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Measuring and Evaluating Energy Security and Sustainability: A Case Study of India

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Abstract

The imperative for energy security is paramount for global, national and internal stability and development. Using an indicator-based approach, the present study develops a framework for sustainable energy security of India. First, it presents the energy supply and demand situation in the country under different scenarios. Then it conceptualizes the notion of energy security and quantifies it for India with the help of different indicators for energy security available in the literature. Both the supply and demand side views and both micro and macro dimensions are considered in assessing how secured India as a country is with respect to our energy future. The dimensions that include energy security are: economic, environmental, social and institutional. This will help planners and policy makers to understand India's energy scene better and design policies to develop sustainable technologies and practices to ensure energy resources last long.

Keywords: energy, development, indicator, security, sustainability

JEL Code: P28, Q41, Q42, Q48

India's Energy Transition—
Securing Power for a Sustainable Future

B. Sudhakara Reddy

Abstract

The imperative for energy security is paramount for global, national and internal stability and development. Using an indicator-based approach, the present study develops a framework for sustainable energy security of India. First, it presents the energy supply and demand situation in the country under different scenarios. Then it conceptualizes the notion of energy security and quantifies it for India with the help of different indicators for energy security available in the literature. Both the supply and demand side views and both micro and macro dimensions are considered in assessing how secured India as a country is with respect to our energy future. The dimensions that include energy security are: economic, environmental, social and institutional. This will help planners and policy makers to understand India's energy scene better and design policies to develop sustainable technologies and practices to ensure energy resources last long.

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1. Introduction

Sustainable energy security[1] is one of the major concerns of countries interested in governing the multi-faceted issue of development. Measuring security requires the identification of its relevant dimensions and indicators which can capture its diverse aspects. The assessment of sustainability is then crucial to most of the stakeholders, as it allows measuring progress, identifying policy areas to be addressed and evaluating the outcome of implemented policies.

Energy security plays an important role in human empowerment. The correlation between energy and development suggests a two-way causation between them. Higher energy use enhances production, promotes economic growth and improves standard of living—all symbols of development—which in turn leads to greater energy consumption. In addition, consumption and production of energy also play a major role in several sustainability issues such as climate change, depletion of natural resources and indoor and outdoor local air pollution (Ruijven, 2008). In short, for stability—global, national and internal—and development, the need for energy security is paramount.

Energy security includes supply as well as demand-side security. Supply security for a country means the country's ability for efficient generation and production of energy from

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[1] We define sustainable energy security as "provisioning of uninterrupted energy services (short and long terms) in an affordable, equitable, efficient and environmentally benign manner".

diversified sources which include renewables. This requires development of new energy sources and ensures ownership or control of such sources within and outside the country. Demand side energy security means universal provision of energy services, which is accessible and affordable to consumers. This involves equitable and efficient distribution and effective conversion from final to useful energy through appropriate practices and end-use technologies. Both supply and demand security necessitate environmental compliance which otherwise cannot be sustained in the long run.

Energy security has an international character. As a concern, it first surfaced in 1973, with the OPEC oil embargo. The initial stage of energy security was linked to the volatile Middle East. However, over time, other issues like regional cooperation and cross-border trade gained prominence. Recently, energy security has drawn high priority policy attention stirred by high oil prices and geo political tensions (Kruyt *et al.*, 2009). The incessant spurt in oil prices, until the end of 2008, is due to rapid increase in energy demand in Asia and underinvestment in energy supply and concerns about stability of countries where significant oil and gas reserves are concentrated. For example, geopolitical tensions such as Iraq war in 2003 and gas dispute between Russia and Ukraine in 2005–06 led to supply disruptions (Löschel *et al*, 2010).

Energy security, as a policy concept, has evolved over a period of time. Narrow definitions of energy security are criticized for being only about oil (neglecting other energy carriers), primary fuel (neglecting conversion technologies), and imports (neglecting domestic infrastructure) (Sauter and MacKerron, 2008). Though energy security is a high priority issue on the political and scientific agenda of industrialized and developing economies (Löschel *et al*, 2010), it is more of a concern for the latter for the following reasons. Firstly, developing countries are likely to account for about two-thirds of increase in energy use and three-fourths of increase in CO_2 emissions during 2010–2030 (IEA, 2012). Secondly, the prevailing *energy poverty* in these countries is presenting a critical challenge of achieving human development. About 2.4 billion people from these countries have no or unreliable access to electricity and about 3.5 billion rely on solid fuels for cooking energy needs. And for the poor among those who have access, the recent increase in energy prices has put pressure on their affordability (Ruijven, 2008). Thirdly, developing countries are a subject of concern worldwide for their high climate-change vulnerability. In the coming decades, it is predicted that billions of people from these regions will face shortages of water and food, and greater risks to health and life as a result of climate change (UNFCCC, 2007). So, the energy security policy for developing countries needs careful appraisal.

India, being a developing economy, faces multifaceted challenge, with energy insecurity at both supply and demand sides (Reddy and Nathan 2010). On supply side, it is heavily dependent on world oil markets as more than 70 per cent of the oil consumed in India is imported indicating a high strain on foreign exchange reserves (BP, 2012). India also suffers from energy deficit of 12.3 per cent (CEA, 2012). As per the estimates of IEA (2012), India will be the third largest emitter in the world by 2015 and the third largest oil importer by 2030, behind China and USA. Nearly, 0.4 billion people in India, i.e., 45.1% of rural and 7.8% of urban households do not have access to electricity. There is an imperative need to reduce dependence on fossil fuel, to secure supply of adequate eco-friendly alternatives and improve the energy infrastructure to provide quality; and reliable energy services to the needy at affordable price.

Measuring sustainable energy security requires identification of its relevant dimensions and a set of indicators which can capture its diverse aspects. A comprehensive assessment of these indicators allow us to study the current situation, find the gaps, and provide policy makers important insights and directions to facilitate the decision-making process. The present study develops an indicator-based analytical framework for appraising the current energy security status of India and future prospects for it. It uses the normalization procedure and describes the indicators' highest and lowest values. In the process it develops a four-dimensional measure to assess sustainable energy security. This approach could be used to create awareness among policy makers, benchmark indicators, monitor changes and contribute to policy formulation.

2. India's energy trajectory

Table 1 presents the final energy use by sector for each of the major fuels. Almost all of the coal used in India is used for electricity generation. The transport sector dominates the use of oil products, accounting for slightly less than half of oil products use. The industrial sector is currently the major end-user of coal, mainly for power generation. Industry also accounts for about 40 per cent of electricity use, with residential, agricultural and commercial sectors accounting for most of the balance of electricity demand. Overall, 34.17 per cent of the total final energy demand is by industrial sector, 26.8 per cent by residential, 13.72 per cent by transport sector and 17.05 for other uses.

