Energy Policy 135 (2019) 110964

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Indian electricity sector, energy security and sustainability: An empirical assessment

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ARTICLE INFO

Keywords:
Sustainable development
Energy security
Electricity sector
India

JEL classification:
Q01
L94
C43

ABSTRACT

Despite progresses achieved in several directions, Indian electricity sector continues to suffer from multiple anomalies that might endanger the energy security of the country. It is pertinent at this juncture to ask the question whether the sector is moving on a sustainable growth trajectory. Using a sustainable development framework, the present study evaluates how sustainable the Indian electricity sector is. It employs 11 indicators representing three dimensions of sustainable development i.e. economic, environmental and social and analyses 12 Indian states over a decade period. The findings of study suggest that the sector is moving towards sustainability though deviations exist in the performance of individual states and individual dimensions. The economic dimension shows a non-linear trend with multiple ups and downs. The environmental dimension indicates first a falling trend up to 2005-06 and rising sharply thereafter. The social dimension reveals a declining trend during the initial periods of the study and picking up in the last few years. Feed-in tariff policy of the Indian government is found to be successful in improving the electricity accessibility and diversifying the electricity supply and raising share of renewable energy which are in line with higher energy security goals.

1. Introduction

Primacy of energy as the fulcrum of development has been reiterated many times in various global forums and declarations. Most prominent and quite recent ones are the specific mention of energy as one of the 17 goals of Sustainable Development Goals (SDG Goal 7), enunciation of the decade 2014-24 as the decade for sustainable energy, and announcement of SE4ALL by United Nations (UN). Goal 7 of SDG with its specific thrust to achieve universal access to energy, promote renewables and progress in energy efficiency dimension clearly guides countries to move in a sustainable development energy trajectory.

These global developments are highly significant for countries like India, where energy-related developmental challenges loom large. India in the last decade or so has demonstrated commendable progresses achieved in various dimensions of the energy sector development. The commitment to transit towards green energy regime with increasingly larger penetration of renewables is quite praiseworthy and has led India to posit as the 4th largest global leader in the solar energy space. The share of renewables in the total installed capacity in the country has climbed up to new high of 20% in the entire energy mix. The climate pledges manifested through India's Nationally Determined Contributions (NDC) to achieve 40 % of renewables by 2030 clearly reiterates India's effort to move in a sustainable development trajectory. Even policies declared domestically also are significant in transforming the Indian energy sector. The Government of India's aggressive and transformative vision to increase the share of renewables in the energy mix with ambitious target of producing 175 GW of renewables by 2022 is a clear manifestation of thrusts laid on the renewable energy. Besides, on the social aspect, there have been commendable achievements in the form of village and household electrification in the country. The most recent statistics suggests that close to 100 % households have been electrified in the country by the end of March 2019. Similarly, on the cooking energy front, visible progresses have been made through recent policy initiatives like Pradhan Mantri Ujjwala Yojana (PMUY). For instance, 40 million new connections have been given in the last four years.

Despite commendable progresses achieved in several directions, Indian electricity sector continues to suffer from multiple anomalies and is passing through a critical juncture at this moment. The heightening

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https://doi.org/10.1016/j.enpol.2019.110964
Received 17 October 2018; Received in revised form 24 May 2019; Accepted 28 August 2019

concerns of climate change, more specifically energy-induced climate impacts have been a major source of concern. A significant chunk (almost 65%) of electricity generation continues to be sourced from fossil fuels. The electricity sector in India is contributing about 44% of total GHG emissions in the country (GoI, 2015). Apprehensions run that per capita emission rates will further be escalated, unless adequate measures are taken to decouple energy from emissions (WRI, 2014). There are associated social issues with the sector, deeply entrenched with the low use and poor access to modern forms of energy. Despite dramatic change in the electricity access profile of the country, access to modern forms of energy continues to be a roadblock. About 780 million, constituting about 64 % of population continues to rely on traditional biomass sources for cooking, having significant environmental and health consequences (IEA, 2017). This coupled with the structural problems of poor balance sheet of electric distribution utilities further accentuate such challenges. Energy security challenges get pronounced with large-scale uncertainties associated with global supply of energy. Recent spike in international oil prices to USD 82 per barrel has been a cause of concern and causing financial hardships for the publicly owned oil companies in India. Often, renewable energy growth is riddled with issues such as off-taker risk, the lack of adequate provisioning of financing, etc. In particular, rooftop PV systems have not been taken up at the projected rate, partly due to financial problems of distribution utilities. There are also techno-economic, financial and regulatory challenges associated with the grid interconnection of such systems.

It is pertinent at this juncture to ask the question whether the sector is moving sustainably and geared up to address the energy security related challenges. While the question is quite pertinent, there have been short shrifts in scholarly efforts to examine this question empirically in the Indian context. Most importantly, given the constitutional status of energy as a concurrent item (entry 38 of the Indian constitution), and prevailing heterogeneous policy, regulatory and administrative energy environment at the sub-national scale, such empirical studies at the sub-national scale can contribute significantly to the existing body of knowledge. The paper in this context carries out an empirical holistic assessment of the sectoral performance by using a sustainable development framework. The paper contributes by carefully identifying a set of variables characterising the sustainable development of Indian electricity sector and analysing how these variables perform over a decade period, individually and conjugately. Though, there are several studies (for example, Kemmler and Spreng, 2007) carried out in various other aspects of electricity sector development, however, the novelty of this study lies in its approach to conduct a holistic assessment of the sector at a more deconstructed level of Indian states by using a sustainable development framework.

The paper organises as follows. Section II of the paper presents a concise review of literature. Third section details out the research approach, data and methods. Section IV discusses the results and discussion, and Section V concludes the paper by highlighting whether electricity sector sustainability enhances energy security.

2. Review of literature

A variety of theoretical approaches and frameworks have been used in the scholarly literature to assess the performance of electricity sector. Emphasis on sustainability assessment of the electricity sector has received a renewed thrust with the declaration of SDGs, though scholarships in this field have evolved over years. Given the plurality and diversity of approaches employed to assess the performance of the sector, it is tenuous to capture the sustainability performance of the sector in a systematic, compact, and coherent manner. Literature in evaluating the electricity sector performance, historically, has been dominated by the economic assessment of the sector, while the social and environmental assessment of the sector has been neglected in the past and have become a new research focus.

The most recent emphasis is on the sustainability assessment of the sectoral performance. This has been received priority recently as sustainable development has taken the front seat in the global discussion agenda of development (Ribeiro et al., 2013). More importantly, the declaration of Sustainable Development Goals (SDGs) by the UN is a clear reflection of the need to emphasize sustainable development of the sector. However, the sustainability studies in the electricity sector differ significantly in their scope, emphasis and approach.

A few scholars have assessed the overall sustainability of the sector and often have included energy security dimensions. Vithayasrichareona et al. (2012) apply a sustainability analytical framework based on the 3As energy sustainability objectives comprising of accessibility, availability and acceptability. The study assesses the sustainability challenges of the electricity sector of five largest energy consumer countries of ASEAN i.e. Indonesia, Thailand, Malaysia, the Philippines and Vietnam. The study concludes that despite visible progresses achieved, these countries continue to face sustainability challenges. Meyar-Naimi and Vaez-Zadeh (2012) make use of a Driving force-State-Response (DSR) framework in the context of Iran's power sector. Indicators are grouped under different criteria such as human, system, and nature. The findings are helpful in choosing appropriate policy-making frameworks in the energy policy sphere. Ediger et al. (2007) construct a sustainability index for fossil fuel energy to rank most efficient management method of fossil fuel resources. The study uses three important ratios i.e. reserve to production (RP) ratio, PC ratio, and Carbon emission (CE) ratio to rank the fossil fuel resources and findings of the study suggest that countries relying primarily on oil, will end up having incompetent energy policies. Apart from the above specific studies on electricity sector sustainability, a large body of literature focuses on analyzing the electricity sector sustainability within the broader framework of energy sector sustainability. For example, Doukas et al. (2012) evaluate the rural communities' energy sustainability in multiple countries in Europe by using the technique of principal component analysis (PCA). The application of this technique to eight rural communities for the year 2009 suggests that communities with high renewable energy percentages and development rates performed well. Tsai (2010) uses a weighted sum method to assess the energy sector sustainability of Taiwan. A composite analysis of three sustainability indicators i.e. CO2 emissions per capita, energy intensity and renewable energy production, reveals that Taiwan is well progressing in the direction of sustainable development. Neves and Leal (2010) focus on developing a set of energy indicators for assessment of energy sustainability at the local level of municipality as well as an action-planning tool. The study proposes a framework for energy sustainability indicators at the local scale. Jovanovic et al. (2010) evaluate the urban energy sustainability of a city in Serbia by using a set of economic, social and environmental indicators. Prediction of future energy needs is done through the application of model for analysis of the energy demands (MAED). In similar vein, Brown and Sovacool (2007) choose a set of twelve indicators to construct an energy sustainability index for USA and the study reveals that the country has not been very successful in addressing some pressing sustainability challenges of the country. Kemmler and Spreng (2007) use energy system as a framework to assess the energy sector sustainability of India. Indicators are chosen from three crucial dimensions of sustainable development i.e. economic, environmental and social. The study concludes that energy access-consumption matrix as a proxy indicator is adequate for comparative analysis. Begic and Afgan (2007) assess the sustainability of energy power systems in Bosnia and Herzegovina. A set of indicators are chosen under four important dimensions of sustainability i.e. resource indicator, environmental indicator, economic indicator and social indicator. The results are claimed to aid decision-makers for the selection of most viable options for new capacity addition in energy power system. In the Indian context, limited scholarly efforts have been undertaken to assess the sustainability of the sector, largely within the context of reforms and regulation of the sector. Most of these studies are piecemeal in nature and examined any singular dimension of the sectoral performance. Key economic dimensions investigated are; pricing (Chikatur et al., 2007; Krishnan and Gupta, 2017), competition (Bhattacharyya and Patel, 2007; Singh, 2010), and privatization (Ghosh and Kathuria, 2011; Kundu and Mishra, 2011). Similarly, the environmental and social performance assessment of the sector has been assessed on a standalone basis. For instance, scholars such as Murthy (2006a,b) and Chikkatur et al. (2007) have assessed the environmental performance of the sector in the context of sectoral reforms and regulation. On the other hand, scholars such as Mukherjee et al. (2009) and Kundu and Mishra (2011) have attempted to link the reforms and regulations to the social outcomes of the sector.

