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Socio-Economic Sustainability of Rural Energy Access in India

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Abstract

Rural energy access has been a persistent issue in India causing the country to become one of the most energy poor nations of the world. Despite the launch of several heavily funded programs for the provision of electricity and modern fuels to rural areas, majority of the country's village households remain neglected and deficient in energy. Calls have been made for the reconstruction of policies, programs and institutional frameworks that engage in dispersion of energy to the rural poor. Such policies, programs and institutional frameworks vary across different states within India. These differences need to be understood in depth to formulate suitable mechanisms for energy access. In particular, social and economic aspects of energy access need to be studied to overcome barriers in providing energy to the rural poor.

This study discerns how different states are performing in terms of providing sustainable energy access to rural people. It conducts an analysis of the socio-economic sustainability of energy access to the rural household in six states of the country (Andhra Pradesh, Himachal Pradesh, Maharashtra, Punjab, Rajasthan and West Bengal) over the course of two time periods(1996-2002, 2005-2011), with the aid of key performance indicators. Results indicate that all the states have improved their energy access conditions over the past few decades. However, the rates of growth are vastly different and some states still continue to remain highly inadequate in their performances. Punjab has consistently been the most successful state while West Bengal continues to be the most energy-poor state despite a reasonable growth in energy sustainability. The possible reasoning behind these disparities could be dissimilarity in economic development between the states, size and population density of the states, isolation of villages and ineffectiveness and inequity of subsidy schemes. These needs further exploration at individual state level. Transition to less-expensive and easily installable renewable technologies, communicating benefits of modern energy to rural population and channeling subsidies towards lower income groups can improve reach of modern energy towards the rural poor of India.

Keywords: Energy access, Indian states, rural areas, domestic sector, key performance indicators, Socio-economic Energy Sustainability Index

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Executive Summary

Majority of the developing countries in the world suffer from dearth of clean, efficient and modern cooking and lighting fuels, hampering their otherwise rapid rates of development. Also, there exist distinct rural and urban divides where priority is given to the provision of energy to easily accessible urban areas while neglecting isolated rural areas. This causes rural areas to fall behind their urban counterparts. It lowers their standards of living and engenders social and economic imbalances due to low productivities, health crises and gender gaps.

India is one such developing country that is struggling to cope with its quick pace of industrialization and growing energy demands. As of 2009, 36% of Indians did not have access to electricity while cooking energy lagged further behind with 70% of Indians continuing to use biomass. Kerosene and firewood remained the most popular fuel choices across the country. The urban-rural discrepancy was glaring with 92% of urban households being provided with electricity while only a meager 55% of rural households had access to electricity. Vast differences were also observed between the states, where the percentage of rural households using electricity as primary lighting energy varied between 96% and 10%, thus skewing the average national figures (Woodbridge et al., 2012).

The objective of this Master's thesis is to investigate the status quo of social and economic aspects of energy access to the rural households of the country. The study endeavors to meet an array of research targets. It intends to gauge the relative performance and trends of rural energy access in India over the past two decades by comparing and contrasting different regions of the country on the basis of energy access metrics. It strives to assess the rate of improvement or decline of energy access of these regions and to understand the reasons for the same. It also develops suggestions for improving energy access to the rural regions of the country based on lessons gleaned from the study.

In order to fulfill these objectives, a theoretical framework of key Social and Economic properties relevant to energy access was fashioned and compiled together to create an index called Socio-Economic Energy Sustainability Index (SEESI), believed to be a reliant and well-rounded indicator of energy access to the rural domestic sector of a developing country.

The first step in the methodology of this thesis involved the selection of states based on diversity in geography, culture, economic prosperity etc., The states that were chosen were Andhra Pradesh, Himachal Pradesh, Maharashtra, Punjab, Rajasthan and West Bengal. This was followed by a survey of various properties used to analyze energy access through a comprehensive literature review. These properties were found to belong primarily to five different dimensions: Technical, Economic, Social, Institutional and Environmental. To satisfy the study's goal of analyzing socio-economic energy sustainability, only the Social and Economic dimensions were examined exclusively and a few choice indicators were selected based on relevance, importance and availability. The indicators for the chosen states were gathered from secondary data sources such as online journals, publications, government archives, annual reports of organizations etc. and were compiled into a single, composite Socio-Economic Energy Sustainability Index by implementation of Principal Component Analysis using XLSTAT tool. The Socio-Economic Energy Sustainability Indices of the sample states were then compared and ranked to appraise successes and failures of the states over the period of study. Decomposition analysis was then performed through construction of radar diagrams with the primary indicators, enabling verification of authenticity of the Socio-Economic Energy Sustainability Index. Finally, conclusions and recommendations were developed based on results of the present study as well as past research about the topic.

It was deduced from the study that Punjab was consistently the best-performing state during the past two decades, ranking best among the six states in terms of socio-economic sustainability followed by Himachal Pradesh, Andhra Pradesh, Maharashtra, and Rajasthan. West Bengal was identified to be the least-performing state over the period of study, although showing a credible improvement over time.

Several conclusions and observations were derived from the above results. Income was found to be main influencing parameter to socio-economic energy sustainability. Punjab and Himachal Pradesh, two of the richest states in India, were found to have the highest SEESI while Maharashtra and West Bengal, two of the poorest states in the study obtained poor SEESI results. Andhra Pradesh and Rajasthan were found to be outliers with respect to the income-SEESI equation due to a number of reasons. Andhra Pradesh, despite its high rural poverty and low per capita income, achieved a radical growth in SEESI due to successful LPG initiatives that were implemented to combat depleting firewood supplies and forest cover. Other factors which were found to be significant were size and population density of states which were directly related to the level of penetration of energy. Rajasthan has an average income and rural poverty yet fared worse than some of the poorer states due to its expansive size and scattered population which imposed topographical and infrastructure challenges. This can be rectified by introducing renewable energy options, as in the case of Punjab where biogas and biomass technologies were distributed and informative training programs and workshops were conducted to communicate the benefits of modern cooking and lighting fuels to the rural society. On the other hand, in the case of Maharashtra and West Bengal, high population densities posed as obstacles to the achievement of more thorough access to energy. Nature of distribution of subsidies was also found to be a prominent factor. Successful states like Punjab and Himachal Pradesh followed a pattern of equitable distribution of subsidies (high, middle and low-income groups) while poorly performing states such as West Bengal and Rajasthan focused their subsidies on grid-connection targeting middle and high-income areas. Improvement was more noteworthy in access of modern fuels for lighting than cooking purposes and a large number of rural households still consumed traditional fuels.

Based on the above results and conclusions, the study proposes a set of recommendations. The states on the lower end of the energy access spectrum must follow strategies adopted and proven effective by the more successful states. Subsidy programs must be restructured to channel more funds to disconnected and lower income households. Subsidies must also be allotted for the right kind of fuels such as those more likely to cross cultural barriers and more prone to be embraced by rural households. Development in the energy sector must be communicated through seminars/ workshops to the public. Setup of more elaborate energy programs must be established to enable enriched and ample permeation of energy in the more densely populated states. Special consideration must be given to the more isolated villages and extra efforts must be taken to make energy access more inclusive. Transition to cheaper and more efficient renewable energy technologies would vastly bolster energy access sustainability levels in all states. Continuous measurement of the socio-economic indicators used in this paper and other similar studies must be conducted to monitor and track progress/decline in energy access throughout the country.

1 Introduction

1.1 Background

In 2005, 28.4% of the rural and 8.6% of the urban world population without access to electricity, and 33.8% of the rural and 23% of the urban world population without access to modern cooking fuels belonged to India (Balachandra, 2011). India's annual rate of growth of energy access has drastically reduced to a mere 4%.

Due to rapid industrialization, electricity demand of the country has been exponentially increasing, but its electricity consumption per capita is still one of the lowest in the world (Niez, 2010). The generation capacity has improved substantially but is unable to supply this growing demand (Modi, 2005; Niez, 2010). The transmission system of the country is unstable with no cohesive grid system and the distribution system is one of the worst in the world because of technical losses, theft of power etc., amounting to 33.7% of total generating capacity. In 2009, thermal power accounted for 60%, hydropower for 24.5%, nuclear power for 2.7% and other renewable energies for a mere 8.8 % of the total installed capacity (Niez, 2010). The consumption of renewable energy has been highlighted as the way for the future; however, it faces several institutional, financial and technological challenges.

In order to address the persistent problems of energy provision to the rural poor, the Government of India has been taking serious measures for more than 50 years (Table 1). Programs for access to better cooking fuels began in 1957 culminating in the more recent National Biomass Cookstove Initiative. To combat the rural electrification crisis, programs stimulated by the Green Revolution began in the 1960s (Oda & Tsujita, 2011) with establishment of the Rural Electrification Corporation. Since then, the Electricity Act (2003), National Electricity Policy (2005) and the Rural Electrification Policy (2006) have been passed to aid these efforts.

Table 1: History of energy programs in India (Source: Balachandra, 2011; Bilolikar & Deshmukh, 2007)

Program	Purpose/Outcome
Supply of kerosene through public distribution system (PDS)- 1957	Households are allotted kerosene consumption quotas that vary by state & region (urban & rural). Nearly 40% of the PDS kerosene gets illegally diverted & is used to adulterate diesel and petrol for transport.
Subsidies on household cooking fuels like kerosene and LPG- late 1960s	Intended to provide affordable access to modern fuels for the poor. Subsidy on LPG is available for all consumers irrespective of income levels. Subsidy on kerosene is available for those without LPG connection. Thus, subsidies are not targeted at the poor.
Minimum Needs Programme- 1974	Provided 100% loans from the central government for last mile connectivity for rural electrification projects in less electrified states.
National Project on Biogas Development (NPBD)- 1982	Disseminated domestic biogas plants, modern cooking fuels and organic fertilizer to rural households. Only about 28% of biogas plants provide primary cooking fuel to relatively rich rural households.
National Programme on Improved Chulhas (NPIC)- 1983	Disseminated advanced biomass cook stoves. Efficient use of fuel wood and avoid deforestation, reduce drudgery for women and health hazards caused by indoor pollution. By 2003, over 35 million stoves had been built; however, the NPIC found to be ineffective in promoting a shift to improved stoves therefore the funding was stopped in 2002.

Kutir Jyoti Scheme- 1988	Provided a single point lighting connections to households below the poverty line (BPL). Connected nearly 7.2 million rural households to the grid till March 2006.
PM's Village Development Program- 2000	Rural electrification was one of the many programs. It offered financing through loans (90%) and grants (10%).
Rural Electricity Supply Technology Mission- 2002	Electrification of all villages and households progressively by year 2012 through renewable energy sources and decentralized technologies, in addition to conventional grid connection.
Accelerated Rural Electrification Programme (AREP)- 2003	Interest subsidy of 4% was provided on loans availed by state governments/power utilities, limited to electrification of un-electrified villages, smaller settlements of lower-caste people and tribal villages, and through both conventional & non-conventional sources of energy
Accelerated Electrification of one lakh villages and one crore households- 2004	Village and household electrification. Accelerated electrification of 100,000 villages and 10 million households by merging the interest subsidy scheme of AREP and Kutir Jyoti programme. Provision was made for providing 40% capital subsidy and the balance as loan assistance on soft terms from REC
Rajiv Gandhi GrameenVidyutikaranYojana (VillageElectrification Programme)- 2005	Development of rural electricity infrastructure and household electrification with 90% capital subsidy and 10% loan assistance. Final connection is provided free of cost for BPL households. Achieved electrification of 79,000 villages and 12 million rural households
National Biomass Cook stove Initiative- 2009	A follow-up to the NPIC, to battle Indoor Air Pollution and climate changes.

Most of these programs were vastly unsuccessful due to prominent corruption involving illegal use of funds and subsidies, and diversion of allocated resources to other low-priority end users, wasteful provision of subsidies that left low income groups unattended and poor construction of equipment and infrastructure (Balachandra, 2011).