Table 1: Sectoral Energy Consumption (MTOE) (2010)

Sector	Biomass	Coal	Oil	Gas	Electricity	Total	%
Residential	72.1		24.90	0.22	12.2	109.32	26.88
Industrial	0.9	87.40	28.81	0.42	21.34	138.96	34.17
Transport			54.29	0.42	1.07	55.79	13.72
Commercial	3.8		1.06		5.07	10.13	2.49
Agriculture			12.72	0.15	10.27	23.14	5.69
Others	0.2		37.79	28.16	2.38	69.33	17.05
Total	78	87.40	159.57	29.37	52.33	406.67	100.0

Source: TERI, 2012

For performing the synthesis of energy trajectory for the period 2010–2030, we use the International Energy Agency's two energy scenarios for India, i.e., *Reference Scenario* (RS) and *Alternative Policy Scenario* (APS)[2] (IEA, 2012**).** Table 2 gives the details of energy demand, electricity generation and CO_2 emissions under the RS and APS.

In the baseline scenario, India will remain heavily dependent on coal**—** produced mostly indigenously**—** constituting half of the primary energy mix. Coal will dominate electricity generation with around 70% share. Oil will account for one-fourth of India's primary energy demand in 2030, which is driven mostly by transportation sector. Natural gas, being a marginal fuel now, registers a higher annual average growth rate of 6.5% in the power generation, and 8.5% in residential, agriculture and services sector combined. Among non-fossil sources, nuclear power capacity is projected to increase from 26 to 134 TWh during 2010–2030. This is below the level targeted by the government, which reflects India's difficulties in constructing new nuclear power plants and its exclusion from international trade in nuclear power plants and materials (IEA, 2012). Though hydropower output more than doubles, its share of power generation will fall from 11.9% in 2005 to 8.3% in 2030 because of the socio-environmental concerns of large dams and resulting displacement. The biomass share will fall in primary energy demand from 24.6 to 14.3% during the same period. Even though biomass fuels presently provide 72% of the domestic energy and 90% of all rural energy needs, in future, they get substituted, as the availability and affordability of modern fuels improve in rural areas and among the urban poor. This is evident from the fact

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[2] The RS assumes that demographic growth, economic development and energy prices would continue to influence the present patterns of demand and supply. The APS, on the contrary, controls the business as usual growth in the energy demand for reasons of energy security or environmental sustainability, which includes climate-change concerns. APS encompasses the policies and practices, which consist of efficiency and emission standardization, use of alternative fuels, clean technologies and demand side managements.

that the share of biomass in domestic energy use declines from *% to below 50% by 2030. Among the renewable sources, wind registers a significant growth with its share of electricity generation rising from just under 0.2% to 1.9%.

Table 2: Energy demand, electricity generation and CO_2 emissions under RS and APS

Source	2010	New Policies Scenario (CPS)			450 ppm Scenario (450)			Change (450~CPS) in 2030 (%)
		2020	2030	AGR*	2020	2030	AGR*	
Total primary energy demand (MTOE)								
Coal	283	478	701	4.6	371	330	0.8	–52.9
Oil	166	225	322	3.4	210	279	2.6	–13.4
Gas	53	77	113	3.9	81	123	4.3	8.8
Nuclear	7	20	35	8.4	21	67	12	91.4
Hydro	10	15	21	3.8	17	39	7	85.7
Biomass and waste	170	190	201	0.8	191	215	1.2	7
Other renewables	2	9	15	10.6	12	36	15.5	140
TOTAL	691	1013	1407	3.6	904	1089	2.3	–22.6
Electricity Generation (TWh)								
Coal	653	1207	1916	5.5	895	692	0.3	-63.9
Oil	26	28	23	-0.6	17	10	-4.7	-56.5
Gas	118	212	349	5.6	253	415	6.5	18.9
Nuclear	26	77	134	8.5	82	257	12.1	91.8
Hydro	114	173	239	3.8	196	454	7.2	90
Biomass and waste	2	17	54	17.9	25	113	22.3	109.3
Wind	20	63	100	8.4	88	196	12.1	96
Geothermal	0	0	1		1	2		100
Solar	0	22	48		30	119		147.9
Tide and Wave	0	0	0		0	1		
CSP					3	22		
TOTAL	960	1799	2864	5.6	1590	2280	4.4	–20.4
CO_2 emissions (Mt)								
Coal	1093	1824	2648	4.5	1404	1100	0	–58.5
Oil	429	588	880	3.7	544	743	2.8	–15.6
Gas	113	167	251	4.1	177	270	4.5	7.6
TOTAL	1635	2579	3779	4.3	2125	2113	1.3	–44.1

AGR is Average Annual Compounded Growth Rate (%) during 2010–2030;
Source: IEA (2012)

Under the alternative policy scenario, there is a reduction in demand of about one-sixth for primary energy and electricity generation in 2030 as compared to reference scenario. The corresponding decrease in CO_2 emission is 27%. There is a reduction in the share of all conventional fossil-fuel resources in primary energy in 2030, with share of coal going down by one-third and so is coal-related CO_2 emission. This is achieved through efficiency improvement of coal based plants through renovation and modernization, and deployment of new technologies. Electricity supply improves not only because of efficient production but also due to reduction in transmission and distribution losses. The demand also lowers because of efficiency improvements in appliances, lighting and air-conditioning equipment. Similarly, introduction of emission standards in vehicles and expanded use of bio-fuels and CNG, and improved public transport system bring a reduction of 17% in share of oil. Unlike coal and oil, natural gas increases its share in final energy due to its high quality, convenience of use and environmental benefits. Among non-fossil fuels, nuclear power is clearly emerging as an option. Both hydro and nuclear will command more than 40% increase in demand under APS in 2030 compared to RS. Biomass use increases in industry and transport sector for its use in combined heat and power plants (CHP) and production of biofuels respectively. The share of other renewable energy sources will increase in primary energy as a result of policies to control pollution and lower greenhouse gas emissions. Among solar, biomass, and wind-based power generation, solar has the highest average annual growth rate, close to 40%, followed by bio- and wind power, which will grow at 16% and 13%, respectively.