It could be deduced from the above studies that scholarly focus in assessing energy systems sustainability has experienced a chequered history. During the early phases of research, energy sustainability assessments were carried out within the broader framework of environmental sustainability. A more refined approach was evolved later to assess energy sector sustainability on an independent manner by including variables from the electricity sub-sector. In addition, it also emanates from the review that the relative importance of an individual dimension such as economic, environmental and social, depends on the socio-economic profile of the country. For instance, while social dimension of energy holds prominence in the developing economies of the world (Vera and Langlois, 2007; Kemmler and Spreng, 2007), other two dimensions of sustainable development are prioritised more in the developed economies of the world. Studies carried out in the Indian context reveal that there have been sporadic and patchy research efforts undertaken to understand the sustainability concerns associated with the electricity sector. Scholarly efforts at best are limited in examining the individual dimensions of the sectoral development. Drawing from the review, the present paper carries out a comprehensive assessment of sustainability of Indian electricity sector.

3. Research approach, data, and methods

3.1. Research approach

The analytical framework of the paper is built on the sustainable development framework enunciated by Kemmler and Spreng (2007) where sustainable development is framed as development in three crucial dimensions i.e. economy, environment and society. This notion and conception of sustainable development has also been applied by several other scholars (Begic and Afgan, 2007; Vera and Langlois, 2007; Jovanovic et al., 2010; Neves and Leal, 2010) in different country contexts to assess electricity sector performance. The present study adopts this notion of sustainable development and applies it in the current context.

3.2. Method

The literature review carried out in section II also clearly brings out that an indicator-based analytical approach is the dominant analytical tool for the sustainability assessment of energy sector as well as electricity sector. The present work builds on this approach and applies an indicator based analytical approach for the sustainability assessment of the sector. The first and foremost methodological necessity is to identify a manageable set of flagship indicators (Kemmler and Spreng, 2007) often called the core set of indicators (Neves and Leal, 2010) representing three dimensions of sustainable development of the sector in the Indian context. The choice of indicators was made in such a manner that they convey information about the state of Indian electricity system. In the process of choosing indicators, one of the basic steps is to convert the raw data into indicators. Since the available data are mostly in absolute terms, there is a need to convert them into relative terms to transform them meaningfully to represent the studied dimensions. OECD (2008) applies three basic criteria for the selection of best possible set of indicators for the sustainable evaluation i.e. policy relevance, analytical soundness, and measurability (OECD, 2008). Since there is no consensus as to what constitutes best set of criteria for selection of indicators, the present study applies the OCED criteria to select the indicators for the study.

In order to arrive at a suitable set of indicators, an exhaustive set of indicators was mapped and listed from the literature reviewed in section II. This list was further supplemented by a set of other indicators, drawn from the assessment of electricity sector regulatory goals and mandates as envisaged in various legal and policy pronouncements. Then, the OECD (2008) criteria was applied to arrive at relevant set of indicators for our study. The applied criteria are as follows;

3.2.1. Relevance or appropriateness of the indicator for the study and in the context of India

Since this study aims at analysing the sustainability outcomes of the electricity sector in Indian context, indicators are chosen to represent the sector-specific sustainability outcomes. It is found that several indicators identified in other studies are not directly relevant for the present study and hence are filtered out.

3.2.2. Analytical soundness and availability of data

The study encountered great difficulty in gathering relevant data for the study.[1] Since the analysis is done for 12 states and for a duration of ten years (from 2001-02 to 2010–11), it was difficult to gather all the relevant data for the entire period and for all the dimensions and subdimensions intended to be studied. The reason being limiting the study till 2010 is that Indian electricity sector experienced a structural change after 2010 due to introduction of Jawaharlal Nehru National Solar Mission (JNNSM) (Kaladharan, 2016). In addition, While, in some cases, data are available for a few years, in some other cases, it was difficult to get the most relevant data for the study. Given the data constraint, the analysis is carried out with limited number of indicators. Checking the analytical soundness was essential for carrying out a robust analysis.

3.2.3. Measurability

Data measurement was also found to be one of the difficult processes of data analysis. One of the measurement issues emerged due to a definitional change[2] introduced in the electricity sector in India. Another crucial issue is about maintaining the directional consistency of data over the period of analysis. To make the indicators directionally consistent, we have converted some indicators by taking their reciprocals.

This exercise led to filtering out several indicators not qualifying aforementioned criteria. From the review of scientific literature , seven indicators were identified which satisfy all the required criteria (Please check Table 1). Additional seven indicators were drawn from the regulatory mandates stated in the Indian context and satisfying the above spelt out criteria (Table 2). In sum, a set of 14 key indicators were identified for the purpose of the study. However, to neutralize the effects of state specific characteristics, few indicators were combined to make them comparable and meaningful. That led to a reduced size of 11 indicators representing three dimensions of sustainable development of the sector.

Then, chosen indicators are grouped under the different dimensions of sustainable development. Literature highlights that grouping is a cumbersome exercise due to the presence of interplay and interdependency of individual dimensions of sustainable development (Kemmler and Spreng, 2007). Expert consultations were solicited for this exercise. A set of four key indicators are chosen for economic dimension as well as for social dimension, and a set of three key indicators are chosen to represent environmental dimension of sustainable electricity sector outcomes. The details of indicators are presented in Tables 3–5.

The indicators chosen to represent the economic dimension of electricity sector outcomes imply that while Average Revenue/Average Cost

[1] The issue of data constraints in the Indian energy sector has also been succinctly highlighted by Kemmler and Spreng (2007). They argue that in many cases data is not readily available. In some cases, data may require reconstruction due to lack of statistical evidence.

[2] For instance, due to a change in the definition of rural electrification, available data for both the periods (before and after the change in the definition) are not logically comparable.

Table 1
List of indicators identified in scholarly literature.

Indicators	Scholarly literature	Criteria: Relevance	Measurability potential	Data Availability
Ratio of industrial to residential prices	Steiner (2001); Hattori (2004); Jamasb et al. (2005)	✓	✓	✗
Cross-subsidies and/or public subsidies	Jamasb et al. (2005); Vithayasrichareona et al. (2012)	✓	✓	✓
End user prices	Delfino and Casarin (2001); IAEA, 2005; Torero and Pasco-Font (2001); Jamasb et al. (2005); Brown and Sovacool (2007); Vithayasrichareona et al. (2012)	✓	✓	✓
Total network length	Jamasb and Pollitt (2003); Jamasb et al. (2005)	✓	✗	✓
Total energy loss at T & D network	Jamasb and Pollitt (2003); Jamasb et al. (2005)	✓	✓	✓
Plant availability factor (Load factor by plant i.e. electricity generation MWh by average capacity MW X 8760 ratio)	Arocena et al., (1999); Steiner (2001); Zhang et al. (2008); Jamasb and Pollitt (2003); Jamasab et al. (2005); Hattori (1999)	✗	✓	✓
Energy intensity	Vera and Abdalla (2005); Kemmler and Spreng (2007); Vera and Langlois , 2007; Vithayasricharoena et al. (2012)	✓	✓	✗
Renewable energy production per capita	Doukas et al. (2012)	✓	✗	✓
RES share in energy & electricity	Vera and Abdalla (2005); Vera and Langlois , 2007; Neves and Leal (2010); Doukas et al. (2012)	✓	✓	✓
CO_2 emissions from energy consumption/by sector	Brown and Sovacool (2007), Jamasb et al. (2005)	✓	✓	✓
Share of HHs without electricity or commercial energy	Vera and Abdalla (2005); Vera and Langlois , 2007; Neves and Leal (2010); Vithayasrichareona et al. (2012)	✓	✗	✓
Share of HH income spent on fuel and electricity	Vera and Abdalla (2005); Vera and Langlois , 2007; Neves and Leal (2010); Vithayasrichareona et al. (2012); Vithayasricharoena et al. (2012)	✓	✓	✗
Accident fatalities per energy produced by fuel chain	Vera and Abdalla (2005); Vera and Langlois , 2007; Neves and Leal (2010)	✓	✓	✗
Security of service (no. of minutes lost) Reliability of service (no. of interruptions)	Giannakis et al., (2005); Jamasb et al. (2005); Vithayasrichareona et al. (2012)	✓	✓	✗
Electricity consumption per capita	Bacon and Besant Jones (2001); Vera and Abdalla (2005); Jamasb et al. (2005); Vera and Langlois , 2007; Neves and Leal (2010); Doukas et al. , 2012	✓	✓	✓

Table 2
Selection of Indicators based on mandated dimensions.