The energy scenario in India in the recent past has seen involvement of the private sector and public participation in the government's energy projects (Ministry of Power-India, 2005). There has been more focus upon rural areas, as mandated by the Rural Electrification Policy of 2006 (Ministry of Power-India, 2006) and attempts at transition to renewable energy sources. Although lessons learned from the ineffectuality of these initiatives resulted in establishment of a more adept institutional and financial model of energy access, the execution of these programs has not been optimum due to social and economic gaps. Furthermore, several factors exist which oppose and work against the possibility of sustainability of these initiatives (Hiremath et al., 2010).

1.2 Objective

The objective of this research study is to provide a perspective of socio-economic sustainability of energy access to rural households in India.

The study intends to gauge the trends of rural energy access for the rural domestic sector of the country over the past two decades by comparing and contrasting different geographical locations on the basis of key energy access indicators. Six states with different profiles, such as geographical location, economic prosperity, education, standard of living, urbanization etc. will be selected. Rural households of these states will be contrasted over a period of time to deduce which states have emerged successful and which have failed in socio-economic energy access sustainability.

Thus, the study strives to assess the rate of improvement or decline of energy access to various rural regions and to understand the reasons for the same. It also develops suggestions for improving energy access to the rural regions of the country based on lessons gleaned from the study.

1.3 Profiles of states under study

The six states that have been chosen for the study are of different climatic, geographical, social and economic profiles. These states are Andhra Pradesh, Himachal Pradesh, Maharashtra, Punjab, Rajasthan and West Bengal and have been highlighted in Figure 1.

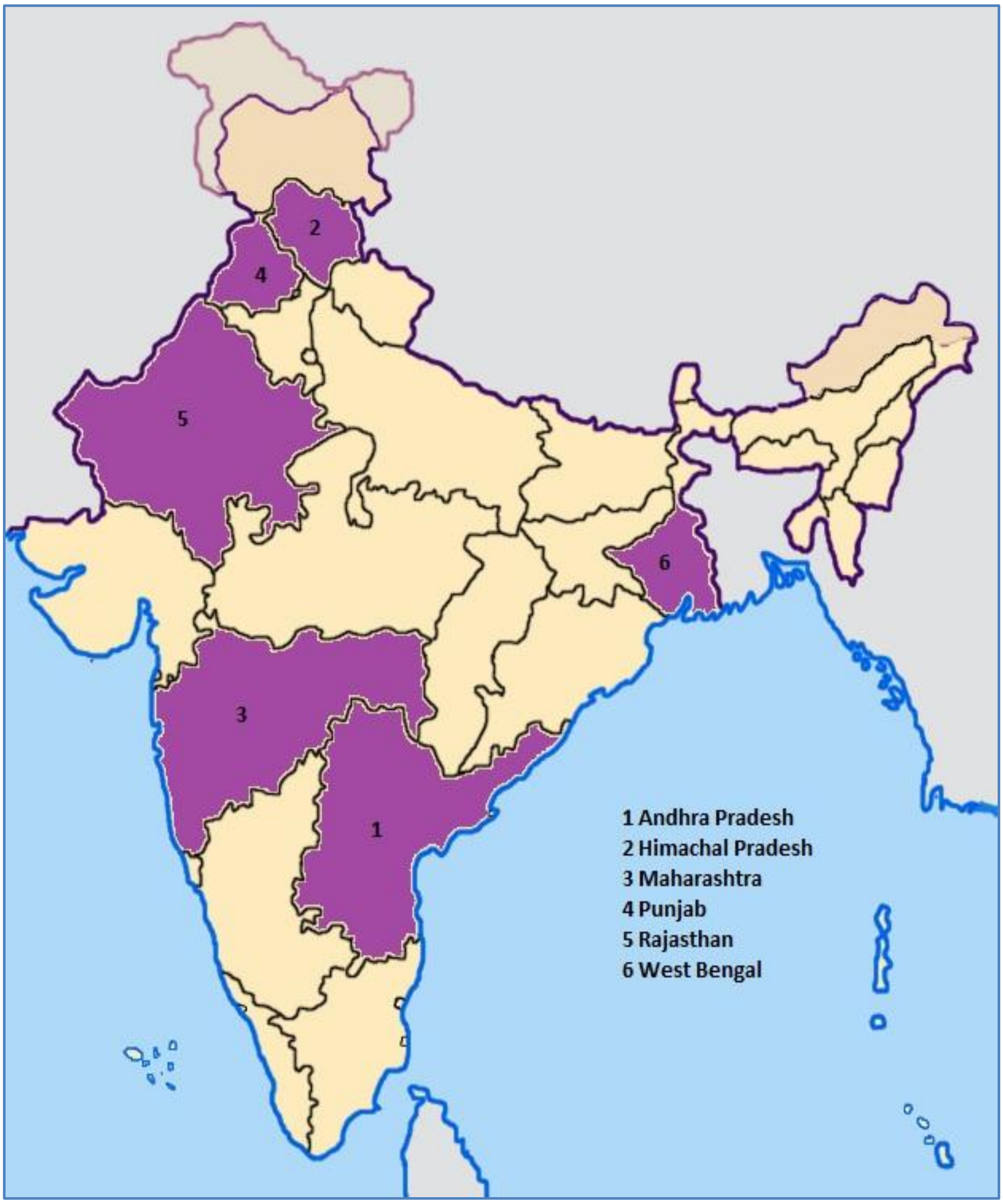

Figure 1: Selection of states for the study

1.3.1 Andhra Pradesh

Andhra Pradesh is the eighth largest state in India with a total land area of 27.5 million hectares. It is located on the south-eastern coast of India and has the second longest coastline in the country. The coastal location of the state led to its manufacturing and export-centric economy. It is also an exporter of several agricultural products and is referred to as the rice-bowl of India. However, the Human Development Index of the state lags behind other major states of the country and has been consistently lower than the national average.

According to the census of 2001, the total population of the state was 76.2 million with a population density of 277 per square km where 73% of the total population was concentrated in the rural areas. Rural poverty was at a substantial 39% and 40% of the population was illiterate (the rural literacy rate being 54.5%). The average monthly income per household was 41USD. The monthly energy use per capita was lowest for the studied states at 18.7KgOE. Fuel wood was the most popular fuel, accounting for 57% of the energy mix, followed by crop residue at 29% (ESMAP, 2002).

By 2011, the population of the state had increased to 84 million, placing tenth in the country, and its population density had risen to 308 per square km. 66.5% of the population was concentrated in the rural areas and the state literacy rate had increased to 67%, with the rural literacy rate being 60.45%. The state encountered the greatest reduction of rural poverty among the six states to 10.96%and the average monthly household expenditure was45 USD (Census, 2011). Firewood was the primary cooking fuel (80%) and electricity was the primary lighting fuel (84%) (Woodbridge, 2012).

Table 2: State profile- Andhra Pradesh

Parameter	2001	2011
Area (million hectares)	27.5	
Population (million)	76.2	84
Population density (persons/ sq. km)	277	308
Percentage of rural population (%)	73	66.5
Percentage of rural poverty (%)	39	10.96
Literacy rate (%)	60	67
Rural literacy rate (%)	54.5	60.45
Monthly household income (2001); Monthly household expense (2011) (in USD)	41	45

1.3.2 Himachal Pradesh

Himachal Pradesh has the second highest rural household incomes among the states in the study and third in the whole country due to its burgeoning hydroelectric power industry, tourism and agriculture. Despite its challenging topography, infrastructure in the state is well-established with well-maintained roads and good sanitation facilities.

The state has a total land area of 5.6 million hectares and is one of the smaller states in the country. According to the census of 2001, the total population of the state was 6 million with a population density of 109 per square km. 90.2% of the population was rural, making it one of the most rural states in the country and 23.5% of the population was illiterate (the rural literacy rate being 75%). The percentage of rural poverty was 25% with the average monthly income per household being97 USD. The monthly energy use per capita was 32.6 KgOE. Fuel wood was the dominant fuel, accounting for 89% of the energy mix (ESMAP, 2002).

In 2011, the population of the state had become 6.85 million with a population density of 123 per square km and it continued to remain one of the least densely populated states in the study. The rural population still constituted a massive 89.96% with a high rural literacy rate of 81.85%. Rural poverty reduced to a mere 8.48% and the average monthly household expenditure was54 USD (highest among the states). Firewood was the primary cooking fuel (76%) and electricity was the primary lighting fuel (98%) (Woodbridge, 2012).

Table 3: State profile- Himachal Pradesh

Parameter	2001	2011
Area (million hectares)	5.6	
Population (million)	6	6.85
Population density (persons/ sq. km)	109	123
Percentage of rural population (%)	90.2	89.96
Percentage of rural poverty (%)	25	8.48
Literacy rate (%)	76.5	84
Rural literacy rate (%)	75	81.85
Monthly household income (2001); Monthly household expense (2011) (in USD)	97	54

1.3.3 Maharashtra

Maharashtra is located on the western coast of India and is the country's most populous state. It is known for its flourishing economy and is referred to as the financial capital of the country. It is the hub of the nation's globally famous entertainment industry, thus attracting migrants from all over India.

The state has a total land area of 30.8 million hectares. According to the census of 2001, the total population of the state was 96.8 million with a population density of 315 per square km. 57.57% of the population was rural with a state literacy rate of 76.88% and a rural literacy rate of 70.36%. The monthly energy use per capita was 36.6 KgOE (highest for the studied states). Fuel wood was the most popular fuel, accounting for 51% of the energy mix, followed by crop residue at 30% (ESMAP, 2002).Rural poverty was at 42% and the average monthly income per household was 58 USD. When the overall state Human Development Index was measured, it stood in the top five; however, when the rural HDI was computed, it fell to the bottom five with only the country's poorest states like Uttar Pradesh lagging behind it. The state fared poorly in terms of infrastructure, housing and sanitation facilities as well.

In 2011, the population had risen to 112 million with a density of 365 per square km. Only 54.7% of the population was rural, making it the most urban-centric state of this study. The state literacy rate had increased to 82.34% with a rural literacy rate of 77%. Firewood was the primary cooking fuel (75%) and electricity was the primary lighting fuel (76%) (Woodbridge, 2012).Maharashtra has the third highest per capita incomes in the country, surpassing the national average by a large margin. However, the prosperity is restricted only to the urban areas. The urban-rural disparity in the state was evident since it continued to remain the most rural-poor of all the sample states despite rural poverty having fallen considerably to 24.22%, with an average monthly household expenditure of 48 USD (Census 2011).

Table 4: State profile- Maharashtra

Parameter	2001	2011
Area (million hectares)	30.8	
Population (million)	96.8	112
Population density (persons/ sq. km)	315	365

Percentage of rural population (%)	57.57	54.7
Percentage of rural poverty (%)	42	24.22
Literacy rate (%)	76.88	82.34
Rural literacy rate (%)	70.36	77
Monthly household income (2001); Monthly household expense (2011) (in USD)	58	48

1.3.4 Punjab

Punjab is the richest among the six states as a result of its status as a forerunner in the agricultural sector due to its high productivity of land. This was enhanced by the state's exceptional yields from the Green Revolution which led to it being far more economically developed than other states in the country. Due to its flourishing economy, the state has consistently maintained a Human Development Index that surpasses the national average. The state is also famous for its developed housing and success in the manufacturing sector.

Punjab has a total land area of 5 million hectares hence it is the smallest state in the study. According to the census of 2001, the state population was 24.3 million with a population density of 484 per square km. The rural population constituted 66% of the total population. The literacy rate of the state was 69.65% with a rural literacy rate of 64.72%. Rural poverty was at 11% with an average monthly household income of98 USD. The monthly energy use per capita was 30.1 KgOE. Dung cake was the most prominent fuel, accounting for 48% of the energy mix, followed by fuel wood at 29%. Monthly electricity use was 1.2 KgOE, highest among the studied states (ESMAP, 2002).

The census figures of 2011 showed that the state population had risen to 27.7 million with a population density of 551 per square km. 62.51% of the population was now rural with a rural literacy rate of 71.42%. The state literacy rate stood at 75.84%. Rural poverty rates were at 7.66%, thus making Punjab the least poor of all the states, with an average monthly household expenditure of 53 USD. Firewood and LPG were the primary cooking fuels (31% and 24% respectively) and electricity was the primary lighting fuel (96%) (Woodbridge, 2012).