3. Indicators of security and sustainability

Indicators can play an important role in turning data into relevant information for policy makers and help in decision-making. They also simplify a complex and large information base. In this way, the indicators provide a “synthesis” view of existing situation. The indicators have become well established and are widely used in diverse fields and at various levels, viz., global, regional, national and local (Anon, 2000). Examples of indicators include such measurements as GDP (Gross Domestic Product) as a way of assessing economic development in a country, the infant mortality rate (IMR) as an indicator of the health status of a community, or the rise in carbon emissions as a way of estimating the environmental conditions of a region. The selection criteria for the construction of indicators include factors such as transparency, scientific validity, robustness, sensitivity and the extent to which they are linkable to each other. The applicability of the criteria depends on the indicator in question, and the purpose of the indicator to be used. However, no single set of criteria will be applicable to all indicators and all situations since each have priorities for data collection and analysis.

In literature, there are multiple ideations for sustainable energy security [3] measurements and there is no single indicator. Indicators are highly context-specific and are based on notions of diversity, import dependency, political stability, market liquidity, etc. (Kruyt *et al*, 2009). Some indicators address just energy security whereas others capture several aspects of sustainability. However, multiple indicators are applied here for broader understanding for sustainable energy security. While using indicators to quantify energy security, we have considered the two dimensions of energy security, namely, supply security and demand security. The indicators linked to supply security attempts to measure the adequacy, reliability, quality and guarantee aspects of energy resources and carriers. This has been in the context of geographical, temporal, production capacity, climate change, economic and diversity considerations. On the other hand, the energy demand security has been attempted to measure from the consumer's perspective. The indicators used for this purpose attempt to measure the capacity of the energy system as a whole to meet the basic needs of the weakest section of the population. The underlying logic is that the energy system can hope to meet the lowest energy needs only after meeting the demands above that. In other words, the indicators under energy demand security measure the extent of energy deprivation.

The notion of sustainable energy security applied here is a "four-dimensional" one. Each dimension has various indicators. This framework sees sustainability not only in economic, environmental, and social terms but also intuitional dimension. This is because governance and institutions are inextricably related and are paramount to project the current status of any system and convert it into a more desirable one in future. The role of institutions is to make decisions that result in energy security while the individuals who run institutions determine the degree of sustainability. Our conceptualisation of sustainable eenergy security quantifies performance providing clear and compelling measures of key variables in economy, environment, social systems, and institutions/governance. For example, environment performance includes things such as the concentration of different pollutants in the air and the amount of resources, such as water and electricity consumed. Social performance includes factors such as affordability, while economic dimension involves issues such as reserve-to-production ratio.

[3] In case of energy security, it is important to include energy sustainability. This is because the concepts of sustainability takes into consideration the sustainable *use* of natural resources, the sustainable *distribution* of natural resources (equity considerations) and maximising the quality of life.

4. Methodology adopted

For the present study, we try to identify the proper performance indicators which reflect different aspects of security and sustainability. It is important that, as far as possible, indicators should be quantitative; however, for some aspects of security, qualitative descriptions may be more appropriate (e.g. institutional aspects). The next step in selection is to understand which dimensions of security and sustainability should be considered. An in-depth literature survey has been carried out to enable us in identifying the indicators. The next step is to link energy security and sustainability which include indicators belonging to the following dimensions—Economic, Social, Environmental and Institutional/Governance. In this context, it is critical to derive the extent of contributions made by each of the dimensions to the overall energy security and sustainability. Simplest assumption is that all the dimensions contribute equally to security and sustainability and all the indicators contribute equally to the dimensions. In other words, it means that all the indicators and dimensions will have equal weights assigned to them. For each dimension, indicators of performance (positive or negative) are considered from the perspective of security and sustainability (indicators whose increasing value has a positive impact while the opposite is true for negative). For example, for certain indicators (e.g., reserve-to-production ratio), an increasing value reflects a positive effect on security and sustainability and for some (e.g., per capita emissions), a negative effect on sustainability. Hence it is important to categorize indicators from this view point for the analysis (Damjan and Peter, 2005).

The criteria for selection of indicators include considerations of data availability and feasibility to collect additional data considered essential to the development of important indicators in future. The indicators are quantified by analyzing extensively the data collected, mostly from secondary sources. The threshold values representing bench marks (maximum and minimum values of countries) are also obtained. Each indicator is evaluated separately and is benchmarked to values that indicate high and low levels of performance in absolute terms. To aggregate indicators, it is necessary to assign a weight, to determine their relative importance to the final composite index. Here, we use Equally Weighted Average (EWA), in which all indicators are given the same weight which is considered to be the most transparent methodology (Yale Center for Environmental Law and Policy, 2005).

Different indicators are expressed in different units and hence they cannot be used in the original units for the calculation of indices and to arrive at the security and sustainability index. For this purpose, normalization procedure is used. For the present study, normalization has been done using the following equations.

First, each dimension, indicators should be oriented in such a way that more desirable outcomes receive a higher (positive) value and less desirable outcomes receive a lower (negative) value.

For a positive effect indicator the equation used is

$$d_{i,j} = (A_{i,j} - a_{i,j})/((b_{i,j} - a_{i,j}) \qquad (1)$$

and for a negative effect it is

$$d_{i,j} = (b_{i,j} - A_{i,j})/((b_{i,j} - a_{i,j}) \qquad (2)$$

where

$A_{i,j}$ = Actual value

$a_{i,j}$ = Minimum threshold value

$b_{i,j}$ = Maximum threshold value

$d_{i,j}$ = Normalized value of the dimension indicator

The calculation of the aggregate index is a step-by-step procedure of grouping various basic indicators into the dimension index. To obtain this index the following equation has been used (Petrosyan, 2010).

$$d_j = \left(\frac{\sum_{i=1}^{I} V_{ij}^2}{I}\right)^{0.5} \qquad (3)$$

where, d_j = Dimension of type "j"

V_{ij} = Variables "i" belonging to dimension "j", i = 1, 2, …., I

I = Number of variables in a dimension

Finally, the dimension indices are combined into the composite sustainable energy security index using the following equation:

$$SESI = \left(\frac{\sum_{j=1}^{J} d_j^2}{J}\right)^{0.5} \qquad (4)$$

where, SESI = Sustainable energy security index

d_j = Dimension "j", j = 1, 2, …., J

J = Number of dimensions

This is an easy approach given that it normalizes indicators to an identical range [0, 1], where higher scores represent better achievement. Also, the re-scaling widens the range of an indicator. For many indicators such as efficiency, the minimum and maximum values needed for the re-scaling are determined based on “natural” minimum and maximum values instead of observed ones. Figure 1 shows the methodology used to estimate the sustainable energy security index.