	Criteria	Indicators
Economic	Physical	Total installed capacity
		Total energy generation
		Total energy sales
	Financial	Average revenue
		Average cost of supply (ACS)
		AT & C Losses
	Competition	Private sector installed capacity
		CPPs net exports
Environment	Renewables	Generation from renewable sources
	Energy efficiency	Auxiliary consumption[a]/ Plant Load Factor
	Environmentally benign	CO_2 emissions
Social	Consumer interest	Per capita consumption of electricity (domestic)
	Social issues like energy access and rural electrification	Agricultural sales
		Subsidy received
	Quality issues	Energy deficit[b]

[a] Auxiliary consumption is taken as a proxy indicator for environment with the understanding that higher auxiliary consumption means, lower electricity available for general consumption, and hence you need to produce more to satisfy the demand, which leads to higher emission generation, in case of fossil fuel-based electricity plants.

[b] Electricity deficit is estimated based on 'demand estimates' of Central Electricity Authority' (CEA), - the technical regulator of Indian power sector and reported in the CEA published 'Annual Electricity Statistics'. Two different types of deficits are estimated i.e. peak deficit and energy deficit. While estimating the deficit, we have taken 'energy deficit' which is more representative of deficit in general.

of Supply (ACS) captures the profitability of the sector, private sector installed generation capacity and CPP are representative indicators for the privatization, one of the initial reform attempts of the Indian electricity sector (Ruet, 2006; Hansen, 2008). Similarly, AT & C is chosen to reflect the economic efficiency dimensions of the sector performance.

The indicators chosen under the social dimension need special mention. It is noteworthy to highlight that some of the indicators which have direct bearing on the social dimensions are not been considered due to inconsistency in the data structure. For example, the data on rural electrification is not comparable for the period under consideration due to a change in definition introduced by the government of India. Second, some of the indicators chosen under the social dimensions like agricultural sales and subsidy, though have implications for economic sector outcomes, expert consultation process emphasized their inclusion under the social dimensions given their importance in a developing country like India. While it is true that subsidies nurture a culture of inefficiency in general, its relevance as a social indicator cannot be undermined in the Indian context, particularly in the context of developing countries like India, where electricity, at least for a section of society, is considered a merit good (Mishra et al., 2016). Electricity deficit is also being considered an indicator in the social category. The argument supporting this to be included in the social category states that lower the electricity deficit indicates larger quantity of electricity is available for the people who lack basic minimum electricity provisions. Per capita domestic electricity consumption represents an indicator of reliability and consumers ability to pay for the electricity, therefore included as a social indicator (IEA, 2011).

Next step is to follow the process of data normalisation to make them comparable and easier for aggregation. Applying both the upper and lower boundary of target values, chosen indicators are normalised by a linear function (Kranjc and Glavic, 2005; Afgan et al., 2000) as follows;

$$I = \frac{X_{is} - \min_n(x_i)}{\max_s(x_i) - \min_s(x_i)}$$

Table 3
Economic indicators.

Name	Unit	Definition
Average revenue/ACS	Rupees	The ratio between average revenue[a] and average cost of supply (ACS[b])
Private sector installed generation capacity	MW	Captures the magnitude of private sector participation in the electricity generation of a state
100 – AT & C losses[c]	%	This is the combined electricity loss due to technical and commercial reasons.
CPPs[d] net exports	GWh	This essentially captures the contribution of CPPs to the electricity availability of a state

[a] Average revenue =. Revenue from sale of power (excluding subsidy) + other income/Total input energy (Kwh)
[b] ACS =. Total expenditure/Total input energy (Kwh)
[c] AT & C Loss =. Net energy input (Mkwh) − Energy realised (Mkwh)X 100/ Net input energy (Mkwh)
[d] Electricity Act 2003 defines captive power plant (CPP) as a generating unit set up generating electricity primarily for own use and includes power plants set up by any co-operative society or association of persons for generating electricity primarily for use of members of such-operative society or association (Electricity Act, 2003)

Table 4
Social indicators.

Name	Unit	Definition/Remarks
Domestic per capita electricity consumption	kWh	Average units of electricity consumed by a domestic consumer in a year
Electricity deficit	%	Refers to differences between the total energy required by the energy available to it from varied sources. Both the energy required and energy available are measured in actual terms.
Agricultural sales as % of total sales	%	Electricity used by the agricultural sector in percentage terms
Subsidy	%	Subsidy released by the state government to the power sector. (there is a difference between subsidy released and subsidy booked)

Similarly, for the environmental dimension, the choice of indicators is done after detailed discussion with experts to reflect the environmental implications of sector functioning. While renewable energy as an indicator captures the positive environmental effects, the inclusion of CO2 emission represents the negative environmental effects of sector outcomes.

Table 5
Environment indicators.

Name	Unit	Definition
Renewable energy generation as % of total generation	%	Contribution of various renewable sources to the gross electricity generation of a state
Auxiliary consumption (thermal)	%	Auxiliary energy consumption is the quantum of energy consumed by auxiliary equipment of the generating station, and transformer losses within the generating station (CERC, 2012).
CO2 emissions[a] (thermal) per unit of power generation	tCO2/MWh	CO_2 emissions from thermal power plants.

[a] In order to estimate the CO2 emission from the power sector, simple operating margin is taken under consideration as reported by CEA (CEA, 2011). The simple operating margin is defined as the weighted average emissions rate of all generating sources except so called low cost or must run plants (such as hydro and nuclear sources). For India, the Co2 intensity of thermal power plants under simple operating margin is .98 tCO2/MWh.

The lower and higher boundaries are assigned “0” and “1” values respectively. Finally, normalised indicators are aggregated to get the composite index. It is suggested by scholars that in order to reach at a pragmatic level of sustainability, it is necessary to assign equal consideration and weights to economic, social and environmental dimensions (Kemmler and Spreng, 2007). Following such an approach, as enunciated by Kemmler and Spreng (2007) equal weights are assigned to all the indicators. The mean scores of all the indicators are summed up and presented as the representative value for those criteria for that year. Similarly, final index is constructed by combining the mean scores of all the criteria. Similar approach is followed for all the states considered for the study.

Using the indicators and applying the approach mentioned in this section, the next section presents some key findings derived from the analysis.

4. Result and discussion

One of the first set of results is related to the overall sustainability of the sector for all the 12 study states. The overall picture captured through the composite index reveals a positive movement in the sustainability outcome (refer Fig. 1), though deviations exist when results are presented in a deconstructed manner. The mean values of the composite index of all the 12 states show that a polynomial curve of order 2 better fits the data indicating that there is one fluctuation in the data set. In order to capture the range of fluctuations from the mean, deviations from the mean values are captured in Fig. 2. It portrays that the deviations from the mean get widened initially, followed by a declining trend and finally get widened again.

While the performance of the composite index reflects a holistic picture, the indices constructed for the individual dimensions of sector sustainability unfolds different stories. The economic dimension of the sustainable outcome shows quite a non-linear trend with multiple ups and downs for the entire period of study, when the mean values for all the 12 states are presented together (Fig. 3) . The R^2 value comes out to be 0.87 with a polynomial curve of order 4. However, the mean and deviations do not reflect any clear pattern, except for the fact that there exist wide degree of fluctuations in majority of the study period barring few initial years.

Similarly, the mean values of all the 12 states for the environmental dimension (Fig. 4) reveals that a polynomial curve of order 3 with R^2 value of 0.94 better fits the curve. It is clear from the figure that post 2005–06, the environmental performance of the sector shows a consistent improvement. It appears that the upward movement in the domain of the environmental dimension could largely be due to the introduction of feed-in-tariff spelt out in the National Electricity Policy declared in 2005 and National Tariff Policy declared in 2006.

Sustainability sector outcome in the social sphere shows a quite fluctuating trend, as a polynomial curve of order 2 fits the data with R^2

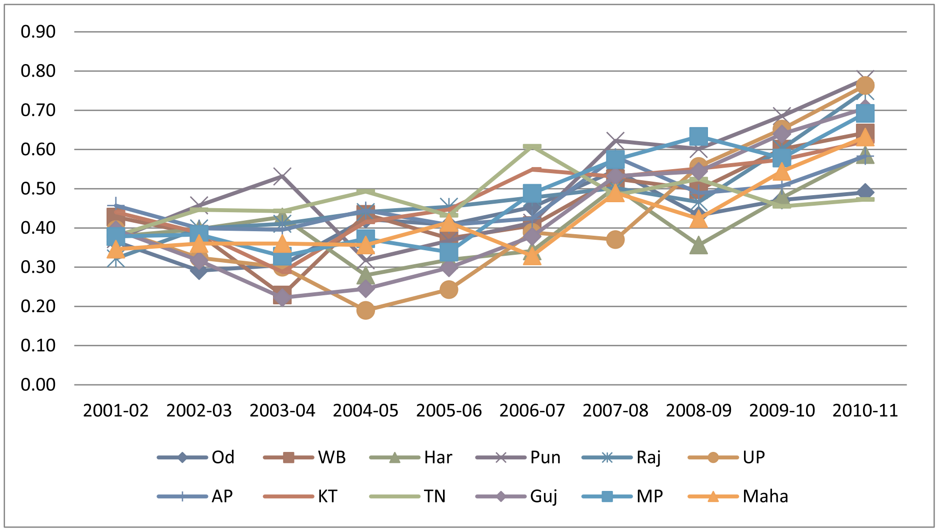

Fig. 1. Movement of composite indices of all 12 states.