Table 5: State profile- Punjab

Parameter	2001	2011
Area (million hectares)	5	
Population (million)	24.3	27.7
Population density (persons/ sq. km)	484	551
Percentage of rural population (%)	66	62.51
Percentage of rural poverty (%)	11	7.66
Literacy rate (%)	69.65	75.84
Rural literacy rate (%)	64.72	71.42
Monthly household income (2001); Monthly household expense (2011) (in USD)	98	53

1.3.5 Rajasthan

Rajasthan is the largest state in India and is located in the north-western region of the country. The state consists mostly of arid, desert areas and regularly faces shortage of water due to its unfortunate weather conditions which acts as a major hindrance to its regional development (Planning Commission, 2006).

The total land area of Rajasthan is 34.3 million hectares, rendering it the biggest state of this study. The census of 2001 showed that the state had a population of 56.5 million with a population density of 165 per square km. The percentage of rural population was 76.6%. The state had a literacy rate of 60.41% while the rural literacy rate was 55.34%. Rural poverty was at 37% with an average monthly household income of82 USD. The state had the third highest household income among the six states yet had high rural poverty. This indicates disparity in the distribution of wealth within the rural community. The monthly energy use per capita was 33 KgOE. Fuel wood was the dominant fuel, accounting for 60% of the energy mix, followed by dung cake at 27%. Monthly electricity use was only 0.1 KgOE, which was lowest among the studied states (ESMAP, 2002).The state lagged severely behind in fuel choices due to the large and impenetrable topographical conditions. The large state has highly dispersed population and connecting these scattered villages to electricity and providing them with modern cooking fuels was a big challenge. This was further fuelled by the fluctuating economy of the state. Due to these obstacles, the state continued to depend on firewood and even switched to more inferior fuels due to depleting firewood supply.

The census of 2011 showed that the state population figure was now 68.5 million with a population density of 200 per square km. The rural population comprised of 75.13% of the total population. The literacy rate of the state was 66.11% with a rural literacy rate of 61.44%. Rural poverty fell drastically to 16.05%, however, so did the average monthly household expenditureto40 USD (least among the states). Firewood was the primary cooking fuel (94%) and kerosene continued to remain the primary lighting fuel (52%) due to lack of connectivity to electricity (Woodbridge, 2012).

Table 6: State profile- Rajasthan

Parameter	2001	2011
Area (million hectares)	34.3	
Population (million)	56.5	68.5
Population density (persons/ sq. km)	165	200
Percentage of rural population (%)	76.6	75.13
Percentage of rural poverty (%)	37	16.05
Literacy rate (%)	60.41	66.11
Rural literacy rate (%)	55.34	61.44
Monthly household income (2001); Monthly household expense (2011) (in USD)	82	40

1.3.6 West Bengal

West Bengal is a state in eastern India and it is one of the most highly as well as densely populated states in the country. West Bengal has a total land area of 8.9 million hectares. The 2001 census of the state showed that it had a population of 80.17 million while its population density was 903 per square km (the highest among the studied states). The rural population constituted 72% of the total population. The state had a literacy rate of 68.64% with a rural literacy rate of 63.42%. West Bengal is the poorest among the six states with rural poverty at 40% and an average monthly household income of merely 49 USD, the lowest among the states. The monthly energy use per capita was 26 KgOE. Crop residue was the dominant fuel, accounting for 41% of the energy mix, followed by fuel wood at 27% (ESMAP, 2002).

The 2011 census showed that the state's population had gone up to 91.28 million and the population density had increased to a staggering 1028 per square km. 68.13% of the population was rural with a literacy rate of 72.13% while the overall state literacy rate was 76.26%. Rural poverty was at 22.52% with an average monthly household expenditure of only 40 USD, the second lowest among the studied states. Firewood was the primary cooking fuel (74%) and kerosene was the primary lighting fuel (65%) (Woodbridge, 2012). The state's conventional energy reforms and policies remained futile against the invariable poverty in the state. Hence, nearly 80% of the rural population continued to remain without grid power (Planning Commission, 2002).

Table 7: State profile-West Bengal

Parameter	2001	2011
Area (million hectares)	8.9	
Population (million)	80.17	91.28
Population density (persons/ sq. km)	903	1028
Percentage of rural population (%)	72	68.13
Percentage of rural poverty (%)	40	22.52
Literacy rate (%)	68.64	76.26
Rural literacy rate (%)	63.42	72.13
Monthly household income (2001); Monthly household expense (2011) (in USD)	49	40

2 Methodology and Data source

The study will measure the social and economic aspects of rural energy sustainability in the sample states through the development and comparison of an index called Socio-Economic Energy Sustainability Index (SEESI). The SEESI is a composite indicator that is derived from a set of relevant individual indicators through Principal Component Analysis technique. The indicators are chosen with reference to data sources such as Mainali et al., (2014), ESMAP (2002), Woodbridge et al., (2012), Kemmler and Spreng (2006), Tsai (2010) etc., The indicators for the sample states were identified through data collection from a literature review of secondary data sources.

2.1 Indicators

According to OECD (2008), an indicator is "a quantitative or qualitative measure derived from a series of observed facts that can reveal relative positions (eg. of a country) in a given area". These indicators can be measured on a regular basis to comprehend the temporal trends of the area in question. These tools have proven to be vastly successful in the analysis of statistical data and in establishing connections between different dimensions and stakeholders of a system (Ilskog, 2008). They are capable of effectively monitoring changes and the long-term consequences of present actions. As per the IAEA handbook from the year 2005, "changes in the indicator values over time mark progress or lack of progress towards sustainable development."

Composite indicators are derived from individual indicators to provide simpler constructs of more complex systems such as the environment, society, economy etc (OECD, 2008). These composite indicators are condensed into single units from complex, multi-dimensional quantities without losing the central information. According to Saltelli (2007), it is easier to identify trends from a composite indicator than to decode several individual indicators. Saisana &Tarantola (2002) state that the use of composite indicators can aid communication between policy-makers and the general public, and ease access to explicable data.

The OECD handbook provides a set of steps that can be followed for optimal construction, evaluation and propagation of composite indicators. These steps have been followed as effectively as possible for implementing this study. They are as follows:

1. *Theoretical framework:* The theoretical framework is designed as a backbone for the combination of the individual indicators into the composite indicator.
2. *Data selection:* The data is selected based on factors such as relevance to context, linkages amongst indicators, capability of showcasing essential information and availability.
3. *Multivariate analysis:* The analysis is intended to process the collected data with the help of a suitable tool/software.
4. *Normalization:* The data is normalized so that the figures become comparable with each other.
5. *Robustness and sensitivity:* The robustness of the composite indicator is analyzed by re-evaluating the previous steps.
6. *Retracing of data:* A decomposition analysis should be able to be carried out i.e. the composite indicator should be able to retraced back to the individual indicators.
7. *Presentation:* The composite indicators should be presented such that easy inferences can be drawn.

2.2 Theoretical framework

2.2.1 Composite indicators for sustainable development

There exist several popular frameworks for the construction of composite indicators for the evaluation of sustainability. One such framework was constructed by the United Nations Commission on Sustainable Development (CSD) and it included four main dimensions- Social, Economic, Environmental and Institutional. Others such as Wang (2009) and Ilskog (2008) included a Technical dimension as well to further enhance this evaluation. These five dimensions have been deemed holistic for the measurement of indices appertaining to several sub-themes of sustainable development. One such index that monitors progress in the provision and access of energy has been labeled the Energy Sustainability Index (ESI) (Doukas, 2012; Khandker et al., 2012; Mainali & Silveira, 2015)

2.2.2 Dimensions of Sustainable Development

The set of indicators being used for statistical analysis has grown over time to be highly inclusive and exact. After the derivation of the framework by CSD and conclusions drawn from Agenda 21, the UN Department of Economic and Social Affairs (UNDESA) produced a set of indicators for sustainable development (IAEA, 2005). Following is a list of popular indicators belonging to this set that have been used by successful studies (Kemmler, 2006; IAEA, 2007; Zhang, 2009; Wang, 2009; Tsai, 2010; Doukas, 2012; Khandker et al., 2012) to determine composite energy indicators. Each of these dimensions and the corresponding indicators has been explained within the context of energy studies.

2.2.2.1 Technical dimension

An important requirement of an energy project is that it be technically sustainable (Ilskog, 2008). Technical sustainability is based upon factors such as operation of the equipment, supply and utilization of fuel, performance quality of administration etc. Three main indicators that have been considered for this purpose are efficiency, primary energy ratio and reliability. *Efficiency* is defined as the ratio of plant output to plant input (technology's ability to convert the primary energy source to electricity). *Primary energy ratio* is defined as ratio of consumption of primary energy to the users' demand energy. *Reliability* is defined as a measure of constancy of energy services (Wang, 2009).

Table 8: Popular indicators of technical dimension

No.	Name of indicator	References
1.	Efficiency	Kemmler and Spreng, 2006; Wang et al., 2009; Jovanic et al., 2008; Doukas et al., 2006; Pilavachi et al., 2006, 2008, 2009; Afgan and Carvalho, 2001, 2004, 2008; Begic and Afgan, 2004; Mamlook et al.,2000, 2001; Akash et al., 1996, 1998; Dinca et al., 2007; Mainali et al., 2014
2.	Primary energy ratio	Wanget al., 2008, 2009; Huang et al., 2005; Beccali et al., 2003
3.	Reliability	Mamlook et al., 2000, 2001; Mohsen and Akash, 1996; Chatzimouratidis and Pilavachi,2008, 2009; Dinca et al., 2007; Wang et al., 2009

2.2.2.2 Economic dimension

Economic sustainability may refer to a wide array of aspects. The products and services should encourage economic development (Ilskog, 2008) while ensuring affordability for consumers as well as investors and distributors. The tariffs must be sufficient for all operating and re-investment capital costs. *Annual electricity consumption per household* is measured as the ratio of electricity use in households to total number of households per year. *Percent of household income spent on energy* is defined as the ratio of household income spent on fuel and electricity to the total household income. *Renewable energy share in energy and electricity* is defined as the ratio of primary energy supply and final consumption, electricity generation and generating capacity by renewable energy to the respective total value. The fourth indicator, *end-use energy prices by fuel type*, is given by the actual prices paid by the final consumer for energy with and without taxes and subsidies (IAEA, 2005).

Table 9: Popular indicators of economic dimension

No.	Name of indicator	References
1.	Annual electricity consumption per household	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; IEA(various editions); EEA, 2002; IEA, 2004; United Nations Division for Sustainable Development, 2007; Kemmler and Spreng, 2006; Tsai, 2010; Woodbridge et al., 2012;ESMAP, 2002; Mainali et al., 2014
2.	Percent of household income spent on energy	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; IEA(various editions); World Bank, UNICEF (Various editions); Schipper, et al., 1985; Woodbridge et al., 2012; ESMAP, 2002; Mainali et al., 2014
3.	Renewable energy share in energy and electricity	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; IEA, World Bank(various editions); UNSD, 1991; EEA, 2002; United Nations Division for Sustainable Development, 2007; Ilskog and Kjellstrom, 2008; Ilskog, 2008; Tanguay et al., 2009; Tsai, 2010; Doukas et al., 2012; Mainali et al., 2014
4.	End-use energy prices by fuel and by sector	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; EEA, 2002; Mainali, and Silveira, 2011

2.2.2.3 Social dimension

Social sustainability is a high-priority dimension since it focuses on the energy access and behavioral tendencies of the stakeholders. *Share of households with electricity* is an indicator that is given by the ratio of households with electricity or commercial energy to the total number of households. *Access to modern cooking fuels* is given by the average percentage of households using electricity, LPG or kerosene for cooking. *Household energy use for each income group and the corresponding fuel mix* is given by the ratio of energy use per household for each income group to the total household income for each income group and the corresponding fuel mix for each income group.