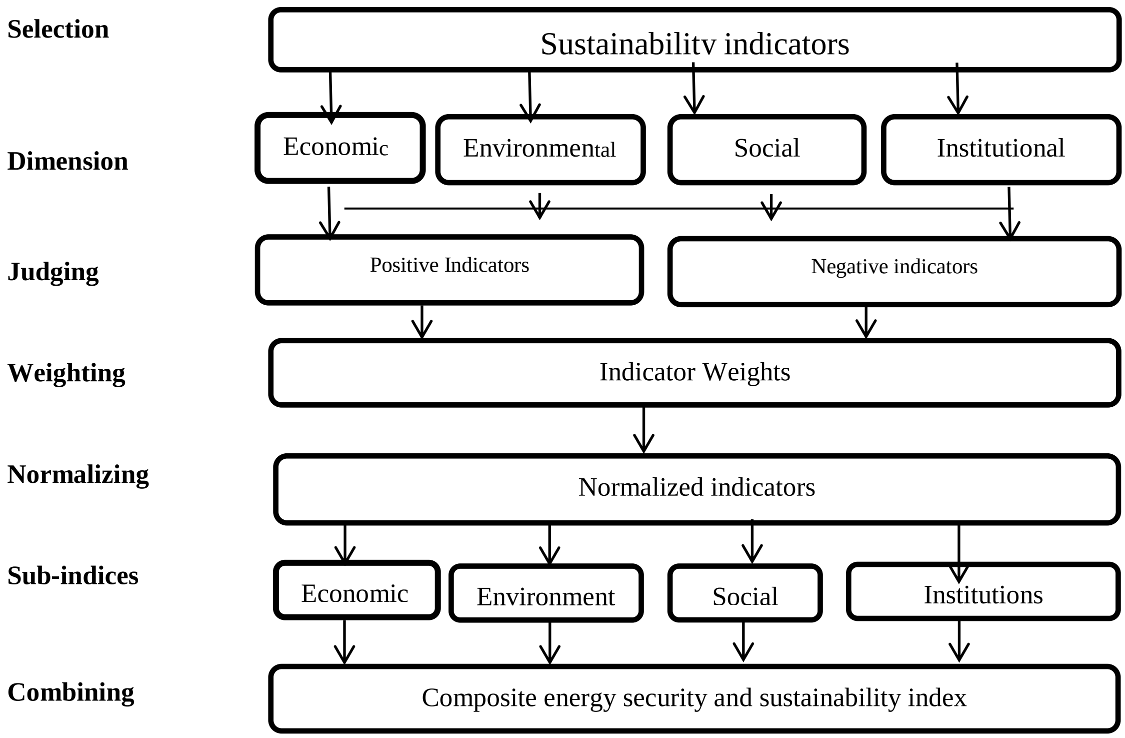

Figure 1: Developing SESI

5 Results

5.1 Economic Dimension

Table 3 shows indicators pertaining to economic dimension. The availability of resources and the reliability of their supply are essential for a sustainable economic growth. All sectors of the economy including residential, commercial, transportation, service and agricultural sectors depend on secure, sufficient and efficient energy services. Job availability, industrial productivity, urban and rural development and all major economic activities are strongly affected by energy input. Electricity is an important and sometimes irreplaceable input to modem productive activities, communication, dissemination of information and other service industries. The energy indicators in the economic dimension consider two themes of production and utilisation patterns, and security of supply. Within the theme of production and consumption patterns the following sub-themes are addressed: overall use and productivity, supply efficiency, production, end-use, diversification (fuel mix) and prices. The security theme includes dependency on imports and strategic fuel stocks. Efficiencies and intensities are important issues affecting energy systems and define sustainability trends. By reducing quantities of energy consumed, improvements in energy efficiencies translate into progress towards sustainable development since investments in energy infrastructure and expenses in fuel costs can be reduced.

The diversification of energy sources, in terms of both reserves and utilisation, is the most important criterion for enhancing energy security. In the category of supply security, the RP ratio for coal is the highest at 111 years, while the figures for oil and gas are 21 and 23. The import dependence of India for RS and APS show that the country will continue to have high import dependency even under APS.

The total energy consumption in 2010 was 530 MTOE. The share of coal is the highest with 47% followed by oil and biomass with 27 and 15 per cent, respectively. Import dependence is often considered as a risk to energy security. The oil import dependency is very high with 70% and in total imports the share of energy is one third. Access to modern energy services is limited to LPG (11% of total households) while more than 90% of the population has access to grid electricity.

There is a direct correlation between energy consumption and economic growth. Energy intensity provides insights into the efficiency and of energy use (how much energy is used to produce a dollar of economic output). The intensity of the society, economy and the sectors reflect the stages of economic development. The energy intensity of India is about 190 (toe/US$ million, ppp) while that of the society is 24 GJ/cap.

There are significant technical and non-technical losses in generating and transmitting electricity. The reported losses for coal-based power generation are more than 70% while the T&D losses for electricity are about 30%. Similarly the utilization efficiency of biomass as well as kerosene stoves is very low.

An average Indian consumes about 170 kg of biomass, 173 l of oil and about 500 kWh of electricity per annum which is significantly less than the world average underlining the significant lack of access to modern energy services, which is a key reason for slow economic growth. The taxes for oil products are very high in India. These are 48% for petrol and 34% for diesel. To rationalize energy use the government is phasing out energy subsidies which are about 1% of the total GDP.

