Indian Council on Global Relations. He speacializes in Energy& Environment Studies. He holds an Masters in Business Administration from IIM- Ahmedabad and a Bachelors degree in Technology from IT-BHU.

2. Siddharth is a solar entrepreneur based at Mumbai.

3. Ajit Pandit is currently the Director of Idam Infrastructure Pvt. Ltd., Mumbai and has more than 17 years of progressive experience in energy and utilities sectors in India. He is recognized by the industry as an expert in policy and regulatory matters concerning electricity industry and the renewable energy sector.

4. Balwant Joshi is currently the Managing Director and one of the founding directors of Idam Infrastructure Pvt. Ltd., Mumbai. He has more than 20 years of experience in energy. He is a well-known expert on policy/regulatory matters concerning electricity, renewable and energy efficiency industry.

5. Dr Shonali Pachauri is Senior Research Scholar in the Energy (ENE) Program at the International Institute for Applied Systems Analysis (IIASA), Vienna. Her research focuses on analyzing heterogeneities in energy access and use, policy pathways for achieving universal modern energy access, socioeconomic and environmental dimensions of household energy use in the developing world.

6. Dr. SudhakarYedla is a Professor at IGIDR, Mumbai. He is a trained professional majoring in all domains of Environmental Management viz. Environmental Engineering, Environmental Economics, Environmental Law, and Policy. He specializes in Environment (Climate Change) and (Sustainable) Development.

7. Dr. Shireesh Kedare is a Professor at Department of Energy Science and Engineering, IIT Bombay. He has a rich industry and R&D experience in solar energy, industrial process heat applications of solar energy, thermal storage and has worked on rural applications of energy and cook stoves apart from his academic responsibilities of teaching and as a PhD supervisor.

The consolidated matrix and the (n x n) judgment matrix, [*A*], for seven different respondents are shown in Table C1.

Table C1: Judgment matrix [A] for different respondents

Consolidated	R1	R2	R3	R4
R1	1.0	1.1	1.5	1.1
R2	0.9	1.0	0.8	1.1
R3	0.7	1.2	1.0	0.9
R4	0.9	0.9	1.1	1.0

Amit29/12/2014	R1	R2	R3	R4
R1	1	1	4	1
R2	1	1	3	3
R3	1/4	1/3	1	1
R4	1	1/3	1	1

Sid 02/04/2015	R1	R2	R3	R4
R1	1	3	5	5
R2	1/3	1	1	3
R3	1/5	1	1	1
R4	1/5	1/3	1	1

Ajit 02/04/2015	R1	R2	R3	R4
R1	1	1/3	2	1/2
R2	3	1	2	2
R3	1/2	1/2	1	1/2
R4	2	1/2	2	1

Joshi 02/04/2015	R1	R2	R3	R4
R1	1	5	2	7
R2	1/5	1	1/5	3
R3	1/2	5	1	5
R4	1/7	1/3	1/5	1

Shonali 12/01/2015	R1	R2	R3	R4
R1	1	1/3	1/5	1/5
R2	3	1	1/3	1/4
R3	5	3	1	1/2
R4	5	4	2	1

Yedla 01/01/2015	R1	R2	R3	R4
R1	1	1	1/3	1
R2	1	1	1/3	1/3
R3	3	3	1	1
R4	1	3	1	1

Kedare 01/01/2015	R1	R2	R3	R4
R1	1	1	3	1/2
R2	1	1	2	1/3
R3	1/3	1/2	1	1/3
R4	2	3	3	1

Each element of the consolidated matrix (b_{ij}) is obtained as a geometric mean of the respective element (a_{kij}) of judgment matrices filled by seven respondents.

$$b_{ij} = (a_{1ij} \cdot a_{2ij} \cdots a_{kij})^{\frac{1}{k}}, \text{ where (k=1 to 7)}$$

The normalized matrix and six iterations for obtaining the normalized principal eigenvector are shown in Table C2.