Table 10: Popular indicators of social dimension

No.	Name of indicator	References
1.	Share of Households with Electricity	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; IEA, World Bank, UNICEF (various editions); UNSD, 1991; WEC, 2000;United Nations Division for Sustainable Development, 2007; IAEA/ UNDESA, 2007; Ilskog and Kjellstrom, 2008; Ilskog, 2008; ESMAP, 2002; Woodbridge et al., 2012; Mainali et al., 2014
2.	Access to modern cooking fuels	NSS 2000, 2010; Pandey and Chaubal, 2011; Joon et al., 2009; Mainali et al., 2014

3.	Household energy use for each income group and corresponding fuel mix	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; IEA, World Bank, UNICEF (various editions); Ilskog and Kjellstrom, 2008; Ilskog, 2008

2.2.2.4 Institutional dimension

Institutional or organizational sustainability refers to factors such as the quality of management of the project, involvement of stakeholders in the project (given by the *degree of local ownership* measured as the ratio of locally owned facilities to total facilities), and the customers' *level of satisfaction with the energy services* (Ilskog, 2008).

Table 11: Popular indicators of institutional dimension

No.	Name of indicator	References
1.	Degree of local ownership	Ilskog, 2008
2.	Level of satisfaction with energy services	Ilskog, 2008

2.2.2.5 Environmental dimension

Environmental sustainability is a measure of environmental responsibility of the project and the level of adherence to local and national legislations (Ilskog, 2008). This is assessed by indicators such as *land use* (which is the amount of annual land use and degradation due to energy production and consumption) and *greenhouse gas emissions from energy production and use per capita and per unit of GDP* (which is given by two values- ratio of total annual GHG emissions to total annual energy production and use; ratio of total annual GHG emissions to GDP) (IAEA, 2005).

Table 12: Popular indicators of environmental dimension

No.	Name of indicator	References
1.	GHG emissions from energy production and use per capita and per unit of GDP	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005;World Bank, IEA, (various editions);EEA, 2003;IPCC, 2001;United Nations Division for Sustainable Development, 2007; Ilskog and Kjellstrom, 2008; Ilskog, 2008; Kemmler and Spreng, 2006; Tanguay et al., 2009; Tsai, 2010; Wang et al., 2008, 2009; Jovanic et al., 2008; Pilavachi et al., 2008; Afgan and Carvalho, 2001, 2004, 2008; Huang et al., 2005; Pilavachi et al., 2006, 2007, 2008; Liposcak et al., 2006; Beccali et al., 2003; Diakoulaki and Karangelis,2007; Cavallaro and Ciraolo, 2005; Burton and Hubacek,2007; Papadopoulos and Karagiannidis,2008; Løken et al., 2009; Mainali et al., 2014
2.	Land use	IAEA/ UNDESA/ IEA/ EUROSTAT/ EEA, 2005; United Nations Division for Sustainable Development, 2007; Wang et al., 2008, 2009; Afganand Carvalho, 2001, 2004; Pilavachi et al., 2006, 2008; Beccali et al., 2003; Madlener et al., 2007

2.2.3 Selection of dimensions and indicators

The indicators mentioned above have been repeatedly used to gauge data and produce effective results in several case studies involving energy studies, both from the supply and demand perspectives. The supply perspectives mostly cover technological details and the interests of the supply end of the network (such as the government, energy agencies and other stakeholders that constitute the energy supply chain) that ensure optimal functioning of the energy provision network while the demand perspectives include those details that exclusively cater to the needs of the recipients.

Some of the indicators in this abridged list, although being highly useful to assess the dynamics of the energy network, are more relevant only from the supply side. These indicators concentrate more upon defects in technological criteria and when measured, will contribute only towards improvement of supply side facilities, having only few impacts upon the issues of energy access. Hence, they are deemed to be extraneous for this study which intends to deal with demand size aspects and focus solely upon energy recipients.

Also, Energy Sustainability Indices (ESIs) are considered accurate when calculated with indicators from all five dimensions. However, this study intends to focus only on the socio-economic aspects of energy access, hence only the Social and Economic dimensions are retained. The resulting index may be labeled as Socio-Economic Energy Sustainability Index (SEESI) and this will provide an outlook on the energy access scenario in the rural households of various states of India. Table 13 shows a more elaborate account of the economic and social dimensions of energy sustainability and the reasoning behind the subsequent selection of indicators within these dimensions follows.

Table 13: Selected dimensions with selected indicators

Name of indicator	
Economic dimension	**Social dimension**
Annual electricity consumption per household	Share of Households with Electricity
Percent of household income spent on energy	Access to modern cooking fuels
Renewable energy share in energy and electricity	Household energy use for each income group and corresponding fuel mix
End-use energy prices by fuel and by sector	

The selected list of socio-economic indicators is as follows:

2.2.3.1 Economic dimension

Availability of modern energy at every level of the society reflects the economic growth of a country. Energy pricing is one factor that dictates consumption patterns which subsequently advances the economic welfare of the society, fosters development& productivity and ensures the elevation of the country to the level of its developed counterparts. The economic dimension is a vital pillar of sustainable development and in order to strengthen it, energy security needs to be maintained by delivering affordable energy at right times in necessary quantities to all sections of the society (IAEA, 2005).

- *Annual electricity consumption per household*: It is the ratio of electricity use in households per year to the total number of households. Electricity-use patterns provide an understanding of the quality of the services that have been provided to a society. This value is an indicator of effective utilization of energy resources since energy efficiencies, amongst several other factors, affect consumption of electricity. On one hand, higher electricity consumption figures signify lack of environmental awareness and pressure on the government to meet growing demands. On the other hand, it is an indicator of economic growth especially in developing countries. Higher the consumption of electricity in rural areas, lesser is the reliance on traditional fuels for lighting and sometimes, even heating and cooking purposes(IAEA, 2005). Thus, when this figure is measured for rural households, it implies an overall growth for the community.

- *Percentage of household income spent on fuel and electricity:* It is the ratio of household income spent on fuel and electricity to the total household income. This indicator demonstrates the degree of energy affordability for the average Indian household. This is a significant figure for this study since programs for improving energy access become redundant if the supplied energy isn't affordable for the customers. Depending on income levels of stakeholders, the amount that households need to expend can be regulated in order to promote modern and efficient energy technologies. They are also driving forces for determination of allocation of subsidies for appropriate segments of population, moderation of fuel prices etc., and hence are vital for sustainable social and economic development (IAEA, 2005).

Renewable energy share in energy and electricity has been regarded as a key indicator for measuring the adaptability to modern and environment-friendly technologies. This indicator provides insights into the amount of energy diversification in the country (IAEA, 2005). In order to meet escalating energy demands while battling the depletion of traditional energy sources, transition to renewable energy technologies is of utmost importance. These figures aren't easy to obtain in the case of developing countries since renewable energy technology is a new and rare phenomenon in rural areas and data is sporadic. This indicator has been eliminated in this study; nevertheless, it is an important indicator to be considered for similar studies in the future.

End-use energy prices by fuel type is an important indicator since it affects affordability, amount of consumption of energy and reflects the economy of the state. This value signifies regulation needs wherein costs can be internalized to promote affordability (IAEA, 2005).Optimal pricing of energy can enhance efficient utilization of energy while attracting more users towards the right type of technology. Due to scarcity of data for this indicator, it has been excluded in this study. However, it is to be noted that similar insights can be drawn from the indicator 'percentage of household income spent on fuel and electricity'.

2.2.3.2 Social dimension

Energy access is highly correlated to several aspects of the social dimension such as poverty, population, education, health and gender implications. In first-world countries, energy is clean, affordable and easily accessible whereas in developing and under-developed countries, traditional and inefficient fuels are used which consume a large amount of time and affect health and family incomes. Inept fuels and technologies cause respiratory diseases over time. Women in poor rural households are forced to spend a vast portion of their day collecting firewood. Because of poor infrastructure and planning, people in developing countries may have to pay more for these inefficient fuels than their counterparts in developed countries have to pay for safe fuels (IAEA, 2005).

The social dimension has two themes: Equity and health. Social equity has the sub-themes of accessibility, affordability and disparities (IAEA, 2005). As defined by the IAEA, "Social equity is one of the principal values underlying sustainable development, involving the degree of fairness and inclusiveness with which energy resources are distributed, energy systems are made accessible and pricing schemes are formulated to ensure affordability." The other theme "Health" focuses on using energy such that it renders no harm to health due to accidents through use of equipment, indoor air pollution etc.,

- *Percentage access to modern cooking fuels*: It is the percentage of population that has access to modern cooking fuels such as LPG, kerosene and in rare cases, electricity. It is given by the average percentage of households using any of the above mentioned fuel types. Despite having access to electricity, many rural households still rely on antiquated cooking fuels such as dung cakes, firewood, bagasse etc., due to various reasons such as ease of use, socio-economic attitudes of the households, affordability etc. Most households use a mix of various fuels, both commercial and traditional. Although electrified, several households may use the electricity only for lighting and other purposes and retain traditional fuels for cooking (IAEA, 2005). Hence, this indicator is useful in probing the permeability of modern fuels in the cooking sector in the average rural Indian household.

- *Percentage of households with electricity:* It is the ratio of households with electricity or commercial energy to the total number of households. This indicator is significant for tracing evolvement in both accessibility and affordability of electricity services to the public (IAEA, 2005). Deficit of electricity access affects the quality of basic services such as food, sanitation, health care, education and communication facilities. Thus, it is viewed as a primary goal of sustainable development to furnish rural areas of developing countries with electricity in order to combat poverty and contribute to continued social and economic development.

Household energy use for each income group and the corresponding fuel mix is an important indicator since it measures the level of disparity between the different income classes of the country and also sheds light on fuel preferences in households. However, very few studies have been conducted to obtain this indicator on a rural, state-wise basis. Hence it has been eliminated for the purpose of this study due to lack of availability of necessary data. It is recommended that this indicator be included in future studies, if data is accessible, since it helps to determine the extent of social and economic inequality in the country and may suggest methods to focus on the lower-income groups in energy development programs.

Table 14: List of selected Socio-economic Indicators

Dimension	Name of indicator	Description	Unit
Economic	Annual Electricity Consumption per household	Ratio of electricity use in households to total number of households per year	(KWh/ month)
	Percent of Household Income Spent on Energy	Ratio of household income spent on fuel and electricity to the total household income	(%)
Social	Access to Modern Cooking Fuels	Average percentage of households using electricity, LPG and kerosene for cooking	(%)
	Share of Households with Electricity	Ratio of households with electricity or commercial energy to the total number of households	(%)

2.2.4 Construction of composite indicator

According to the World Energy Council (2012), the Energy Sustainability Index is defined as the index that measures the energy sustainability performances of several sample states/ countries. The three pillars of this index are energy security, social equity and environmental impact mitigation. This study narrows down the ESI to the SEESI- Socio-economic Energy Sustainability Index which focuses only on the social and economic aspects of energy sustainability. Thus, the SEESI may be defined as the index that measures the socio-economic dimensions of energy sustainability.

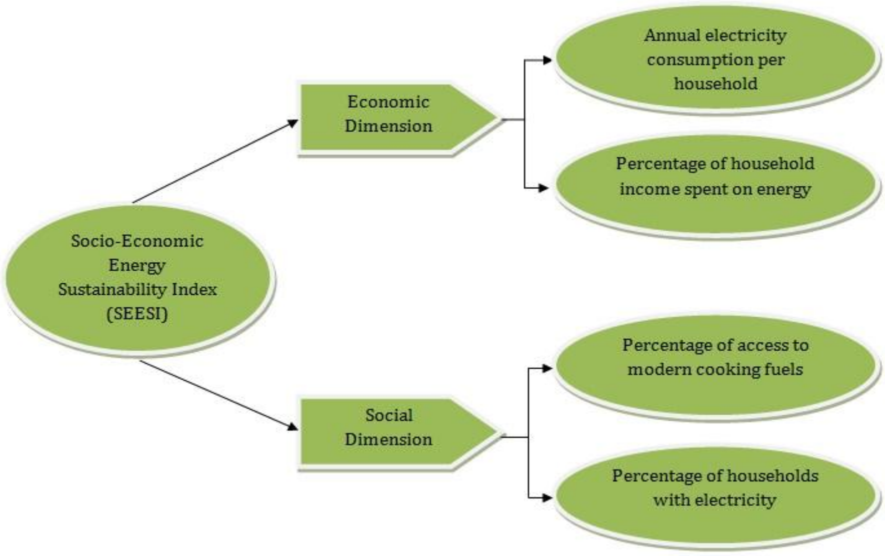

Figure2: Theoretical framework for construction of SEESI

2.3 Evaluation of indicators

The data that has been collected for the purpose of this study is mainly from

- A report published by ESMAP in 2002 that used the data from the ORG Household Survey findings of 1996.
- A report published by IFMR in 2012 based on the National Sample Survey Organization 61st round of reports.
- The 55th and 66th round of reports published by the National Sample Survey Organization in 2001 and 2012.