Table 3 Sustainable energy security indicators—Economic dimension

Category	Subcategory	Indicator	Unit	Value
Supply Security	Total primary energy consumption per capita	Coal	kgoe	500
		Oil	bbl/day 1,000 people	3
		Gas	M^3	54
	Reserves-to-production ratio	Coal	Yrs.	111
		Oil	Yrs.	21
		Gas	Yrs.	23.3
	Import Dependence	Share of energy imports	%	33
		Share of oil imports	%	70
		Oil vulnerability index	No	0.93
		Fuel imports as a % of GDP	%	5.9
	Supply infrastructure	Villages connected to grid	%	92
		Villages with LPG connection	%	11
		Villages with road connectivity	%	62
Diversifi-cation	Fuel share in primary energy	Biomass	%	24
		Coal	%	38
		petroleum products	%	26
		Natural gas	%	7
		Renewable energy	%	30
	Fuel share in final energy	Biomass	%	31
		Oil	%	20
		Electricity	%	13
		Share of fossil fuels in power generation	%	76
		Share of fossil fuel in installed capacity	%	78
		Locally produced fuel (biofuel or fossil fuel)	%	70
		Renewable energy as a % of total electricity supply	%	12.5
Energy intensity	National energy intensity	Energy intensity of society (final energy use/cap)	GJ/cap	24
		Energy intensity of economy (energy use/GDP)	toe/$ million (ppp)	190
	Sectoral energy intensity	Industry	koe/$ (ppp)	0.04
		Commercial	koe/$ (ppp)	0.06
		Agriculture	koe/$(ppp)	0.09
		Passenger transport	MJ/PKM	1.4
		Goods transport	MJ/ton-km	3
Energy Efficiency	Energy production efficiency	Coal-based power plants	%	27
		Gas-based power plants	%	39
		Hydro-power plants	%	80
		Renewable power	%	15
		Oil refineries	%	75
	Energy Transmission/transport efficiency	Power grid efficiency (T&D)	%	78
		Efficiency of oil distribution system	%	80
		Coal Transport efficiency	%	70
	Energy end-use efficiency (HH sector)	Biomass stove efficiency	%	15
		Kerosene stove efficiency	%	30
		LPG stove efficiency	%	70
		Electrical appliance efficiency	%	75
Energy consumpt-ion	Final energy consumption	Biomass	kg/cap	170
		Oil	l/cap	173
		Natural gas	cu.m/cap	54
		Electricity	kWh/cap	498
Taxes and subsidies	Energy taxes	Taxes as share of petrol price	%	48
		Taxes as share of diesel price	%	34
		Taxes as share of electricity price	%	15
	Energy S subsidies	Diesel subsidies as a % of GDP	%	1
		Kerosene subsidies as a % of GDP	%	0.6
		Electricity subsidies as a % of GDP	%	1

5.2 Social Dimension

The social dimension of energy security measures the impact of energy services on social well-being in terms of accessibility, affordability and disparity. It reflects the need for households to have access to modern energy services for cooking and lighting. Hence sustainable energy security indicators of the social dimension play an important role in many developing countries that lack access to these services due to affordability problems. In countries like India poor spend a few hours a day collecting wood for cooking and heating. If the households have to use commercial carriers like kerosene and electricity, they will consume a significant portion of their monthly household income. The themes that are considered under the social dimension include: affordability, equity and reliability of supply.

Table 4: Sustainable energy security indicators-Social dimension

Category	Subcategory	Indicator	Unit	Value
Affordability	Energy prices	Biomass fuels	US$/GJ	2.4
		Electricity	USc/kWh	12
		Gas	US$/l	0.5
		Petrol	US$/l	1.1
		Diesel	US$/l	0.82
		Kerosene	US$/l	0.25
	Energy expenditure in total expenditure	High-income households	%	5
		Middle-income households	%	7
		Low-income households	%	8
		BPL households	%	12
	Energy connectivity	HH with electricity connection	%	56
		HH with LPG connection	%	25.4
Equity	Energy access	Households using kerosene for lighting	%	42
		Households using solid fuels for cooking	%	56
		Traditional energy in total household energy use	%	65
	Energy adequacy	Electrical power use	W/cap	90
		Solid fuels use per capita	GJ/cap	2.2
		Petroleum fuels use per capita	l/cap	175
Reliability	Energy rationing	Average load shedding in rural areas	hrs./day	12
		Average load shedding in urban areas	hrs./day	6
		Peak demand shortage	%	13
		Energy shortage	%	10
	Energy quality	Unplanned interruptions/year	No.	35
		Household electricity consumption	kWh/cap	498
		Non-commercial energy in total energy consumption by households	%	54

Table 4 provides information on social indicators of sustainable energy security for India. The indicator pertaining to the prices of energy carriers addresses the issue of affordability. Even though, the price per unit of energy for cooking is the lowest for biomass fuels, its low efficiency (about 10%) makes them the costliest fuel. Monthly energy expenditures are shown for four different levels of income. The figure shows the share of income that is spent on energy services at each level of income. The data indicate that the segments of the society with lower income levels not only use inefficient fuels but also spend a large share of their monthly income (8–12 per cent) on basic energy needs. Energy costs thus significantly impact the basic needs and how much disposable income is available for other needs such as education or health care.

It is important that adequate, affordable and reliable energy services are necessary for sustainable human development. As the table shows only 56% of the households have electricity connection and about 25% LPG. Even for these households reliable energy supply remains a dream. There is no electricity supply for nearly 50% of the time in rural regions and 25% of the time in urban regions. Therefore, sustainable energy security requires increase in accessibility and affordability of energy services.

5.3 Environmental dimension

The extraction/production, generation, transportation, distribution and use of energy create pressures on the environment at the household, national, regional and global levels. These environmental impacts depend on how the energy is produced and used, the nature of fuel mix, the structure of the energy system and related regulatory actions and policy prescriptions. The environmental indicators are divided into three themes: climate change, air pollution and ecological impacts. Water and land quality are important categories of environmental dimension. Energy activities degrade and acidify land and affect water quality as well as agricultural productivity. The household use of fuel wood result in deforestation that leads to erosion and soil loss. The quantity of greenhouse gases (GHG) that are generated will decide whether humankind is changing the climate for the worse (Table 5).

Table 5: Sustainable energy security indicators-Environmental dimension

Category	Subcategory	Indicator	Unit	Value
Global Climate Change	GHG emissions	CO_2 emissions from power generation	t/cap	0.9
		CO_2 emissions from transport sector	t/cap	0.125
		CO_2 emissions from industry	t/cap	0.34
		GHG emissions per capita	t/cap	1.45
	GHG intensity	CO_2 emissions/GDP	kg/US$ PPP	0.565
		CO_2 emissions/kWh of power generation	Kg CO_2/GJ	70
		CO_2 emissions per capita	kg	1.45
Air pollution	Energy production	AAQS (PM10)	ug/m^3	75
		AAQS (SO2)	ug/m3	90
	Energy consumption	Standard for sulphur (S) content of diesel fuel in parts	ppm	500
		SO_2 emissions per populated area	1000 t/sq.km of land area	1150
		Air pollution index	No.	77.5
Ecological	Water pollution	Share of waste water treated (%)	%	35
		Water quality index	No.	35
	Soil pollution	Waste collected and adequately disposed (%)	%	25
		Solid waste (kg/cap/year)	kg/cap/y	150
	Ecological impacts	Forest cover	% of land area	23.7
		Rate of deforestation attributed to energy use	%/year	0.35

5.4 Institutional/governance dimension

The institutional/governance challenge is one of the often major ignored problems (structure, players, influences, actions, and constraints) countries like India faces in energy security and sustainability. Institutional indicators help measure the effectiveness of a national sustainable energy security development strategy/plan, capabilities, adequacy and effectiveness of investments in capacity building, R&D development and also monitor progress towards appropriate and effective legislative, regulatory and enforcement measures to foster efficient energy systems.