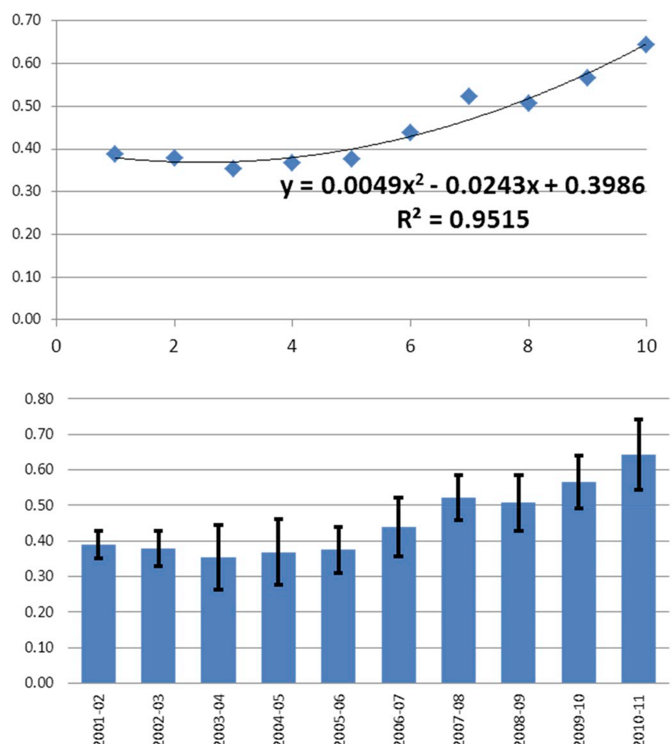

Fig. 2. Mean and deviation of composite index for all 12 states combined.

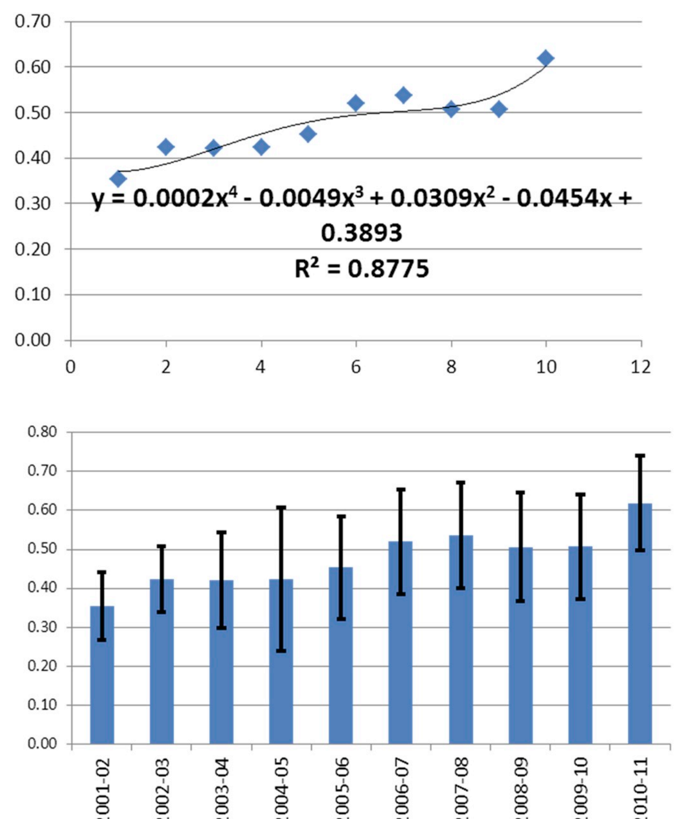

Fig. 3. Mean and deviation of economic outcome index for all 12 states combined.

value of 0.92 (Fig. 5). It could be evident from the figure that the curve represents a ‘U’ pattern demonstrating a declining trend initially and rising after some time.

The findings, when presented state-wise, unfolds sustainability performance at the state level, both composite index measures as well as index measures of sector outcomes. Trends and patterns of the movement of individual dimensions in study states is presented in a consolidated manner is presented in Table below (Table 6). It could be observed from the table below that Punjab, UP, and to some extent, Gujarat and Rajasthan show an increasingly rising trend of sustainable sector outcomes in all the three dimensions of sustainable development, compared to others. Most states are performing well in the environmental front in recent years. However, outcomes in the social dimension are not very encouraging. In the economic front, the performance has been very uneven across the states and does not reveal any clear trend and pattern.

To begin with the findings of individual states, while composite index for the state of Odisha reveals a positive trend (Fig. 6), individual dimensions indicate quite uneven pattern of growth. Economic and environment dimensions demonstrate increasing but fluctuating trend, whereas social component of the sector development shows a declining trend and picking up in the later years. It can be argued that fluctuating private investments in the state's power sector is contributing to the fluctuations of the economic index values. It appears that environmental dimension of the sectoral growth has been shaped by the failure of hydro power generation experienced in the state, which was reflected in the changing energy mix. For example, fall in the hydro power

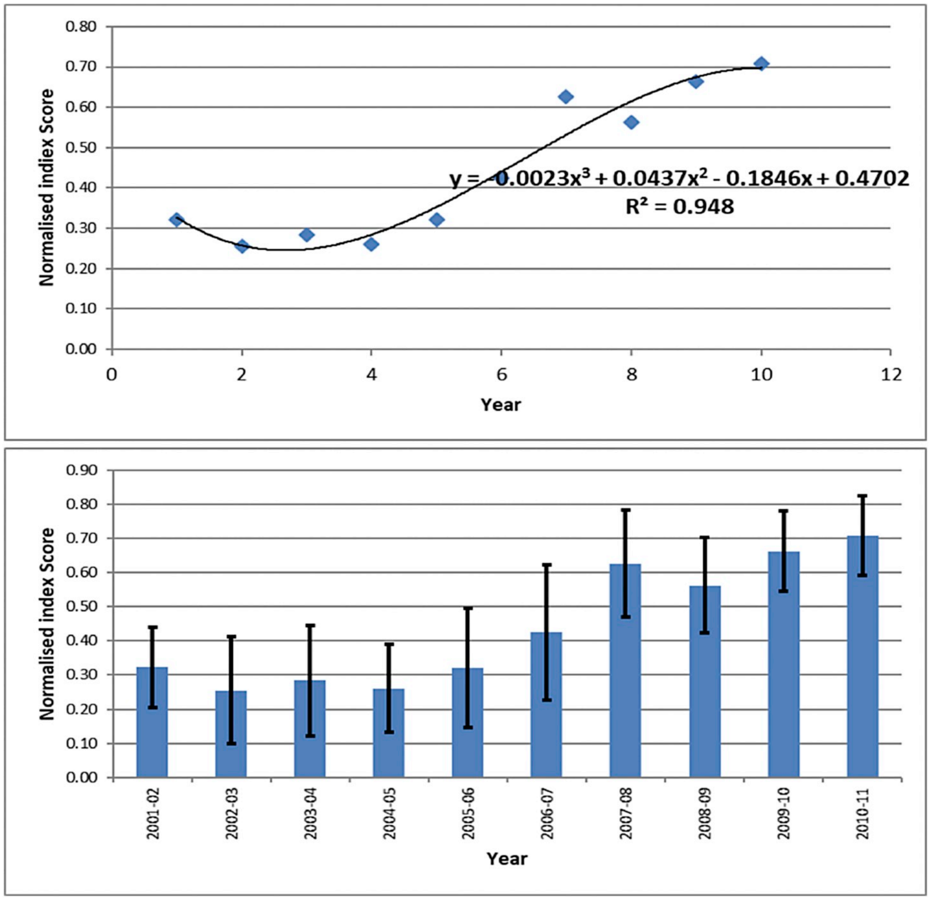

Fig. 4. Mean and deviation of environment outcome index for 12 states combined.

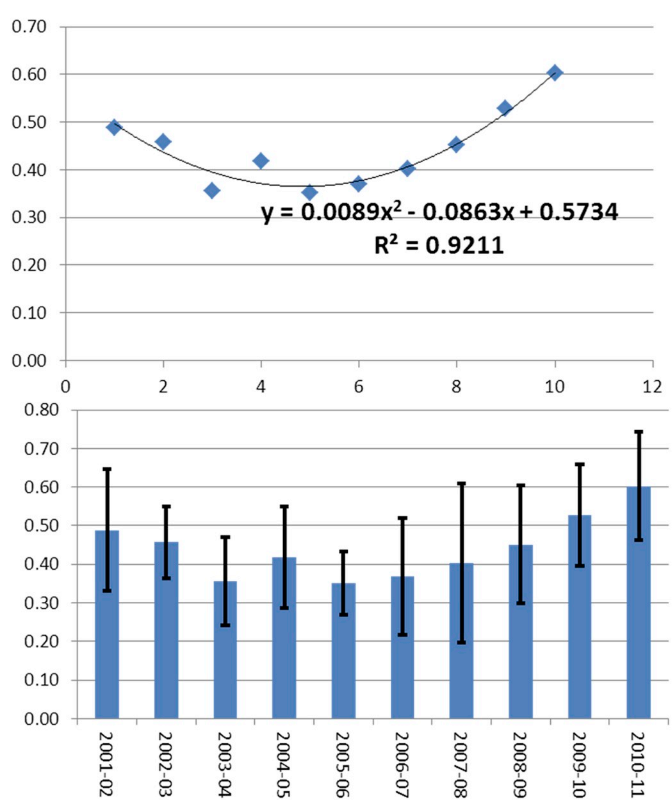

Fig. 5. Mean and deviation of social outcome index for 12 states combined the studied states.

generation in 2002-03 has led to sudden drop in the environmental performance of the state. Social dimension of the sector development is primarily influenced by declining agricultural consumption and fluctuating nature of the rate of energy deficit in the state.