The indicator data for each of the states is listed below.

2.3.1 Andhra Pradesh

The ESMAP report of 2002 showed that the annual electricity consumption per household in the state was 13kWh/month. 64% of the total number of households was found to be electrified. The percentage of household income spent every month on energy was discovered to be 6.7%. According to the National Sample Survey Organization (55th round report), the percentage of access to modern cooking fuels available to rural households in Andhra Pradesh was 3.56%.

According to Woodbridge (2012), the annual electricity consumption per household had increased to 44.6 kWh/month in recent times. This increase was very much lower than the improvement that the other sample states had shown over time. The percentage of household income spent monthly on energy had only marginally increased to 9%. The NSS 66th round of findings of 2009-10 showed that the percentage of access to modern cooking fuels had risen to 20.18%, which was the best improvement among the sample states. The state had reported fuel wood shortages ever since the early 90s which culminated with the implementation of several forestry schemes, funded by international donors such as the World Bank, to combat these shortages as well the accompanying deforestation in the state. Meanwhile, the percentage of households with electricity had shot up to 89.7%. This was due to the state's 10-year reform program begun in the 90s which including changes in pricing of electricity and restructuring of the state electricity boards.

Table 15: Indicators for Andhra Pradesh

Dimension	Indicators	1996-2002	2005-2011
Economic	Annual Electricity Consumption per household (kWh/month)	13	44.6
	Percentage of Household Income Spent on Energy (%)	6.7	9
Social	Percentage of access to modern cooking fuels (%)	3.6	20.2
	Percentage of Households with Electricity (%)	64	89.7

2.3.2 Himachal Pradesh

According to the ORG Household Survey (1996), the annual electricity consumption per household in the state was 48 kWh/month. The average household spent 3.8% of its total income on energy every month and the percentage of households that had been electrified was found to be 96%, highest among the studied states. The NSS 55th round report of 2001 showed that the percentage of access to modern cooking fuels for an average household in Andhra Pradesh was 10.46%.

During the latter half of the time frame, according to Woodbridge (2005), the average household annually consumed 78.6 KWh of electricity per month. Similar to Andhra Pradesh, it spent 9% of its total income on energy per month, which was the lowest among the studied states. Himachal Pradesh had a total electrified household rate of 96.6%; although only slightly higher than its previous value, it was the highest in comparison with the other states. The NSS 66th round of reports showed that the state had an access percentage of 28.18% to modern cooking fuels. This was due to its LPG initiatives that were introduced to battle high levels of deforestation in the state. This was supplemented by the subsidization of modern cooking wares to discourage use of traditional fuels.

Table 16: Indicators for Himachal Pradesh

Dimension	Indicators	1996-2002	2005-2011
Economic	Annual Electricity Consumption per household (kWh/month)	48	78.6
	Percentage of Household Income Spent on Energy (%)	3.8	9
Social	Percentage of access to modern cooking fuels (%)	10.5	28.2
	Percentage of Households with Electricity (%)	96	96.6

2.3.3 Maharashtra

During 1996-2002, the annual electricity consumption per household in the state was 27kWh/month according to ESMAP (2002). The percentage of the average household income that was spent on energy was 4.6% per month. The percentage of households electrified was 65% and the NSS report (2001) showed that the percentage of access to modern cooking fuels was 8.6% for the average rural household in Maharashtra.

During the latter half of the time frame between 2005 and 2011, the annual electricity consumption per household had risen to 49.8% while the percentage of income spent on energy per month had increased to 11%. The percentage of households electrified had increased only to 73.8% (Woodbridge et al., 2012). The NSS report (2010) showed that the percentage of access to modern cooking fuels had risen to 18.59%.

The comparison of indicators between the two time periods showed that the state was one of the least improved states in the study.

Table 17: Indicators for Maharashtra

Dimension	Indicators	1996-2002	2005-2011
Economic	Annual Electricity Consumption per household (kWh/month)	27	49.8
	Percentage of Household Income Spent on Energy (%)	4.6	11
Social	Percentage of access to modern cooking fuels (%)	8.6	18.6
	Percentage of Households with Electricity (%)	65	73.8

2.3.4 Punjab

For the period of 1996-2002, the annual electricity consumption per household was 77kWh/month which was significantly higher than the other studied states for the same time period. The percentage of household income spent on energy was 7.8%, which was found to be highest among the studied states (ESMAP, 2002). The percentage of rural households with electricity was 94%. The percentage of access to modern cooking fuels was 13.43%, once again the highest among the studied states (NSS, 2001).

For the period of 2005-2011, the annual electricity consumption per household was 88.9% which was the highest among the studied states but the lowest increase from its previous value in 1996(Woodbridge et al., 2012). The percentage of household income spent on energy was 13% (the highest amount among the studied states). The percentage of households with electricity was 95.5%. The percentage of access to modern cooking fuels was 34.8%, also the highest among all the studied states (NSS, 2012).

The state’s remarkable performance with respect to almost all the socio-economic indicators was found to go hand-in-hand with its economic prosperity and its well-maintained and accessible infrastructure and housing. The state is also famous for promoting renewable energy programs and devices to all sectors of its population through effective seminars, workshops and training programs.

Table 18: Indicators for Punjab

Dimension	Indicators	1996-2002	2005-2011
Economic	Annual Electricity Consumption per household (kWh/month)	77	88.9
	Percentage of Household Income Spent on Energy (%)	7.8	13
Social	Percentage of access to modern cooking fuels (%)	13.4	34.8
	Percentage of Households with Electricity (%)	94	95.5

2.3.5 Rajasthan

As per ESMAP (2002), the annual electricity consumption per household in Rajasthan was 10 kWh/month, the lowest among the studied states during 1996-2002. The percentage of household income spent on energy was 2.1% which was also found to be lower than the other studied states for the period of 1996-2002. The percentage of households with electricity was 34% and the percentage of access to modern cooking fuels was 3.34% (NSS, 2001).This low rate of access to electricity and modern cooking fuels was attributed to the large size of the state and the population being scattered and hence cumbersome to cater to International agencies have been supporting social forestry programs in the state to combat deforestation and depleting firewood supplies. However, these programs were opposed by the state's difficult geography. Due to lack of penetration of modern fuel choices and due to declining firewood stock, villages in Rajasthan continued to switch to more inferior fuels.

As per Woodbridge (2012), the annual electricity consumption per household was 48kWh/month. The percentage of household income spent on energy was 10% which was found to be the highest rise among the studied states. The percentage of households with electricity was 58.3%. The percentage of access to modern cooking fuels was found to be 5.94% according to NSS (2012) and was the least improved compared to the other states.

Table 19: Indicators for Rajasthan

Dimension	Indicators	1996-2002	2005-2011
Economic	Annual Electricity Consumption per household (kWh/month)	10	48
	Percentage of Household Income Spent on Energy (%)	2.1	10
Social	Percentage of access to modern cooking fuels (%)	3.3	5.9
	Percentage of Households with Electricity (%)	34	58.3

2.3.6 West Bengal

The annual electricity consumption per household was found to be 12kWh/month in 1996 for West Bengal (ESMAP, 2002). The percent of household income spent on energy was found to be 6.6% and the percentage of households with electricity was found to be 23% (lowest among the studied states). The state failed to meet its fuel requirements even in the early 90s when demands were six times as much as supplies. Consequently, the percentage of access to modern cooking fuels was found to be 1.19%, which was the least among the studied states, according to NSS (2001).

The annual electricity consumption per household was found to be 48.9% according to IFMR (2012). The percentage of household income spent on energy was 10%. Distributive injustice was observed in the state with poorer households having to spend larger percentages of their income on energy while richer households were provided with subsidies and hence spent lesser portions of their income on energy. This was due to the unfair subsidy system implemented in the state (Santhakumar, 2003, Kemmler, 2006; WEC, 2010; Balachandra, 2011). Another issue that was noticed was the urban-rural disparity. The state provided cheaper, subsidized energy to the more accessible urban areas while neglecting the rural areas (Planning Commission, 2010).

The percentage of households with electricity was only 40.3%, the least among the six states, but the highest improvement over the time frames. The percentage of access to modern cooking fuels was 5.36%, once again the lowest among the studied states (NSS, 2012).

Table 20: Indicators for West Bengal

Dimension	Indicators	1996-2002	2005-2011
Economic	Annual Electricity Consumption per household (kWh/month)	12	48.9
	Percentage of Household Income Spent on Energy (%)	6.6	10
Social	Percentage of access to modern cooking fuels (%)	1.2	5.4
	Percentage of Households with Electricity (%)	23	40.3

2.3.7 Final data

Table 21presentsthe final compiled list of data for the selected indicators for all the sample states. Table 22 highlights the percentile changes in indicator values for each of the states between the two chosen time periods.

Table 21: Compiled values of indicators for all the states

State	Time period	Economic Dimension		Social Dimension	
		Annual Electricity Consumption per household (kWh/month)	Percentage of Household Income Spent on Energy (%)	Percentage of access to modern cooking fuels	Percentage of Households with Electricity
		EC1	EC2	S1	S2
Andhra Pradesh	1996-02	13	6.7	3.6	64
	2005-11	44.6	9	20.2	89.7
Himachal Pradesh	1996-02	48	3.8	10.5	96
	2005-11	78.6	9	28.2	96.6
Maharashtra	1996-02	27	4.6	8.6	65
	2005-11	49.8	11	18.6	73.8
Punjab	1996-02	77	7.8	13.4	94
	2005-11	88.9	13	34.8	95.5
Rajasthan	1996-02	10	2.1	3.3	34
	2005-11	48	10	5.9	58.3
West Bengal	1996-02	12	6.6	1.2	23
	2005-11	48.9	10	5.4	40.3

Table 22: Percentile change in indicator values from 1996-02 to 2005-11

State	Percentile increase in Economic indicators		Percentile change in Social indicators	
	Annual Electricity Consumption per household	Percentage of Household Income Spent on Energy	Percentage of access to modern cooking fuels	Percentage of Households with Electricity
Andhra Pradesh	243%	34%	461%	40%
Himachal Pradesh	64%	137%	169%	1%
Maharashtra	84%	139%	116%	14%
Punjab	15%	67%	160%	2%
Rajasthan	380%	376%	79%	71%
West Bengal	308%	52%	350%	75%

In Table 22, the states that showed the best improvement are highlighted in green while those that showed the least improvement are highlighted in red. Andhra Pradesh showed the highest improvement with respect to two indicators: percentage of household income spent on energy and access to modern cooking fuels. Rajasthan showed the best improvement in terms of annual electricity consumption per household. However, it also showed the highest increase in percentage of income spent on energy and hence fared poorly with respect to that indicator. Additionally, it developed the least in terms of access to modern cooking fuels. West Bengal exhibited the highest growth with respect to percentage of households with electricity. Punjab and Himachal Pradesh, although having the best indicator values, showed less growth in terms of electricity consumption and percentage of electrified households respectively.

2.4 Tools

A variety of multivariate analysis methods are available for the analysis of data and formulation of composite indicators. Some of the popular methods are Principal Component Analysis, Factor Analysis, Cronbach Coefficient Alpha Analysis and Cluster Analysis (OECD, 2008). Owing to its multiple strengths, Principal Component Analysis has been chosen for this particular case.