The indicators for this dimension are difficult to measure since they address issues that are quantitative in nature. The governance index given here measures how well countries address various challenges (Anon, 2013), viz., prevailing legal and institutional framework that supports transparency and accountability, information published about the resource sector, safeguards to promote integrity in its governance and broader institutional environment conducive to accountable resource governance. There are also other indicators such as availability of policies, private sector participation. Changes in one component can affect governance as a whole. As areas of analysis and policy reform, they should be considered individually as well as collectively. For the purposes of this study for each indicator, we have assigned scores. The available indicator sets that measure aspects of each category are summarised in Table 6.

Table 6: Sustainable energy security indicators—Institutional dimension

Category	Sub-category	Indicator	Unit	Value	Remarks
Resource governance	Practices	Institutional and legal setting	Score	60	
		Reporting practices	Score	72	
		Safe guards and quality controls	Score	83	
		Enabling environment	Score	71	
		Governance of state owned companies	Score	92	
Energy sector governance (score)	Policy	Availability of national energy policies	Score	2	3=Comprehensive Policies in place 2=Policies framework ready 1 = Policies are being worked out 0 = None
		Extent of implementation of national energy policies	Score	1	3 = Implemented fully 2 = Process going on 1 = Plan is in place; 0 = No plan
		Quality of energy planning (integrated planning or sub-sector)	Score	1	3 = Whole of energy sector plan/roadmap operational 2 = Sub-sector plan with framework 1 = Energy sector plan in preparation 0 = No plan
		Level of coordination (how decisions and directions given at regional level translate into practical action)	Score	1	1 = Meetings lead to relevant national action; 0 = No action
	Institutions	Adequacy energy institutions at the national/regional level	Score	2	3 = Energy ministry; 2 = Department 1 = Energy office; 0 = None
		Public–private partnerships in energy sector	Score	1	3 = High; 2 = Medium 1 = Low; 0 = None
		Efficacy of institutions for delivery of energy services	Score	1	3 = High; 2 = Medium 1 = Low; 0 = None
	Legislation	Availability various acts related to energy	Score	3	3 = In place; 2 = Finalised 1 = In preparation; 0 = No act
		Efficacy of implementation of above acts	Score	1	3 = High; 2 = Medium 1 = Low; 0 = None
		Energy efficiency standards		2	3 = Implemented fully 2 = Implemented partially 1= In preparation; 0=No standards
Private sector participation	Contribution	Share in total installed capacity	%	9	
		Share in total power generation	%	10	
	Participation	Share of private sector investment in total power sector investment		8	
		Availability of enabling framework for private sector participation	Score	2	3= Comprehensive Framework in place 2 = Framework ready 1 = Being worked out; 0=None
		Share of petroleum refinery capacity	%	20	
Finance/ funding	Financial Access	Ease of access to finance for energy project financing	Score	2	3 = High; 2 = Medium 1 = Low; 0 = None
		Ease of access to finance for energy efficiency/renewable energy for HHs	Score	1	3 = High; 2 = Medium 1 = Low; 0=None

Even though India faces significant economic challenges, it exhibits good practices in many categories. It adopts transparent and accountable systems for managing its resources. And though India's overall institutional governance is weak, it initiated reforms in government-owned companies, as reflected in its high score. In case of legislation and policies the government effectiveness is moderate relatively. In these cases, governance is less likely to improve the ability of citizens to hold governments accountable. On the other hand, private sector participation scores well in government effectiveness but fall short in financing. Overall, policy implementation is a problem area that lags behind the overall governance environment. The improvements in this area could be a springboard for more governance effectiveness.

6 Sustainable energy security index for India

To develop a composite sustainable energy security index for India we have consolidated individual indicators under each category and then normalized the values into a single form. For normalization, we used the maximum and minimum possible values from countries with the highest and lowest values for that indicator. This results in threshold values (maximum and minimum) for every indicator. Using this data, the sustainable energy security index (SESI) has been obtained. This provides a single number (within the range of 0 and 1) for comparing the level of security of a country. India's performance is best understood by looking not only at its overall SESI score but by examining its results with respect to key indicators of different dimensions (Appendix A). The category- and dimension-wise sustainable security indicator values and the SESI are presented in Table 7. We observe from the table that India performs reasonably well in economic and environmental dimensions but not in social and institutional. With respect to social sustainability, India has an indicator value of 0.493 while it is 0.561 for institutional sustainability. In economic sustainability, India scores 0.628 and the overall SESI is 0.593 which is above the halfway mark.

The high values for various dimensions are not surprising. In general, energy use depends on (i) production system and (ii) life style. In countries like India production systems are inefficient and hence the high energy intensity which results in low energy security. At the same time, people have non-energy intensive life style (low energy use for a given activity) resulting in low per capita use. This is a sustainable way of resource use. However, in ideal situation efficiency of the production system should increase and of the lifestyle decrease

Table 7: Sustainable energy security index for India

Dimension	Category	Index		
		Category	Dimension	SESI
Economic	Supply security	0.544	0.628	0.593
	Diversification	0.556		
	Energy intensity	0.705		
	Energy efficiency	0.452		
	Energy consumption	0.853		
	Taxes and subsidies	0.499		
Social	Affordability	0.449	0.493	
	Equity	0.421		
	Reliability	0.591		
Environmental	Global climate Change	0.846	0.673	
	Air pollution	0.716		
	Ecological balance	0.360		
Institutions/ governance	Resource governance	0.721	0.561	
	Energy sector governance	0.657		
	Private sector participation	0.294		
	Finance/funding	0.471		

7. Achieving sustainable energy security—Priority areas and policy responses

There are a number of indicators which are more qualitative in nature and are difficult to quantify and this needs to be considered in decision making process and in the final formulation of major energy policies.

The set of indicators developed here help policy makers and energy analysts in assessing the current situation of a given country. This will result in raising awareness of the need to develop an integrated approach towards energy security and sustainability that help in developing energy projects, programs and strategies. It is important to understand that each country needs to select the energy indicators within the proposed core set that are most relevant to the country's energy system or to the policy priorities. If needed, additional indicators, specifically designed to address conditions or priorities unique to a given country, might be added. Also, a country can expand the core set of indicators by adding additional indicators such as those pertaining to reliability of energy systems. This will be useful in assessing and monitoring the status and progress of specific strategies towards a more secure and sustainable energy system.