The sustainability assessment of the West Bengal's electricity sector has some interesting revelations (Fig. 7). Assessment of the individual dimensions of sector outcomes does not show any clear pattern, though the aggregated index value indicates a steady state of growth. Economic performance has been satisfactory though the trend shows a downward movement after 2004–05. A sudden rise in the index value in 2004-05 is largely due to a sporadic rise in average revenue triggered by rise in income from non-tariff sources such as unscheduled interchange (UI) charges and income from trading. On the environmental front, the trend is fluctuating, though increasing. This is again due to a rise in renewable energy generation from 2006-07 and concomitant reduction in CO2.

The sustainability assessment of the state of Haryana presents a case of smooth transition in both the aggregated and individual dimensions of sector sustainability up to 2006-07 and fluctuation thereafter (Fig. 8). The fluctuation in the economic dimension of the sustainability outcomes could be linked to the heavy drawl of energy by captive power plants (CPPs) from the grid from 2008-09 onwards and, by some extent, to the sudden spurt in private investment into the state's power sector. Similarly, the environmental dimension takes an upward trend from 2006-07, though fluctuating in its movement largely because of a rise in renewable energy generation starting from 2006-07. In a similar vein, the social dimension of sustainable sector outcome shows an increasing trend with fluctuations from year to year. This is primarily because of fluctuations in the gap between energy demand and energy availability in the state.

The sustainability assessment of the state of Punjab demonstrates a unique pattern of growth (Fig. 9). All the three dimensions clearly show a declining trend in the early period up to 2005–06, and thereafter,

Table 6
State wise trends in individual dimensions of sustainability.

	States with positive trend	States with negative trend	States with no trend
Economic	Gujarat, Punjab, Uttar Pradesh	Tamil Nadu, West Bengal	Andhra Pradesh, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan
Environment	Gujarat, Karnataka Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Uttar Pradesh, Tamil Nadu,	NA	Andhra Pradesh, Haryana, Odisha, West Bengal,
Social	Punjab, Rajasthan, Uttar Pradesh	Odisha	Andhra Pradesh, Gujarat, MP, Maharashtra, Karnataka, Haryana, Tamil Nadu West Bengal

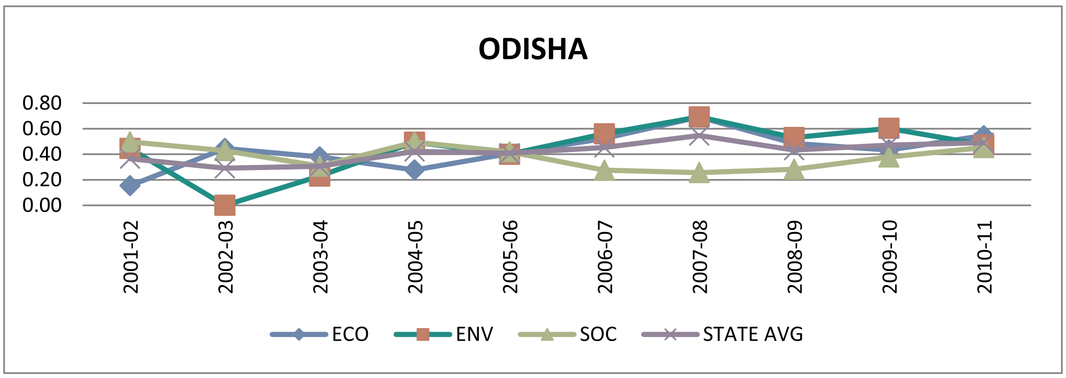

Fig. 6. Movement of both individual and composite sustainable sector outcome indices for Odisha.

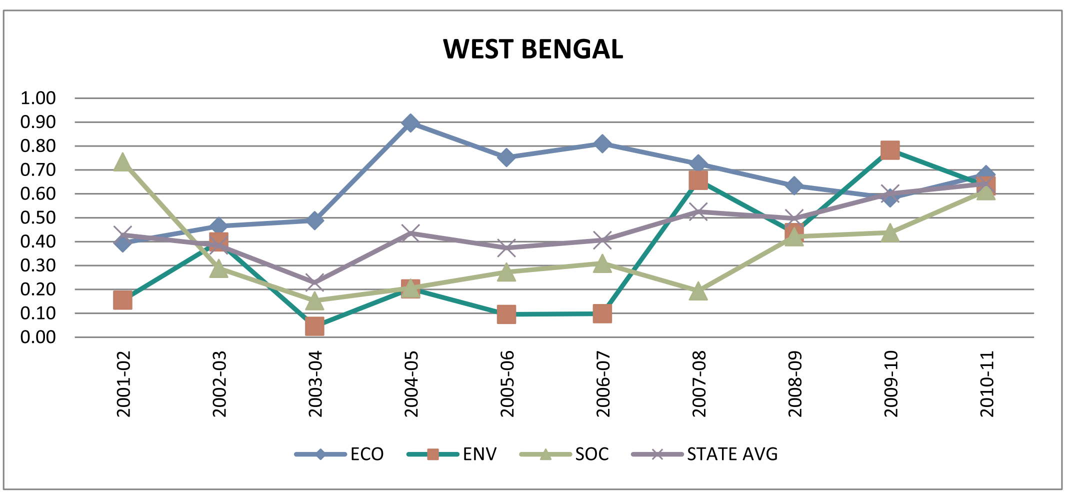

Fig. 7. Movement of both individual and composite sustainable sector outcome indices for West Bengal.

picking up. The environment component increases largely due to a change in the energy mix with an increasing share of hydro energy. This also resulted in less CO2 emissions, further contributing positively to the environmental health of the sector. In the economic sphere, the growth could be attributed to the rise in the private installed capacity combined with reduction in AT & C losses, and a gradual decline in CPPs net drawl from the state's availability.

The case of the state of Rajasthan exhibits an interesting development as far as the individual dimensions of sustainability are concerned (Fig. 10). All the individual dimensions show a steady growth pattern up to 2007–08. Afterwards, there have been sharp increase in both the social and environmental dimensions, except the economic one. The change in the environmental dimension could be attributed to the reduction in the auxiliary consumption, whereas the high growth in the social dimension could be attributed to the rise in domestic per capita consumption of electricity and fall in energy demand leading to a reduction in energy deficit.

The case of the state of Uttar Pradesh shows an upward movement not only in the aggregated dimension of the sector outcomes but also in all the individual dimensions (Fig. 11). While both the economic and social dimensions are growing at moderate rates, the environmental dimension shows a declining trend up to 2005-06 and picking up thereafter. This is primarily because of growth in the renewable energy generation combined with a change in the energy mix with a greater share of hydro, thereby resulting in reduction in CO2 emissions.

In the state of Andhra Pradesh, while the overall trend shows a steady growth pattern, the individual dimensions of sustainable sector outcomes diverge significantly (Fig. 12). The economic dimension of the sector outcomes shows a marginal decline in contrast to the environmental dimension which shows an upward trend after 2005-06 and then declines towards the end of the study period. The increasing trend of the environmental dimension of sustainable outcome after 2005-06 is due to an increase in the hydro electricity generation in the energy mix and thereby a reduction in the CO2 emissions. On the social front, the sustainable sector outcome reveals first a declining and then rising trend towards the end of the study period.

In a similar vein, the state of Karnataka shows a consistent upward movement in its composite sustainable sector index (Fig. 13). However,

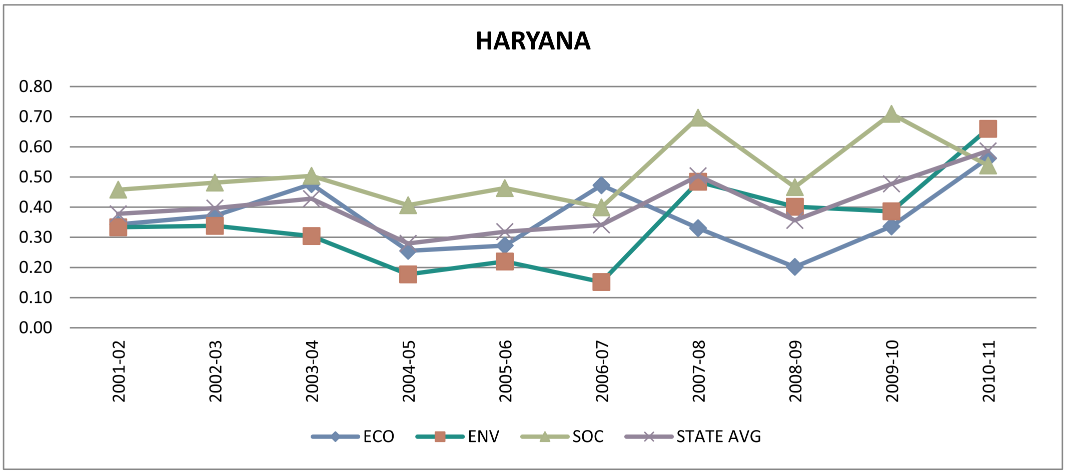

Fig. 8. Movement of both individual and composite sustainable sector outcome indices for Haryana.