2.4.1 Principal Component Analysis

Principal Component Analysis (PCA) is a statistical method that has been popularly used to find patterns between data of high dimensions in order to highlight the similarities and differences between them (Smith, 2002; Ediger et al., 2006; Hatem, 2008; Jose & Riesgo, 2008; Mainali & Silveira, 2015; Rovira, 2009; Zhang, 2009). It can present a visualization of the interactions between the various “variables” which, in the case of this study, are the chosen indicators of the energy landscape of India. The chosen case sites (states of India) are referred to as the “observations” as per PCA terminology. Since it is a dimensional reduction technique (i.e. after finding patterns between the data, the PCA technique compresses the data on to fewer dimensions), it will lead to a clearer map of the relationships between the variables.

The data collected for the indicators will be analyzed with the modular software XLSTAT, a conclusion will be drawn and recommendations made.

This technique uses the following steps to obtain the end results:

- Calculation of standard deviation.
- Calculation of correlation matrix: Some PCAs calculate the covariance instead of the correlation matrix. But the correlation matrix is used in cases where the variables are of different scales. Hence the correlation matrix is used to standardize the data. The type of correlation matrix that is used for this analysis is the Pearson's correlation matrix, which is the suggested method for computation using XLSTAT.
- Calculation of Eigen values and Eigen vectors.
- Calculation of feature vectors: Only the highest valued and hence most significant Eigen vectors and values are taken: these are called the feature vectors and are sufficient enough to provide an accurate relationship between the data. This is where the reduction of dimensions takes place.

2.4.2 Calculation of composite indicator

The Socio Economic Energy Sustainability Index (SEESI) can be given by:

$SEESI = a + b1X1 + ... + bk + Xk + e$........(Doukas, 2012)

where b1..bk are the vectors of parameters in each domain, X1...Xk are the list of indicators that are being used to measure the socio-economic energy sustainability and e is the error term which is considered negligible.

Since this study uses six states, the SEESI can be given as:

$$SEESI = a + b1X1 + b2X2 + b3X3 + b4X4 + b5X5 + b6X6 + e$$

After normalization of data, the PCA is performed and the correlation matrix is obtained which signifies the correlation between the various indicators. Those which are correlated with values close to +1 or -1 are said to be strongly positively or negatively correlated respectively. And those which are correlated with values close to 0 are said to be minimally correlated SAS PCA tutorial guide).

The PCA also gives the values of the Eigen values and Eigen vectors which are important for determining the SEESI.

The theory behind the calculation of the Eigen values is given by the determinant equation:

$$(R - \lambda I) = 0$$

where R is the correlation matrix, λ is the symbol for Eigen values and I is the unit matrix. This equation is solved for obtaining the Eigen value and in the process, the Eigen value with the largest rate is retained while those with smaller rates are ignored since they denote smaller variations.

Similarly, to calculate the Eigen vectors, the following determinant equation is used by the software:

$$(R - \lambda_j I) F_j = 0$$

where R is the correlation matrix, λ_j is the Eigen value, I is the unit vector and F_j is the Eigen vector corresponding to the Eigen value.

The primary use of PCA is to reduce the number of dimensions and this is accomplished by the use of Principal Components (PCs). The PCs are considered to be normalized linear functions of the indicator variables and are considered to be mutually orthogonal. The first PC accounts for the largest variation of the indicator variables, the second for the second largest variation and so on. In order to perform this, the transposed matrix of normalized indicators for each state is multiplied with the transposed matrix of the Eigen vectors on the left to get a Principal Component matrix.

Next, the matrix of Eigen values is multiplied with the matrix of the Principal components. This is divided by the sum of all the Eigen values. The resulting value is the value of the SEESI.

This is indicated by the following formula:

$$SEESI_k = \frac{\lambda_1 PC_1 + \lambda_2 PC_2 + \ldots + \lambda_j PC_j}{\lambda_1 + \lambda_2 + \ldots + \lambda_j}$$

This procedure is followed to calculate the SEESI for each state.

2.5 Data adjustments

2.5.1 Positive and negative indicators

The indicators are categorized into positive and negative indicators with respect to the nature of effect that they have on the SEESI. When increase in an indicator signifies higher socio-economic energy sustainability, it is a positive indicator and when it has a negative effect, it is a negative indicator. Positive indicators are assigned a positive sign while negative indicators are assigned a negative sign.

Economic dimension:

Annual electricity consumption per household (EC1): Although energy consumption awareness aims to reduce reckless use of resources by improved efficiency of devices and consumer concern for the environment, this indicator is considered to be a positive indicator since electricity access to the rural poor has been neglected and increase in electricity consumption in rural areas is an indication of improvement of energy services in the country.

Percentage of household income spent on energy (EC2): This indicator is considered to be a negative indicator since it is ideal that less of the household income should be dedicated to energy services, especially in the case of rural areas, so that other living concerns can be focused upon by the household.

Social dimension:

Percentage of access to modern cooking fuels (S1): This indicator is an important symbol of the infusion of modern cooking fuels into the rural household. It is thus regarded as a positive indicator.

Percentage of households with electricity (S2): It is taken as a positive indicator since it's a direct indicator of energy access-higher the share of households with electricity, better the improvement of energy services in the country.

The adjusted indicators are shown in Table 23.

Table 23: Positive and negative indicators

State	Time Period	Economic Dimension		Social Dimension	
		EC1: Annual electricity consumption per household (kWh/month)	EC2: Percentage of household income spent on energy (%)	S1: Percentage of access to modern cooking fuels (%)	S2: Percentage of households with electricity (%)
Andhra Pradesh	1996 – 2002	13	-6.7	3.6	64
	2005 - 2011	44.6	-9	20.2	89.7
Himachal Pradesh	1996 – 2002	48	-3.8	10.4	96
	2005 - 2011	78.6	-9	28.2	96.6
Maharashtra	1996 – 2002	27	-4.6	8.6	65
	2005 - 2011	49.8	-11	18.6	73.8
Punjab	1996 – 2002	77	-7.8	13.4	94
	2005 - 2011	88.9	-13	34.8	95.5
Rajasthan	1996 – 2002	10	-2.1	3.3	34
	2005 - 2011	48	-10	5.9	58.3
West Bengal	1996 – 2002	12	-6.6	1.2	23
	2005 - 2011	48.9	-10	5.4	40.3

2.5.2 Normalization

Before performing the Principal Component Analysis, Normalization needs to be carried out on the data since all the indicators have been measured with different units (OECD, 2008). There are several normalization methods and the one used here is Min-Max Normalization. This method is found to be useful since it expands the interval of a set of indicators lying within a small range, thus having a more sizeable effect on the SEESI. The chosen variables are transformed to the 0-1 range where 0 implies lowest socio-economic energy sustainability and 1 implies highest socio-economic energy sustainability. The formula for the normalized values is given by:

$$x_{ik} = \frac{X_{ik} - Min\,(X_i)}{Max(X_i) - Min\,(X_i)}$$

The ensuing results are showed in Table 24.

Table 24: Normalized indicators

State	Time Period	Economic Dimension		Social Dimension	
		EC1: Annual electricity consumption per household (kWh/month)	EC2: Percentage of household income spent on energy (%)	S1: Percentage of access to modern cooking fuels (%)	S2: Percentage of households with electricity (%)
Andhra Pradesh	1996 – 2002	0.04	0.58	0.07	0.56
	2005 - 2011	0.44	0.37	0.56	0.91
Himachal Pradesh	1996 – 2002	0.48	0.84	0.28	0.99
	2005 - 2011	0.87	0.37	0.80	1.00
Maharashtra	1996 – 2002	0.22	0.77	0.22	0.57
	2005 - 2011	0.50	0.18	0.52	0.69
Punjab	1996 – 2002	0.85	0.48	0.36	0.96
	2005 - 2011	1.00	0.00	1.00	0.99
Rajasthan	1996 – 2002	0.00	1.00	0.06	0.15
	2005 - 2011	0.48	0.28	0.14	0.48
West Bengal	1996 – 2002	0.03	0.59	0.00	0.00
	2005 - 2011	0.49	0.28	0.12	0.24

3 Results and discussion

3.1 Intermediate results

3.1.1 Correlation matrix

The correlation matrix is used to show correlations among the different variables. When two variables are significantly positively correlated, an increase in one value could lead to an increase in the other. When two variables are significantly negatively correlated, an increase in one variable causes a decrease in the other. From Table 25, it is evident that the annual electricity consumption per household (EC1) is positively correlated to both percentage access to modern cooking fuels (S1) and percentage of households with electricity (S2), while both the social dimension indicators (S1 and S2) are positively correlated too. An increase in percentage access to modern cooking fuels and electricity could rationally cause an increase in the annual electricity consumption per household. The positive correlation between modern cooking fuels and electricity access may imply that households that had access to one of these resources were mostly likely to use the other. Percentage of household income spent on energy (EC2) was found to be negatively correlated to annual electricity consumption per household (EC1) and percentage access to modern cooking fuels (S1) i.e. as access to modern cooking fuels was provided or electricity consumption per household increased, the percentage of income spent on energy reduced. This may be because, people spent less income while procuring modern subsidized fuels than for unsubsidized traditional fuels.

Table 25: Correlation matrix

Variables	Annual Electricity Consumption per Household (EC1)	Percentage of Household Income Spent on Energy (EC2)	Percentage Access to Modern Cooking Fuels (S1)	Percentage of Households with Electricity (S2)
Annual Electricity Consumption per Household (EC1)	1	-0.66	0.82	0.76
Percentage of Household Income Spent on Energy (EC2)	-0.66	1	-0.62	-0.32
Percentage Access to Modern Cooking Fuels (S1)	0.82	-0.62	1	0.77
Percentage of Households with Electricity (S2)	0.76	-0.32	0.77	1

3.1.2 Eigen values

Eigen values are a set of scalars associated with a matrix equation that indicate how their special matrix (Eigen matrix) is altered after being multiplied by another matrix (Smith, 2002). In Table 26, F1, F2, F3, F4 are factors. A factor is a linear combination of the original variables. Thus, the initial list of 12 variables has been reduced to 4 factors without losing valuable information. The factors corresponding to each Eigen value are arranged in descending order where each factor is mapped to the variability with the original data (Variability %) as well as the cumulative variability (Cumulative %). The Eigen values that contribute to a high percentage of the variance are sufficient to generate maps that account for the original unreduced table. In this case, the first Eigen value possesses 74.9% variability and the second possesses 17.35% variability (hence a cumulative of 92.26% variability). These two Eigen values are sufficient to perform the Principal Component Analysis.

Table 26: Eigen values

	F1	F2	F3	F4
Eigen value	3.00	0.69	0.18	0.13
Variability (%)	74.91	17.35	4.48	3.26
Cumulative %	74.91	92.26	96.75	100.00

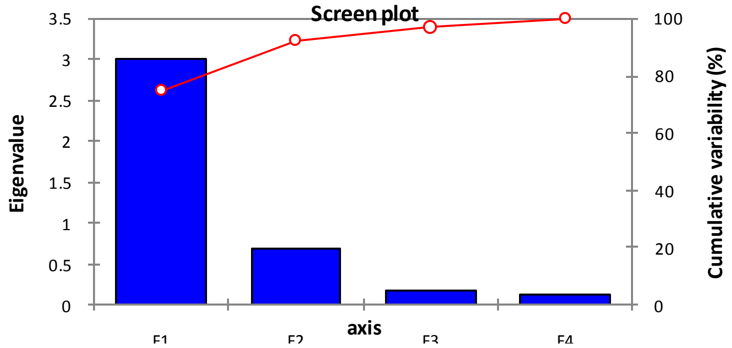

Figure3: Plot of Eigen values vs. Factors

3.1.3 Eigen vectors

An Eigen vector is a matrix v which when multiplied with a square matrix A would yield a multiple of v (with the multiple being the Eigen value). This is illustrated as $Av= \lambda v$ where λ is the Eigen value (Smith, 2002). The corresponding Eigen vectors for each of the factors are shown in Table 27.

Table 27: Eigen vectors

	F1	F2	F3	F4
EC1	0.55	0.00	-0.60	-0.59
EC2	-0.42	0.79	0.04	-0.44
S1	0.54	0.08	0.78	-0.30
S2	0.48	0.60	-0.16	0.61

3.1.4 Squared cosines of the variables

Table 28 presents the squared cosines of the variables. This matrix of vectors is transposed and then multiplied with the original normalized indicators to get the matrix of principal components (PCs).