The estimated SESI for India is not high. Even though it has strong underlying systems and less stress on several fronts, it has less developed institutional capacity to manage the challenges it has to address, including severe water-quality issues. India struggles with the pressures of a large population, low efficiency of energy use and environmental externalities associated with rapid economic growth and resource extraction. To attain higher security and sustainability, it has to consider the following, viz., i) reduce dependence on imported oil and secure adequate alternative supply to meet rising demand; ii) address environmental impact of energy use, iii) design policies to improve efficiency of generation and use, supply infrastructure and transportation networks and (iv) strengthen institutional base.

Progress on energy security and sustainability is not possible under conditions of economic failure and social inequity. At the same time, it is impossible to degrade the environment beyond a certain point while enjoying economic success. At the same time, we need institutional capacity and performance which create conditions under which the rest of the dimensions (economic, environmental and social) are maintained. The role of the government is to maintain positive relationships among various dimensions of sustainability.

To assess the correct picture of a country's energy scene, comprehensive statistical databases are required. The government should improve and expand the energy data collection mechanisms, monitoring systems and approaches adopted. These include the establishment of arrangements to collect missing data, modification of existing data compilation procedures and building capacity that is required to perform these functions. These efforts will result in the collection of necessary data base for the development of energy indicators relevant to sustainable development criteria and in the incorporation of results in on-going programmes. This will also be useful in developing future scenarios with necessary modelling tools which allow a more comprehensive monitoring mechanism and analysis of sustainability trends and objectives (Vera and Abdalla, 2006). Because of the range and complexity of issues that fall under various dimensions, policymaking needs to be made more data-driven and empirical. SESI supports this goal.

8. Conclusions

This paper presents the development of a sustainable energy security index that depicts the performance of India from various perspectives—economic, environmental, social and institutional. It discusses how different indicators can be associated into security and sustainability sub-indices and finally into an overall indicator of a country's performance. This helps to focus on measures and policies that should be taken to achieve the goal. The approach is therefore presented as a guide which has been designed to be as flexible as possible to facilitate its use. It should be noted that the generic framework in no way constitutes a "ready-to-use " list but rather a reference point where relevant criteria and indicators can be selected according to the requirements, the actors and the types of resources dealt with.

India's increasing dependence on natural gas and petroleum fuels makes it vulnerable to supply disruptions and price spikes. The various dimension of sustainable development are primarily concerned with reduction of spending on energy, infrastructure investment and providing clean and efficient energy systems. To achieve this, existing resources should be used efficiently and a wide range of resources should be harnessed in the achievement of these objectives. Until now low attention has been paid to the linkages between the social and the economic dimensions of energy security. The essence of sustainable development lies precisely at the interfaces and trade-offs between the conflicting objectives of economic and social development and environmental protection. Hence, the country should design strategies to secure supply sources and reduce energy demand. Diversification will remain the fundamental starting principle of energy security for fossil fuels. It also requires developing a new generation of "clean coal" and low carbon technologies encouraging a growing role for a variety of renewable energy sources including hydrogen fuel as they become more competitive. A move towards more sustainable technologies and fuel types is needed to meet future challenges Investment in energy-efficient as well as renewable energy technologies and infrastructure will require conducive economic and environmental policies. In a world of increasing interdependence, energy security will depend much on how countries manage their relations with one another. That is why energy security will be one of the main challenges for India's foreign policy in the years to come. The energy security policies of the country need to be oriented to sustainable development as the primary goal and climate mitigation as its byproduct. Energy being critical need for MDG, India must target in the next couple of decades, for universalization of provision of energy services for all its citizens.

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Appendix A: Estimation of Sustainable Energy Security index

Dimension	Category	Sub-category	Indicators	Unit	Actual value	Threshold Values		Normalisation	Indicator Values			
						High	Low		Sub-category	Category	Dimension	ESSI
Economic	Supply security	Primary energy consumption per capita	Coal	kgoe	500	2,100	15	0.77	0.923	0.544	0.628	0.604
			Oil	bbl/day/ 1,000 people	3	103	2	0.99				
			Gas	M^3	54	4,315	30	0.99				
		Reserves-to-production ratio	Coal	Yrs.	111	481	19	0.20	0.124			
			Oil	Yrs.	21	258	8	0.05				
			Gas	Yrs.	23.3	220	10	0.06				
		Import dependence	Share of energy imports	%	33	90	7	0.69	0.562			
			Share of oil imports	%	70	85	0	0.18				
			Oil vulnerability index	No	0.93	1.11	0.3	0.22				
			Fuel imports as a % of GDP	%	5.9	30	1.4	0.84				
		Supply infrastructure	Villages connected to electric grid	%	92	100	0	0.92	0.630			

			Villages with LPG connection	%	11	100	0	0.11				
			Villages with road connectivity	%	62	100	10	0.58				
	Diversification	Fuel share in primary energy	Biomass	%	24	47	4	0.47	0.660	0.556		
			Coal	%	38	77	0.06	0.51				
			Petroleum products	%	26	85	18.8	0.89				
			Natural gas	%	7	60.1	1.5	0.91				
			Renewable energy in total primary energy supply	%	30	98	1.6	0.29				
		Fuel share in final energy	Biomass	%	31	98	0	0.32	0.427			
			Oil	%	20	51	0	0.61				
			Electricity	%	13	22	0.5	0.58				
			Share of fossil fuels in elec. generation	%	76	100	0.1	0.24				
			Share of fossil fuels in installed capacity	%	78	100	0.1	0.22				
			Share of locally produced fuel as a % of total supply	%	70	75	10	0.92				
			Share of renewables as a% of total power supply	%	12.5	99.8	0	0.13				

	Energy intensity	National energy intensity	Energy intensity of society	GJ/cap	24	325	8	0.95	0.870	0.761		
			Energy intensity of economy	toe/$ million (ppp)	190	519	98	0.78				
		Sectoral energy intensity	Industry	koe/$2005ppp	0.04	0.1	0.01	0.67	0.634			
			Commercial sector	koe/$2005ppp	0.06	0.11	0.02	0.56				
			Agricultural sector	koe/$05p	0.09	0.11	0.008	0.20				
			Passenger transport	MJ/PKM	1.4	4.5	1.3	0.97				
			Goods transport	MJ/tonne-km	3	5	1.2	0.53				
	Energy Efficiency	Energy production efficiency	Coal-based power	%	27	45	23	0.18	0.430	0.452		
			Gas-based power	%	39	51	27	0.50				
			Hydro-power	%	80	90	70	0.50				
			Renewables	%	15	20	10	0.50				
			Oil refineries	%	75	91.4	65	0.38				
		Energy transport efficiency	Power grid (T&D)	%	78	92	70	0.36	0.482			
			Oil distribution	%	80	90	60	0.67				
			Coal transport	%	70	85	62	0.35				
		Energy end-use efficiency	Biomass stove	%	15	30	10	0.25	0.443			
			Kerosene stove		30	40	25	0.33				