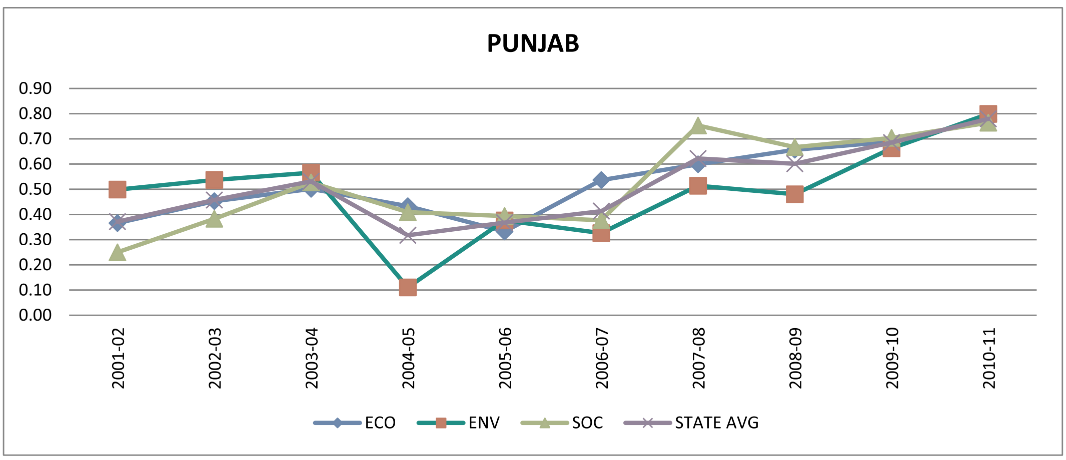

Fig. 9. Movement of both individual and composite sustainable sector outcome indices for Punjab.

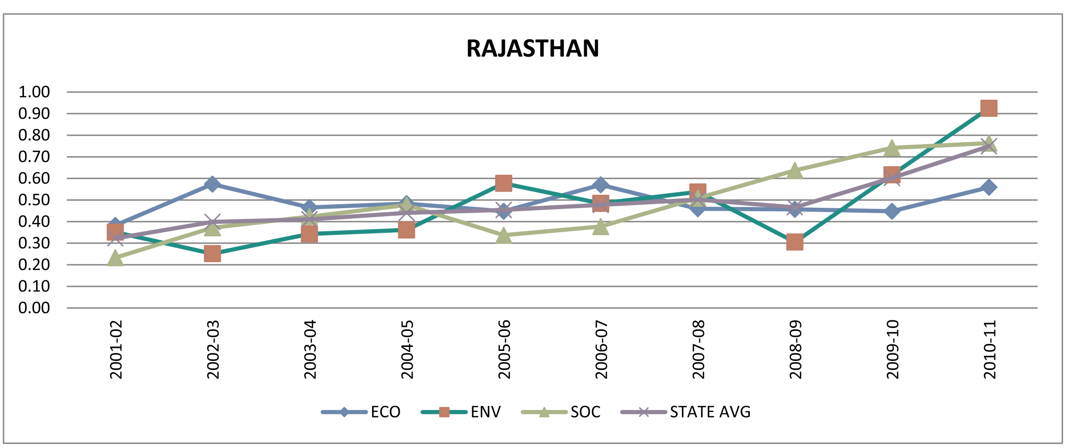

Fig. 10. Movement of both individual and composite sustainable sector outcome indices for Rajasthan.

the individual dimensions reveal quite dissimilar patterns. While the economic and social dimensions of sustainable outcome reveal moderate growth trends, the environment component shows a high growth rate starting from the year 2003–04. Majorly, two factors contribute to the high rise in the environmental dimension. First, the renewable energy component started rising in the state after 2003-04 and second, due to a reduction in CO_2 emissions resulting from an increase in the share of electricity from hydro sources. The growth of renewable energy in the state could be attributed to the policy initiatives undertaken by the state.

In case of Tamil Nadu, while environmental dimension of the sectoral performance shows a consistent and steady growth trend, the economic dimension reveals a downward movement; on other hand, the social dimension of sustainable outcome portrays a fluctuating growth trend for the entire period under consideration (Fig. 14). The upward movement in the environmental dimension is due to large scale emphasis on the promotion of renewable energy, especially wind energy. The slowdown in the economic dimension of the sustainable outcome is caused due to multiple factors such as decline in the average

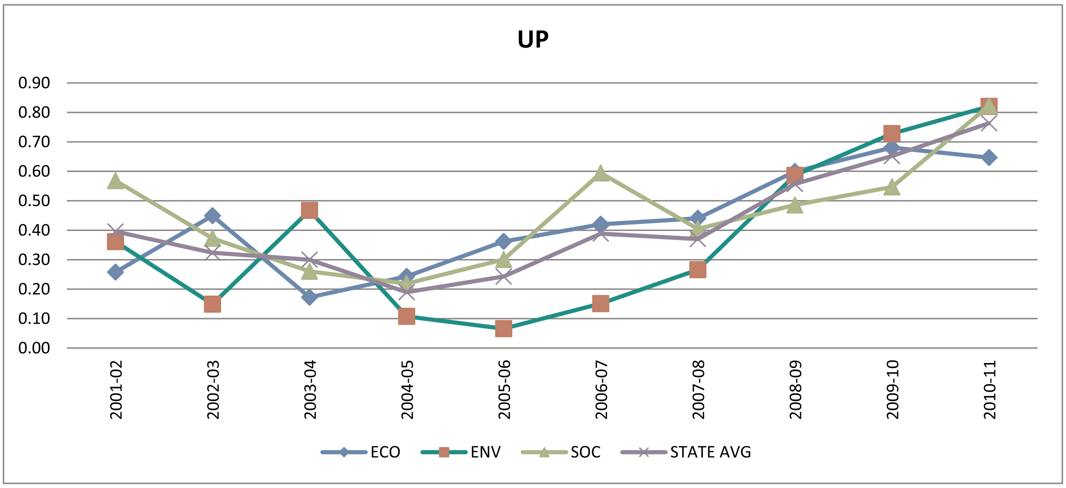

Fig. 11. Movement of both individual and composite sustainable sector outcome indices for UP.

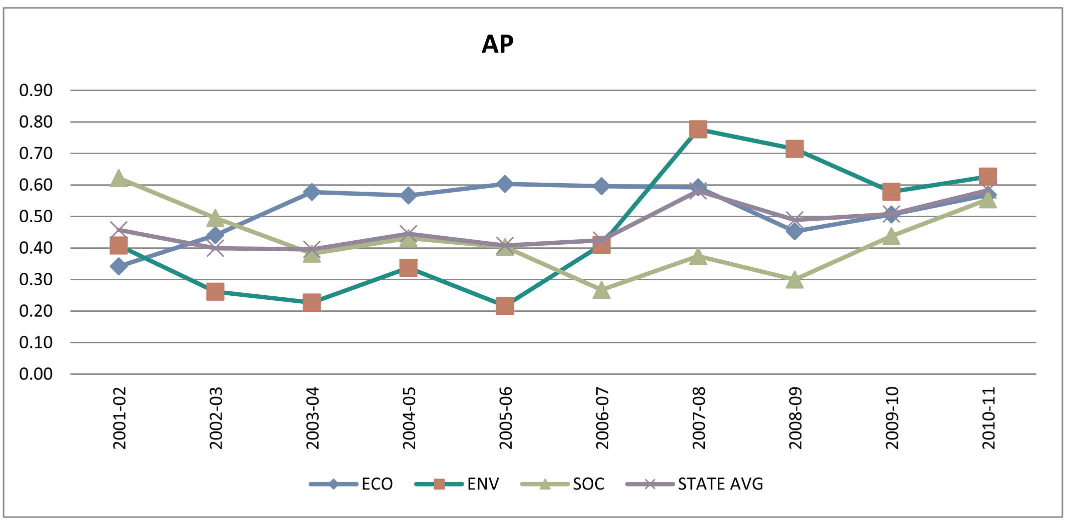

Fig. 12. Movement of both individual and composite sustainable sector outcome indices for Andhra Pradesh.

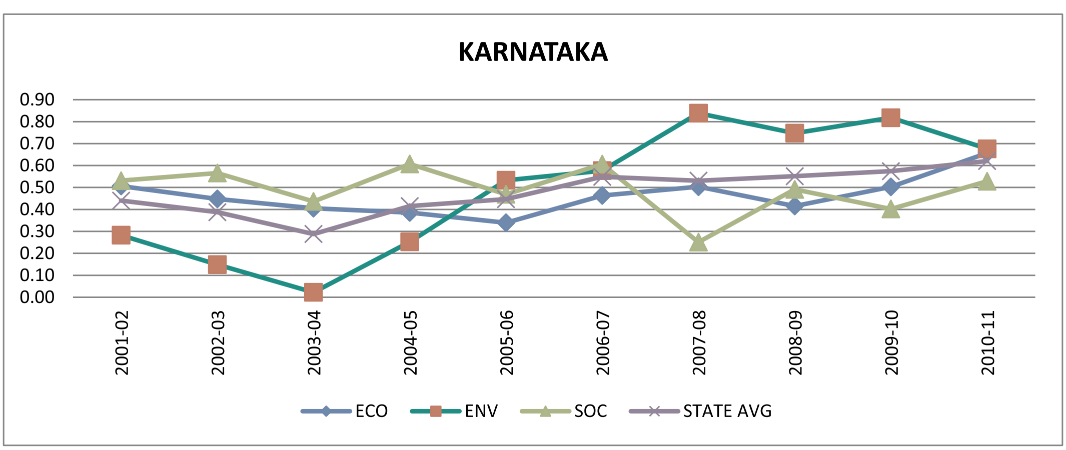

Fig. 13. Movement of both individual and composite sustainable sector outcome indices for Karnataka.

revenue, coupled with rising AT & C loss and the growing reliance of CPPs on available electricity of the state.