Table 28: Squared cosines of the variables

	F1	F2	F3	F4
EC1	0.89	0.00	0.06	0.04
EC2	0.54	0.44	0.00	0.03
S1	0.87	0.01	0.11	0.01
S2	0.69	0.25	0.01	0.05

3.2 Final results

After calculating the Principal Components, the final calculations are performed using the following formula to calculate the Socio-Economic Energy Sustainability Index.

$$SEESI_k = \frac{\lambda_1 PC_1 + \lambda_2 PC_2 + \ldots + \lambda_j PC_j}{\lambda_1 + \lambda_2 + \ldots + \lambda_j}$$

3.2.1 Socio-Economic Energy Sustainability Index

Figure 4 lists the Socio-Economic Energy Sustainability Indices for the two sample time periods for the six sample states. The figure shows that among the six states, Punjab obtained the highest SEESI during both the observed time periods, followed by Himachal Pradesh. While Andhra Pradesh fared poorly during the 90s and early 2000s, it exhibited a large growth, the highest among all the sampled states, and came to be ranked third in the energy sustainability analysis. Maharashtra showed the least improvement in SEESI while Rajasthan and West Bengal were found to have the lowest SEESI values during both the time frames, despite West Bengal's significant improvement in its socio-economic energy index.

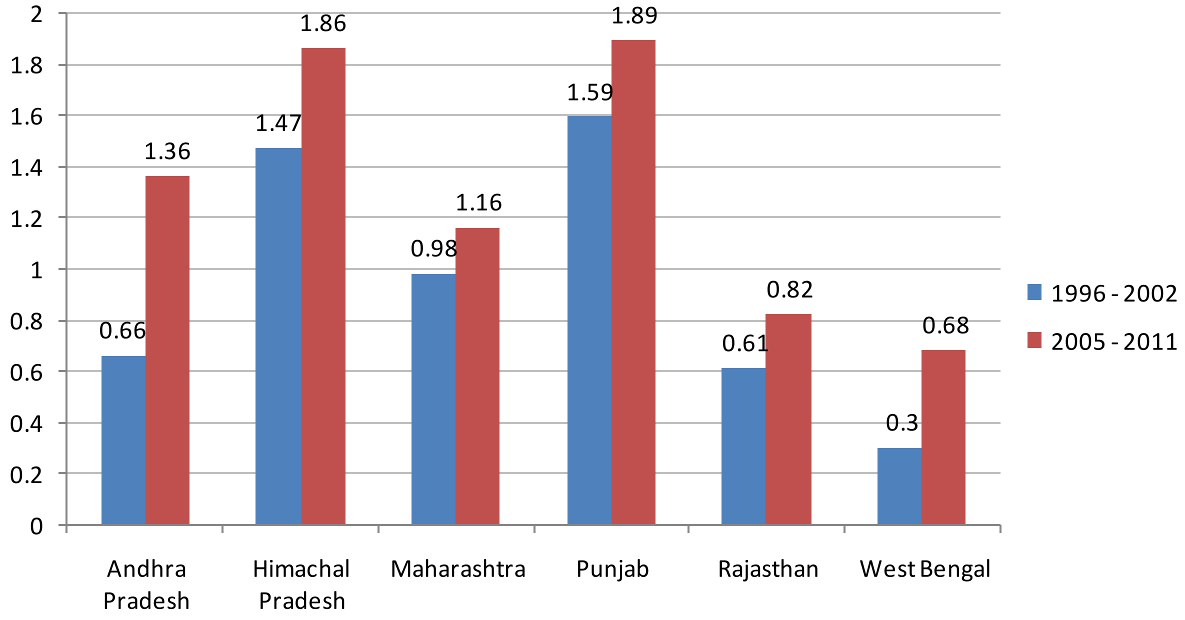

Figure 4: Socio-Economic Energy Sustainability Index of the examined states

By adjusting the SEESI figures to percentile values (Figure 5), we can see the results ranging between the values of 0 and 1 with respect to each individual time set.

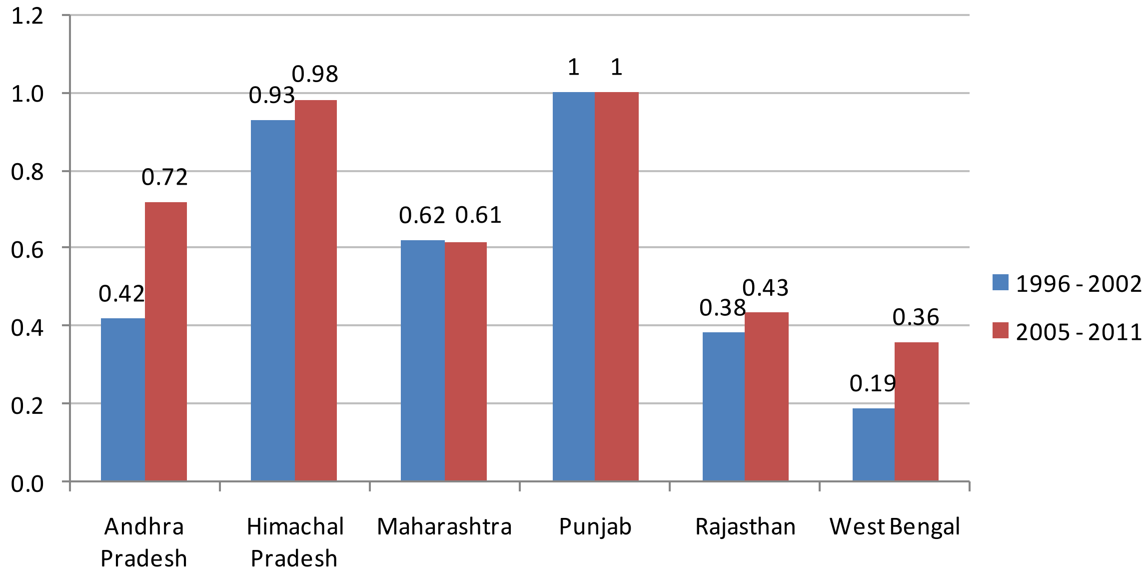

Figure 5: Socio-Economic Energy Sustainability Index of the examined states in Percentile

Among the studied states, Punjab has the highest annual electricity consumption per household, increasing 15% over the time periods. The state also had an exceptional access to modern cooking fuels, increasing 1.5 times from its initial value, and ensuring that at least one-third of the rural population had provision of up-to-date cooking fuels. Punjab consistently had over 94%of its rural population connected to electricity even during the early 90s, when the national average for percentage of households connected to electricity was only 56%. The state continued to sustain its successful performance, with over 95.5% of its rural population having access to electricity by 2011 while the national average had risen only to 67%. This may be ascribed to the state having better constructed houses and relatively modern infrastructure (ESMAP, 2002). The state, which is one of the richest states in the country, spends a rather large sum of its household income on energy and this is the sole indictor that it must focus to improve. On the other hand, the state's willingness to spend more on modern fuels and technologies is deemed to have aided in the growth of its energy indicators. Overall, due to its impressive performance, Punjab procured the highest socio-economic energy index values throughout the past two decades. This can be attributed to the Punjab Energy Development Agency's attractive promotional schemes and activities such as the subsidized family biogas program, the biomass gasifier program that was deployed to meet unmet electricity demands in villages and ambitious energy policies such as the New and Renewable Sources of Energy Policy. The state also conducted several seminars and workshops to educate its people about the benefits of modern fuels and technology. The ORG household survey of 1996 also indicated that Punjab's rural population were more aware and inclined towards renewable energy devices and were willing to make a transition from traditional technologies for improved health benefits.

Himachal Pradesh was a close contender, following immediately behind Punjab in the index scale. The state is famous for its LPG initiatives that were introduced to combat deforestation. These initiatives were strongly funded by the World Bank, German Agency for Technical Cooperation and Overseas Development Agency (ESMAP, 2002). Hence the state had the highest LPG connectivity, even more so than the leading state, Punjab. The LPG schemes were designed to ensure availability of fuel even to lower income and rural households unlike many of the other states. The state also disseminated subsidized modern cooking utensils to discourage use of fuel wood, a technique that was also noticed in Punjab. According to an ORG household survey, the rural population was disposed to switch fuels unlike several other states; even by 2002, 40% of the rural population had switched to modern fuels. The state was also noticed for extensive connection to electricity, and high consumption of energy, attributed like Punjab, to its high rural incomes, lower energy tariffs and modern dwellings.

West Bengal possessed low access to electricity and modern cooking fuels. The state showed fuel deficit even in the early 90s when demands were six times as high as supplies. Distributive injustice was high in the state, with poorer households paying a larger percentage of the household income for power than the richer households, showing unfair and inefficient implementation of subsidies. A disparity between rural and urban areas was also noticed, with urban areas being provided with cheaper energy than rural areas (Planning Commission, 2010). Rajasthan was another state that accompanied West Bengal with its fuel and electricity shortages. The linkages between regional development and fuel access and use were apparent from this analysis. While West Bengal was found to be lacking in energy sustainability due to its meager economic development, Rajasthan failed to succeed despite its above average economy due to its insurmountable topographical challenges and infrastructure setbacks.

3.3 Decomposition analysis:

A decomposition analysis is useful for broadening the analysis and for identifying the contribution of each of the indicators towards the final composite indicator (OECD, 2008). It is a method that enables backtracking to the initial raw data to verify the validity of the analysis. In this study, this has been carried out by mapping radar diagrams for the best and worst performing states for both the time periods.

3.3.1 Radar Diagrams

The results obtained using the PCA have been verified by constructing radar diagrams from the original normalized data. The surface area of the graph for each state signifies the level of sustainability.