Table C2: Normalised matrix and iterations

Normalization	Normalized matrix				Normalized principal Eigenvector	
					1st iteration	6th iteration
R1	0.28	0.25	0.33	0.27	29%	**28.5%**
R2	0.26	0.24	0.19	0.26	24%	**23.9%**
R3	0.19	0.29	0.22	0.22	23%	**22.8%**
R4	0.26	0.22	0.25	0.25	25%	**24.8%**
					EV	Difference[62]
1st iteration	0.282	0.288	0.286	0.283	28.47%	-5.9E-04
	0.242	0.235	0.241	0.239	23.93%	1.9E-03
	0.23	0.229	0.223	0.230	22.82%	-2.0E-03
	0.247	0.248	0.25	0.247	24.77%	6.6E-04
2nd iteration	0.285	0.285	0.285	0.285	28.46%	-1.6E-04
	0.239	0.239	0.239	0.239	23.94%	8.7E-05
	0.228	0.228	0.228	0.228	22.84%	1.4E-04
	0.248	0.248	0.248	0.248	24.77%	-7.2E-05
3rd iteration	0.285	0.285	0.285	0.285	28.46%	9.9E-07
	0.239	0.239	0.239	0.239	23.94%	-4.9E-07
	0.228	0.228	0.228	0.228	22.84%	-9.8E-07
	0.248	0.248	0.248	0.248	24.77%	4.8E-07
4th iteration	0.285	0.285	0.285	0.285	28.46%	3.9E-11
	0.239	0.239	0.239	0.239	23.94%	-1.4E-11
	0.228	0.228	0.228	0.228	22.84%	-4.6E-11
	0.248	0.248	0.248	0.248	24.77%	2.2E-11
5th iteration	0.285	0.285	0.285	0.285	**28.46%**	0.0E+00
	0.239	0.239	0.239	0.239	**23.94%**	-2.2E-16
	0.228	0.228	0.228	0.228	**22.84%**	-2.2E-16
	0.248	0.248	0.248	0.248	**24.77%**	-2.2E-16
6th iteration	0.285	0.285	0.285	0.285	**28.46%**	-5.6E-16
	0.239	0.239	0.239	0.239	**23.94%**	-5.0E-16
	0.228	0.228	0.228	0.228	**22.84%**	-4.4E-16
	0.248	0.248	0.248	0.248	**24.77%**	-5.0E-16

After the 6th iteration, the consistency index is calculated as follows:

$CI = (\lambda_{max} - n)/(n-1)$; Principal Eigenvalue, $\lambda_{max} = 4.028$; $n = 4$; $CI = 0.009$

The consistency of the judgment is checked as follows:

$CR = CI/RI$, $RI = 0.90$ for $n=4$ (read from table); $CR = 0.009/0.90 = 1\%$

As the calculated CR<10%, the obtained result is consistent and the sixth iteration is considered acceptable. The final allotted weights for R1, R2, R3, R4 are 28.5, 23.9, 22.8, and 24.8% respectively.

[62] Difference between successive Eigen Vectors

Appendix D: Calculations for indices

(a) Calculation of Dimensional indices for Residential Sector (2012)

Table D1.1 Scoring matrix for residential sector (Availability)

	Scores			
Metrics	R1	R2	R3	R4
Rural	0.26	0.00	0.44	0.00
Urban	0.40	0.95	0.91	0.56

Table D1.2 Weighting matrix for residential sector (Availability)

Metric	Weight
R1	28.5
R2	23.9
R3	22.8
R4	24.8

Table D1.3 Index obtained from multiplication of scoring and weighting matrix

Residential sector	Availability Index
Rural	0.18
Urban	0.69

Table D2.1 Scoring matrix for residential sector (Affordability)

	Scores		
Metrics	R5	R6	R7
Rural	0.92	0.94	0.52
Urban	0.98	0.65	0.63

Table D2.2 Weighting matrix for residential sector (Affordability)

Metric	Weight
R5	62.1
R6	18.8
R7	19.1

Table D2.3 Index obtained from multiplication of scoring and weighting matrix

Residential sector	Affordability Index
Rural	0.85
Urban	0.85

Table D3.1 Scoring matrix for residential rural and urban areas (Efficiency)

	Scores		
Metrics	**R9**	**R10**	**R11**
Rural	0.10	0.18	0.46
Urban	0.33	0.75	0.46

Table D3.2 Weighting matrix for residential sector (Efficiency)

Metric	Weight
R9	24.4
R10	47.6
R11	27.9

Table D3.3 Index obtained from multiplication of scoring and weighting matrix

Residential sector	Efficiency Index
Rural	0.24
Urban	0.57

(b) Calculation of SES Index for residential sector (2012)

Table D4.1 Dimensional Indices for residential sector

Region	Dimensional Indices			
	AVL	AFF	ACP	EFF
Rural	0.18	0.85	0.96	0.24
Urban	0.69	0.85	0.96	0.57

Share of total population (%): Rural – 68.4; Urban: 31.6

Table D4.2 SES Index for residential sector obtained from matrix multiplication

	AVL	AFF	ACP	EFF
SES Index	0.34	0.85	0.96	0.34

(c) Calculation of SES Index for different sectors (2012)

Table D5.1 Scoring matrix for various sectors (Dimensional Indices)

Dimensional Index	AVL	AFF	ACP	EFF
Residential	0.34	0.85	0.96	0.34
Industrial	0.92	0.98	0.19	0.40
Services	0.99	0.95	0.80	0.94
Agricultural	0.79	0.60	0.59	0.50
Transport	0.96	0.87	0.73	0.98

Table D5.2 Weighting matrix

Dimensional Weights
27.4
26.9
20
25.6

Table D5.3 SES Index for various sectors obtained from matrix multiplication

Sectors	SES Index of sector
Residential	0.60
Industrial	0.66
Services	0.93
Agricultural	0.62
Transport	0.89

(d) Calculation of SES Index for demand sub-system (2012)

Table D6.1 SES Index for various sectors (from Table 5.3)

Sectors	SES Index of sector
Residential	0.60
Industrial	0.66
Services	0.93
Agricultural	0.62
Transport	0.89
Non Energy	1
Others	1