Analysis for Gujarat shows the presence of unevenness and dissimilar growth patterns in the individual dimensions of sustainable outcomes, though combined sustainable sector outcomes exhibit a consistent upward trajectory (Fig. 15). While the environmental dimension portrays at a high growth rate after 2005–06, there has been the deceleration in the social dimension of sustainable growth outcomes up to 2008-09 and increasing afterwards. The growth of the environmental dimension is associated with a rise in renewable generation, combined with a fall in the auxiliary consumption, and a reduction in CO2 emissions.

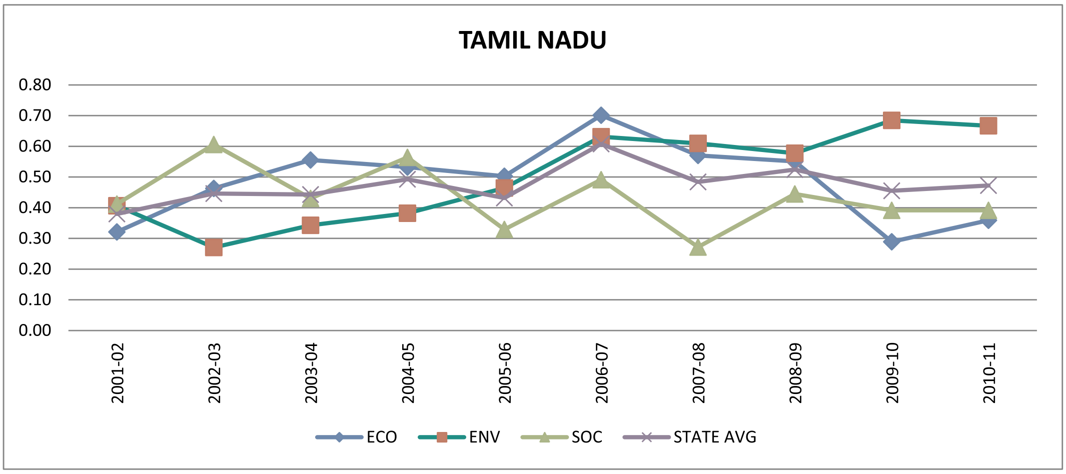

Fig. 14. Movement of both individual and composite sustainable sector outcome indices for Tamil Nadu.

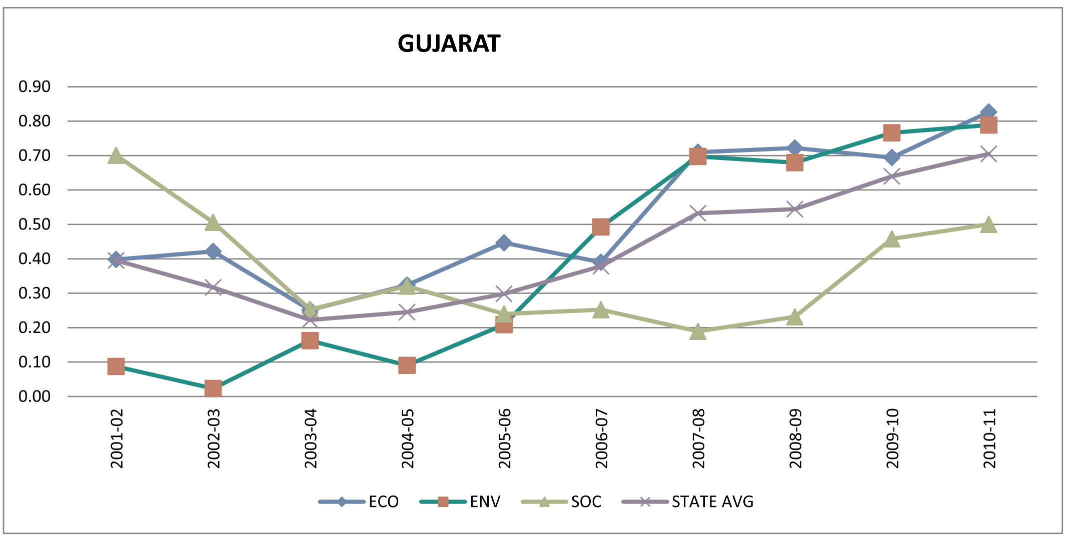

Fig. 15. Movement of both individual and composite sustainable sector outcome indices for Gujarat.

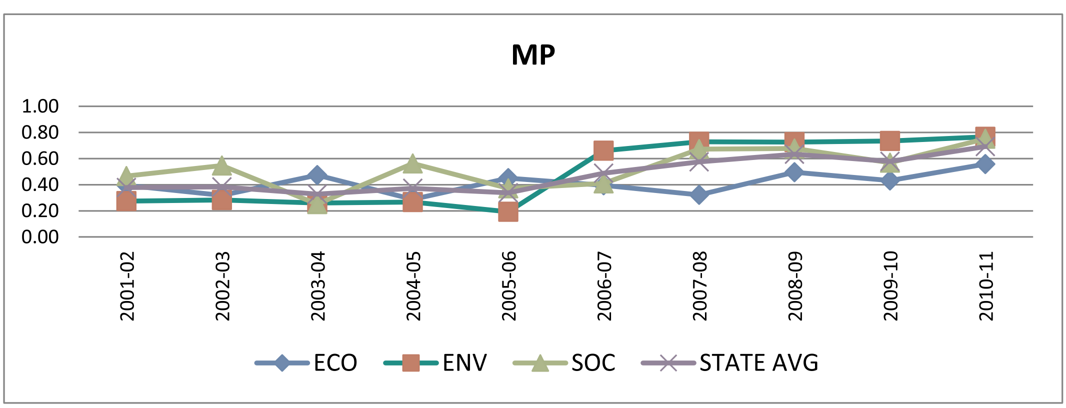

Fig. 16. Movement of both individual and composite sustainable sector outcome indices for Madhya Pradesh.

The growth of sustainability outcome in the state of Madhya Pradesh brings out some interesting findings (Fig. 16). While the overall trend demonstrates an increasing growth pattern after 2005–06, there have been visible differences in the individual dimensions. The economic and social outcomes show more or less a steady growth pattern with some fluctuations. However, there has been a sudden spurt in the growth of environmental dimension from 2005-06. This is largely due to growth in the renewable energy from the 2005-06 because of introduction of feed-in-tariff in the state.

The sustainability assessment of the state of Maharashtra, more or less, shows an increasing trend in its composite index measure (Fig. 17). Though the economic and environmental dimensions show upward movements throughout the study period, the social dimension of the outcome shows a bit of declining trend till 2006-07 and then rises consistently. This could largely be attributed to the static rate of domestic per capita consumption of electricity in the state from 2001-02 to 2005–06, which increases consistently thereafter. This is combined

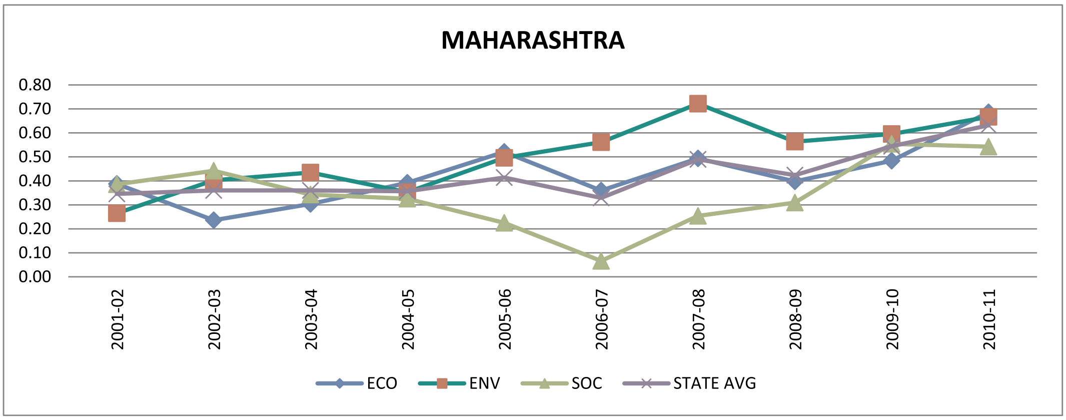

Fig. 17. Movement of both individual and composite sustainable sector outcome indices for Maharashtra.

Table 7
Grouping of states.