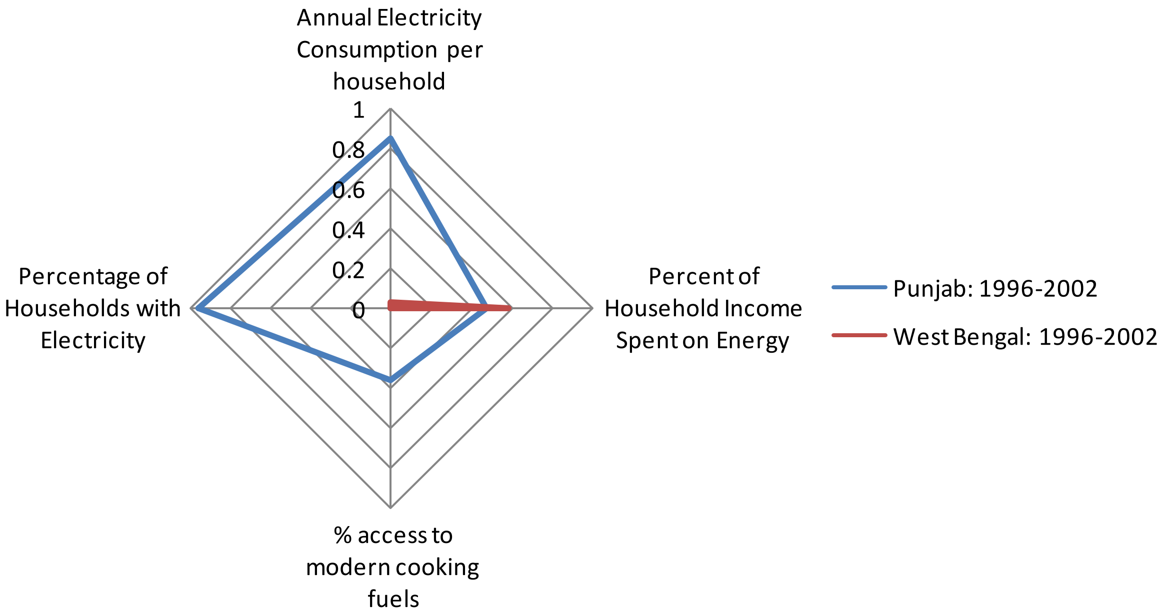

Figure 6: Radar diagram of SEESI for examined states, 1996-2002

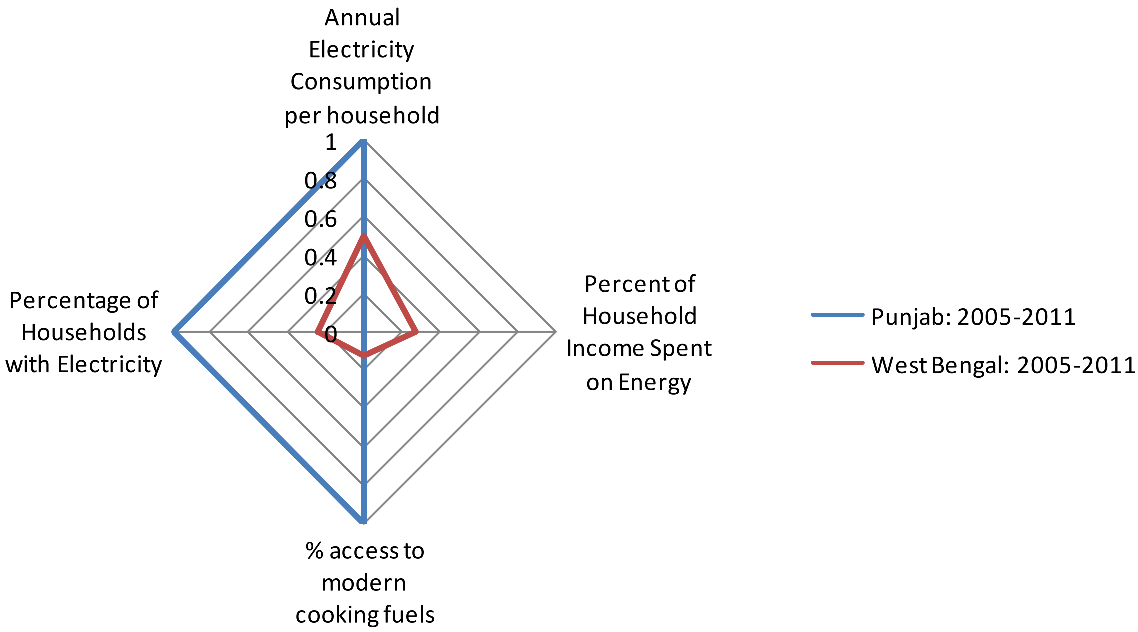

Figure 7: Radar diagram of SEESI for examined states, 2005-2011

In the radar diagram for both the time periods, it is evident that the results are in accordance with the rankings obtained from the PCA. The shift between Punjab and West Bengal are illustrated in the diagram. For both the time periods, the data for Punjab (the most successful state in socio-economic energy sustainability) creates a graph of higher area than that created by the data of West Bengal (the least successful state in socio-economic energy sustainability).

Between 1996 and 2011, the percentage of access to modern cooking fuels, annual electricity consumption per household and percentage of electrified households rose in Punjab to indicate best performance among the studied states. However, the share of household income spent on energy also increased for Punjab.

West Bengal witnessed a marginal increase in electricity consumption, modern cooking fuel access and percentage of households with electricity while experiencing a small decrease in the percentage of income spent on energy. Yet, it continued to remain the least successful of all the states in terms of socio-economic energy sustainability and the contrast between the state's performance with the performance of Punjab is palpable from the radar diagrams.

4 Conclusion

This thesis has explored a technique to measure the sustainability of rural energy access in various diverse regions of a developing country. The analysis concentrated upon the domestic sector of rural communities in India and i) measured various key indicators that shed light upon socio-economic energy sustainability over a period of time, ii) consolidated these key indicators into a comprehensive, composite 'Socio-Economic Energy Sustainability Index' (SEESI), iii) verified the validity of this composite indicator with the aid of a decomposition analysis, iv) correlated the status of the final composite indicator as well as the primary sub-indicators with the social, economic, regional development of each of the states and v) associated changes and differences in indicators in the states over a period of time to policies and programs implemented to stimulate the same.

In 2010, 56% of the rural population continued to remain without proper energy access (World Bank, 2011). This was mainly due to the government's inclination towards concentrating on setup of energy supply rather than focusing on development of energy access carriers and maintenance of reliability and quality of supply (Balachandra, 2011; Bilolikar & Deshmukh, 2007; World Bank, 2011).As stated by Balachandra (2011), unaffordability due to poverty and inaccessibility due to inadequate infrastructure are the root causes of this problem. This is validated by the results of this thesis. Solutions for this issue have mostly revolved around improving supply-side features, with demand-side aspects taking a backseat. Although 74% of Indian villages were claimed to be electrified in 2005, only 52.5% continued to be so in 2009, while urban areas had an electrification rate of 93.1% (Niez, 2010; Balachandra, 2011).This is an indication of the unreliability of the infrastructure for energy access (Modi, 2005; Balachandra, 2011). Also, the standards for obtaining the status of 'electrified village' have been diminutive (the number of households electrified should be at least 10% of the total households in the village) (Niez, 2010). Hence, a more holistic approach needs to be implemented in order to ensure the sustainability of energy provision and usage.

According to the household energy access studies conducted by Ekholm et al. (2010), Kemmler (2006) and Pandey & Chaubal, (2011), higher incomes were found to directly interrelate with higher energy sustainability. This was proven by the results of this study since in the richest states such as Punjab and Himachal Pradesh, the high economic development and per capita incomes were synchronized with the socio-economic sustainability index values. The richer the state, the higher were the values of the primary indicators and subsequently superior was the end composite indicator. Punjab, a state that has consistently remained on top of the economy ladder of the country due to its success as an agricultural story, was able to maintain and improve its socio-economic energy sustainability with ease. Punjab further enhanced this sustainability through promotion of biogas and biomass technologies and far-reaching awareness programs that led to its villages adopting modern fuels eagerly. It also successfully implemented a New and Renewable Sources of Energy Policy which further motivated the use of renewable resources for energy in rural areas. This was followed by Himachal Pradesh, also a highly agriculturally intensive, predominantly rural state, which further supplemented its energy sustainability through the implementation of programs and subsidies aimed at the promotion of LPG.

Andhra Pradesh, although lacking in economic success, grew steadily with respect to energy sustainability due to drastic measures that were implemented in the state to battle its depleting forest cover. Interest shown by international agencies such as the World Bank, Overseas Development Agency etc., encouraged the state to enforce forest recovery programs, as part of which LPG was promoted in order to cut down on fuel wood dependency. This not only prohibited deforestation but also stimulated a social change in the rural areas with several households adopting modern cooking energy. The ten-year reform program begun in the 90s in the state also contributed significantly towards increasing the percentage of electrified households and decreasing the percentage of income spent on energy through changes in pricing of electricity and restructuring of the state electricity boards.

Maharashtra, Rajasthan and West Bengal could be proclaimed to be the failures of this study. Maharashtra, albeit a forerunner in economic prowess, faced setbacks in its socio-economic indicators. This was attributed to the state's focus on urban areas and improvement of resources and infrastructure only in cities. Villages continued to remain neglected and deprived of energy. Any subsidies continued to be provided to middle and high-income households while lacking focus on low-income areas. In no other state was the rural-urban disparity evident as much as in Maharashtra. Over the time period, rural poverty in the state continued to climb and the SEESI had increased only by 18%. This state was once again evidential of the relation between household income and energy access. The vast population of the state further acted as an obstacle to providing wide-ranging energy access.

Low energy access may be explained by factors such as difficulties faced in grid extension to more isolated villages as postulated by Kemmler, 2006, Cust et al., 2007 and WEC, 2010. In confirmation of this theory, Rajasthan stood alone as the state with faced heavy orchestration issues. The state possessed average income levels and rural poverty. The percentage of rural poverty in the state was lower than Maharashtra; yet, it ranked fifth in SEESI during both the decades, lagging behind Maharashtra in both cases. This was accredited to the vast expanse of desert land and the sparse and scattered population. Any energy access solutions that were implemented in the state were met with stubborn topographical challenges. In order to improve the socio-economic energy sustainability of this state, a solution must be devised to counter the rugged terrain. Grid connection to remote rural areas is expensive and challenging. Instead, transition should be made to renewable energy technologies (such as biomass and hydro) which are cheaper and more sustainable (Cust et al., 2007; WEC, 2010). Persistence must also be exercised to reach the spread-out rural communities and attain maximum electricity and modern cooking fuel access.

West Bengal fared last in its socio-economic energy sustainability over the whole time frame. This is associated with the state's exceedingly low economic development and rocketing rural poverty rates. According to Kemmler, 2006 and Bilolikar & Deshmukh, 2007, unsustainable tariff rates resulted in lower energy sustainability. This was true in the case of West Bengal- any financial measures that were undertaken by the government were futile since the state distributed a large portion of the allotted subsidies to population belonging to higher monthly per capita consumption expenditure (MPCE) quantiles while well-performing states such as Punjab and Himachal Pradesh allotted more equitable distribution to their population (Santhakumar, 2003, Kemmler, 2006; WEC, 2010; Balachandra, 2011).It was similar to Maharashtra in that there was a large urban-rural divide where cheaper energy was provided to urban areas, while neglecting rural areas. The large population of the state further acted detrimentally to the state of affairs, much like Maharashtra.

It is also to be noted that although the percentage of electrification of villages has increased in all the states owing to more efficient electricity schemes, the percentage of access to modern cooking fuels still remains low for almost all the states. Most rural areas still continue to rely on traditional fuels for cooking even when provided with electricity. This indicates that more policy changes need to be made and awareness needs to be spread about confining use to only modern fuels rather than combining use of both traditional and modern fuels as proposed by Bhattacharya (2005) while analyzing energy access to rural areas of several parts of India.

Thus, there are several factors that influence the socio-economic energy sustainability of a rural region. The primary indicator that improves energy sustainability is rural households is household income. Only with rapid economic development can hurdles such as fuel and technology affordability be dealt with. Another prominent contributor is the uneven distribution of subsidies with respect to several parameters such as income levels, nature of fuels, accessibility of the area etc. It was found that middle and high-income households were benefited with subsidies (Kemmler, 2006; WEC, 2010; Balachandra, 2011) or subsidies were provided to grid-connected households rather than those that were still unconnected. More progress might have been made even in the leading states if subsidies had been favored towards lower income groups. More accessible areas are chosen for provision of subsidies while the remote places are neglected (Cust et al., 2007). Also, choice of application of subsidy to appropriate lower-cost fuels- for example, LPG over kerosene- may result in higher penetration of modern fuels into society (Ekholm et al., 2010; Pandey & Chaubal, 2011). There may also be the case of over-subsidization: Cust et al. (2007) found that even the poorest rural households were willing to pay more for good quality supply of electricity. The size and population density of the states may be influencers of the sustainability index (Kemmler, 2006; Oda, 2011). Last, but not the least, are the cultural differences that exist in developing countries which prevent uninformed rural societies from taking to modern fuels and technologies easily. This can only be overcome by knocking down social barriers and conducting training, awareness programs, seminars and workshops to improve adaptation to changes in energy phenomena.

This thesis has conversed about some of the key issues that are relevant in the discussion of energy sustainability in rural areas of developing countries. The Socio-Economic Energy Sustainability Index that has been formulated in this study is designed exclusively for the domestic rural energy sector. Although sizeable inferences have been made with this help of this study, further research can be carried out to additionally investigate this subject. Supplementary indicators may be included and levels of disparities within the states may also be explored. Various other dimensions such as technical, institutional and environmental dimensions can also be included to expand this socio-economic energy sustainability to a more holistic and complete energy sustainability study. Indicators of other nature can be utilized to expand the scope of study to non-domestic, non-rural sectors. Thus, monitoring energy developments in rural areas remains a vast topic of immense potential.

Through extensive research into several key indicators, this study has probed into the extent of energy access to rural households in different geographical locations of India. Conclusions have been drawn on the basis of socio-economic energy sustainability index values to analyze how different states of India have fared in their energy access positions over a range of years. Interpretations have been presented regarding the reasons behind their respective rankings and recommendations have been made to enable advancements of each of the states in the rural energy access sector.

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