		(HH sector)	LPG stove	%	70	80	55	0.60				
			Electrical appliance	%	75	85	65	0.50				
	Energy consumption	Final energy consumption (Per capita)	Biomass energy	kg/cap	170	1100	25	0.13	0.853			
			Oil	l/cap	173	5610	50	0.98				
			Natural gas	cu.m/cap	54	3163	30	0.99				
			Electricity	kWh/cap	498	15600	103	0.97		0.853		
	Taxes and subsidies	Energy taxes (as a share of energy price)	Petrol	%	48	76	42	0.18	0.161			
			Diesel	%	34	75	30	0.09				
			Electricity	%	15	56	5	0.20				
		Energy subsidies (as % of GDP)	Diesel	%	1	2.8	0.8	0.90	0.687			
			Kerosene	%	0.6	0.9	0.15	0.40				
			Electricity	%	1	2	0.5	0.67		0.499		
Social	Affordability	Energy prices	Biomass fuels	US$/GJ	2.4	4	0.05	0.59	0.415			
			Electricity	USc/kWh	12	50	1	0.22				
			Gas	US$/l	0.5	1.9	0.05	0.24				
			Petrol	US$/l	1.1	2.52	0.09	0.42				
			Diesel	US$/l	0.82	2.03	0.07	0.38				
			Kerosene	US$/l	0.25	0.4	0.1	0.50		0.449		
		Share of energy expenditure in total expenditure	High income HH	%	5	14.1	2.8	0.81	0.519			
			Middle income HH	%	7	11	1.5	0.42				
			Low income HH	%	8	12	2.7	0.43				
			BPL households	%	12	15	3.5	0.26			0.546	

		Energy connectivity	HH with electricity connection	%	56	100	11	0.51	0.403			
			HH with LPG connection	%	25.4	92.3	1.6	0.26				
	Equity	Energy access	HH using kerosene for lighting	%	42	89	0	0.47	0.586			
			HH using solid fuels for cooking	%	56	96.2	0	0.58				
			Traditional energy in total HH energy	%	65	95	0	0.68				
		Energy adequacy	Household electrical power per capita	W/cap	90	2620	28	0.02	0.103			
			Household solid fuels use per capita	GJ/cap	2.2	12	0.1	0.18				
			HH petroleum fuels use per capita	l/cap	175	5760	58	0.02		0.421		
	Reliability	Energy Rationing	Average load shedding in rural areas	hrs./day	12	20	0	0.40	0.737			
			Average load shedding in urban areas	hrs./day	6	12	0	0.50				
			Peak demand shortage (%)		13	65	10	0.95		0.717		

			Energy shortage (%)		10	80	5	0.93				
		Energy quality	Unplanned interruptions/year	No.	35	6	82	0.38	0.696			
			HH electricity consumption	kWh/cap	498	15600	103	0.97				
			Non-commercial energy in total HH energy consumption	%	54	90	0	0.60				
Environmental	Global climate change	GHG emissions	CO_2 emissions from electricity	tonne per capita	0.9	2.06	0.1	0.59	0.897	0.846	0.673	
			CO_2 emissions from transport sector	t/cap	0.125	12.8	0.011	0.99				
			CO_2 emissions from industrial sector	t/cap	0.34	12.06	0.013	0.97				
			GHG emissions	t/cap	1.45	44	0.1	0.97				
		GHG intensity	CO_2 emissions/GDP	kg/US$ PPP	0.565	4.83	0.026	0.89	0.791			
			CO_2 emissions/kWh of power generation	Kg CO_2/GJ	70	120		0.42				
			CO_2 emissions/cap	kg/US$ PPP	1.4	31	0.06	0.96				
	Air Pollution	Energy production	AAQS (PM10)	ug/m^3	75	175	40	0.74	0.652	0.716		
			AAQS (SO_2)	ug/m^3	90	175	20	0.55				

		Energy consumption	Standard for sulphur (S) content of diesel fuel in parts	ppm	500	5000	50	0.91	0.775			
			SO_2 emissions per populated area	1000 tons /sq. km. land area	1150	21390	30	0.95				
			Air pollution index	No.	77.5	97	28	0.28				
	Ecological	Water pollution	Waste water treated	%	35	100	10	0.28	0.250	0.360		
			Water quality index	No.	35	96	18	0.22				
		Soil pollution	Waste collected and adequately disposed	%	25	100	11	0.16	0.134			
			Solid waste	kg/cap/y	150	780	75	0.11				
		Ecological impacts	Forest cover	% of land area	23.7	90	2	0.25	0.555			
			Deforestation attributed to energy	%/year	0.35	1.23	0.05	0.75				
Institutional/ governance		Resource governance index	Institutional/legal setting	Score	60	100	26	0.46	0.721	0.721		
			Reporting practices	Score	72	97	23	0.66				
			Safe guards and quality controls	Score	83	98	26	0.79				
			Enabling environment	Score	71	98	9	0.70				

			Governance of state owned companies	Score	92	99	15	0.92				
	Energy sector governance (score)	Policy	Availability national energy policies	Score	3	3	0	1.00	0.745			
			Extent of implementation of energy policies	Score	1	3	0	0.33				
			Quality of energy planning (integrated planning)	Score	1	3	0	0.33				
			Level of coordination (directions given at regional level translate into action)	Score	1	1	0	1.00				
		Institutions	Adequacy of institutions at the national/regional level	Score	2	3	0	0.67	0.471	0.657	0.561	
			PPP in energy sector	Score	1	3	0	0.33				
			Efficacy of institutions for delivery of services	Score	1	3	0	0.33				

			Availability various acts related to energy	Score	3	3	0	1.00				
		Legislation	Efficacy of implementation	Score	1	3	0	0.33	0.720			
			Energy efficiency standards	Score	2	3	0	0.67				
		Contribution	Share in total installed capacity	%	9	100	0	0.09	0.095			
			Share in total power generation	%	10	100	0	0.10				
	Private sector participation		Share of private sector investment	%	8	100	0	0.08				
		Participation	Availability of enabling framework for private sector participation	Score	2	3	0	0.67	0.404			
			Share of petroleum refinery capacity	%	20	100	0	0.20		0.294		
	Finance/funding	Financial Access	Ease of access to finance for energy project financing	Score	2	3	0	0.67	0.471			
			Ease of access to finance for energy efficiency for HH	Score	1	3	1	0.00		0.471		