Note: Share of final energy: Residential - 36; Industry – 33; Services – 4; Agriculture – 5, Transport – 15; Non energy – 7; and others – 2

Demand sub-system SES index obtained from matrix multiplication = 0.71

(e) Calculation of SES Index for demand sub-system for different years

Table D7.1 Scoring matrix for different years (Dimensional Indices)

Sectors	SES Index of sector		
	2002	2007	2012
Residential	0.49	0.57	0.60
Industrial	0.59	0.63	0.66
Services	0.78	0.82	0.93
Agricultural	0.57	0.54	0.62
Transport	0.84	0.87	0.89

Weighting matrix for dimensional weights: Same as Table B6.1
Same weights are used for all years

Table D7.2 Demand sub-system SES index obtained from matrix multiplication

Years	SES Index		
	2002	2007	2012
Demand sub-system	0.61	0.67	0.71

Appendix E: Scenarios

A.
B. Scenarios for weights to metrics

Table E1. Scenarios[63] for weights to Availability metrics for residential sector and calculated AVL Index

Scenarios	Scenarios for weights to Metrics				Scenarios	Actual weights to Metrics				**AVL Index**
	R1	R2	R3	R4		R1	R2	R3	R4	
Sc 1	Min	Min	Max		Sc 1	8	10	38	44	0.1889
Sc 2	Min	Min		Max	Sc 2	8	10	31	51	0.1580
Sc 3	Min	Max	Min		Sc 3	8	43	11	38	0.0697
Sc 4	Min		Min	Max	Sc 4	8	30	11	51	0.0697
Sc 5	Min	Max		Min	Sc 5	8	43	38	11	0.1889
Sc 6	Min		Max	Min	Sc 6	13	43	38	6	0.2021
Sc 7	Max	Min	Min		Sc 7	57	10	11	22	0.1995
Sc 8	Max		Min	Min	Sc 8	57	26	11	6	0.1995
Sc 9	Max	Min		Min	Sc 9	57	10	27	6	0.2701
Sc 10		Min	Min	Max	Sc 10	28	10	11	51	0.1227
Sc 11		Min	Max	Min	Sc 11	46	10	38	6	0.2895
Sc 12		Max	Min	Min	Sc 12	40	43	11	6	0.1545
					Consolidated wt	28.5	23.9	22.8	24.8	0.1761

Table E2. Scenarios[64] for weights to Affordability metrics for residential sector and calculated AFF Index

	Actual weights to Metrics			
Scenarios	R5	R6	R7	AFF Index
Sc 1	33	33	34	0.7902
Sc 2	33	33	34	0.7902
Sc 3	74	11	15	0.8619
Sc 4	55	11	34	0.7851
Sc 5	58	33	9	0.8913
Sc 6	74	17	9	0.8875
Consolidated wt	62.1	18.8	19.1	0.8471

[63]Scenarios are created by allocating minimum weights to two metrics, maximum weight to one metric and the balance is allotted to the fourth metric. Consolidated weights are shown for relative comparison.

[64] Scenarios are created by allocating minimum weights to one metric, maximum weight to another metric and the balance is allotted to the third metric and only actual weights are shown in the table. Consolidated weights are shown for relative comparison.

Table E3. Scenarios[65] for weights to Efficiency metrics for residential sector and calculated EFF Index

Scenarios	Actual weights to Metrics			
	R9	R10	R11	EFF Index
Sc 1	9	65	26	0.2431
Sc 2	9	45	46	0.3003
Sc 3	65	23	12	0.1598
Sc 4	31	23	46	0.2833
Sc 5	24	65	11	0.1886
Sc 6	65	24	11	0.1569
Consolidated wt	24	48	28	0.2364

Table E4. Scenarios[66] for weights to dimensions and calculated SES Index for the demand sub-system

Scenarios	Scenarios for weights to Dimensions				Actual weights to Dimensions				SES Index
	AVL	AFF	ACP	EFF	AVL	AFF	ACP	EFF	
Sc 1	Min	Min	Max		10	9	51	30	0.6483
Sc 2	Min	Min		Max	10	9	43	38	0.6394
Sc 3	Min	Max	Min		10	57	9	24	0.7788
Sc 4	Min		Min	Max	10	43	9	38	0.7272
Sc 5	Min	Max		Min	10	57	22	11	0.7932
Sc 6	Min		Max	Min	10	28	51	11	0.7184
Sc 7	Max	Min	Min		37	9	16	38	Not possible
Sc 8	Max		Min	Min	37	43	9	11	0.7734
Sc 9	Max	Min		Min	37	9	43	11	0.6856
Sc 10		Min	Min	Max	37	16	9	38	Not possible
Sc 11		Min	Max	Min	29	9	51	11	0.6808
Sc 12		Max	Min	Min	23	57	9	11	0.8011
				Consolidated weights	27.4	26.9	20	25.6	0.7093

[65] Same as note 64

[66] Scenarios are created by allocating minimum weights to two metrics, maximum weight to one metric and the balance is allotted to the fourth metric. Consolidated weights are shown for relative comparison.