Basis	Categories	States
Reform status	Early reforming states (ERS)	Andhra Pradesh, Haryana, Karnataka, Odisha, Rajasthan, Uttar Pradesh
	Late reforming states (LRS)	Gujarat, Maharashtra, Madhya Pradesh, Punjab, Tamil Nadu, West Bengal
Human development status	High human development states (HHDI)	Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu
	Low human development states (LHDI)	Andhra Pradesh, Madhya Pradesh, Odisha, Rajasthan, Uttar Pradesh, West Bengal
Economic freedom status	High economic freedom states (HEFS)	Gujarat, Tamil Nadu, Madhya Pradesh, Haryana, Karnataka, Andhra Pradesh, Rajasthan
	Low economic freedom states (MESF)	Punjab, Maharashtra, Uttar Odisha, Pradesh, West Bengal

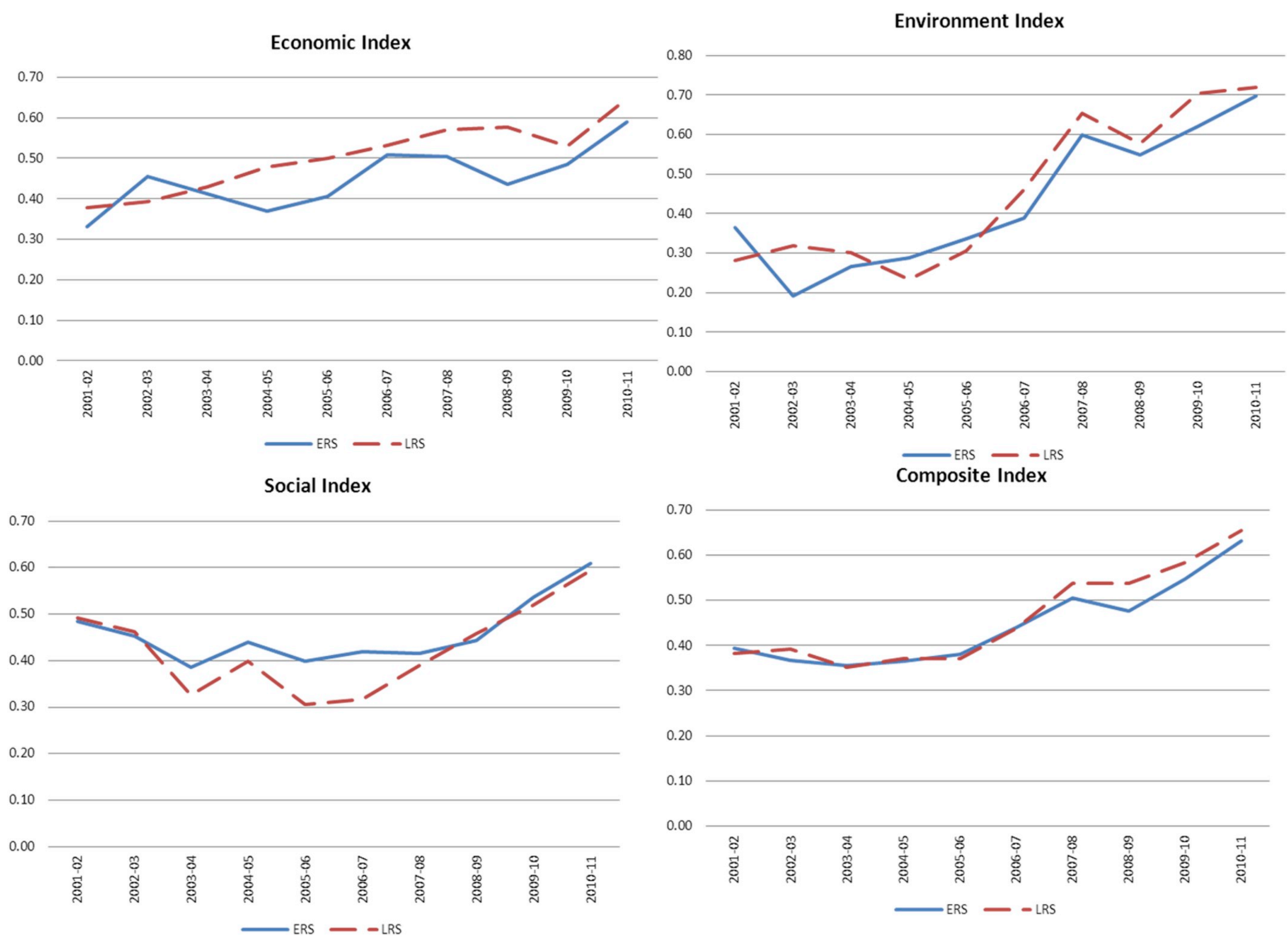

Fig. 18. Comparison based on status of reform (ERS: Early Reforming States, LRS : Late Reforming States).

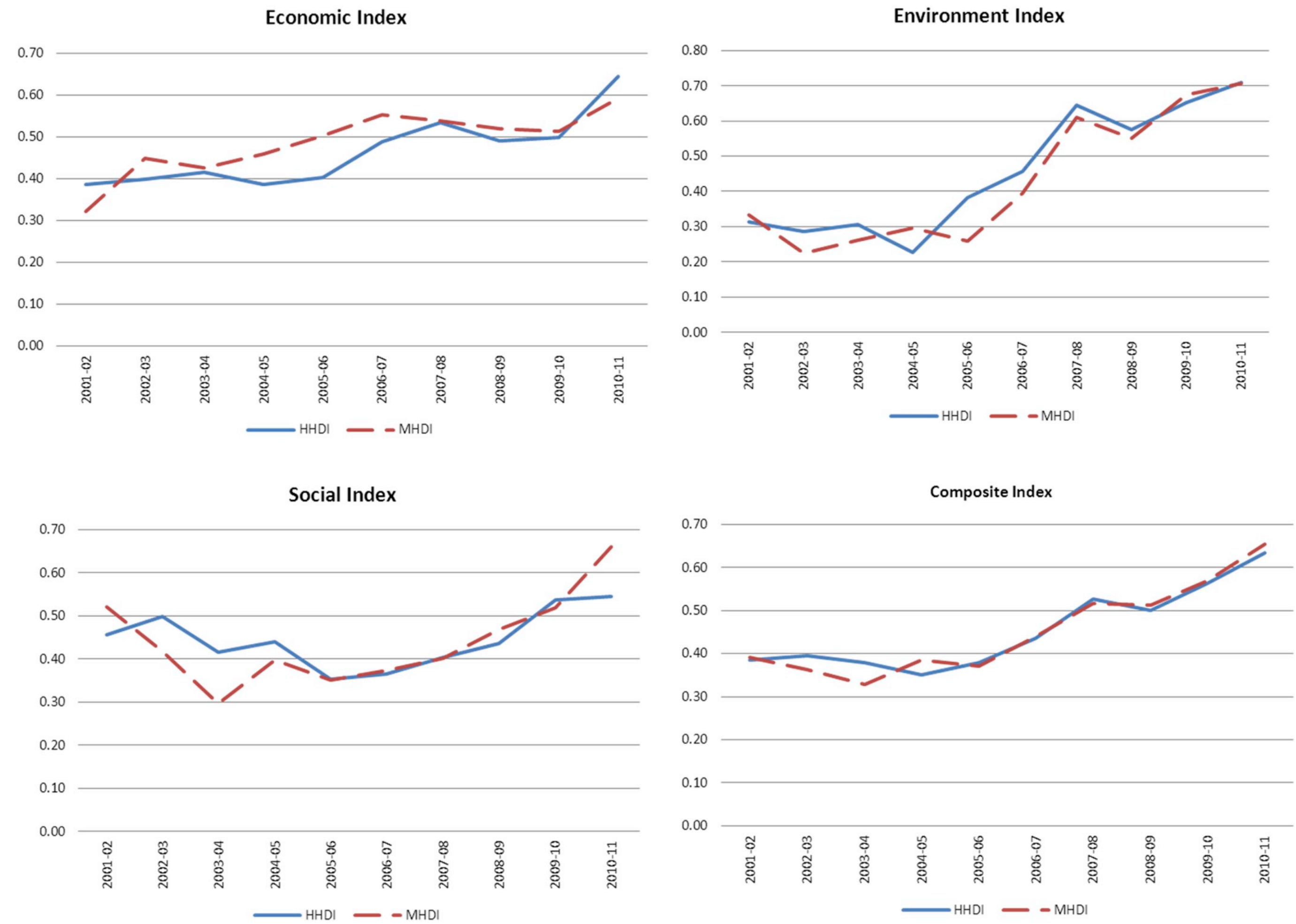

Fig. 19. Comparison based on status of human development (HHDI: High Human Development States , LHDI : Low Human Development States).

with a marginal decline in the electricity deficit from 2006-07.

In order to get a better picture of the variations in performance at the sub-national levels, the studied states are logically grouped under different categories (Table 7). First set of grouping takes status of reform into account. The grouping is done with the understanding that early reforming states have more experience in reform compared to late reforming states, thereby differently positioned as far as electricity sector outcomes are concerned. States which have unbundled their state utilities before 2003 are grouped as early reforming states, and states which have unbundled their state utilities after 2003 Act, are grouped as late reforming states. Second important grouping is done based on human development status of the chosen states. The grouping is done with expectation that the electricity sector outcomes will be different for the states with different human development achieved by the states. States having HDI of 0.5 or above are grouped in one category and states having HDI below 0.5 are ranked in the other group. Third category is based on the economic freedom[3] levels secured by states under consideration. Grouping is done to identify the differences in sector outcomes for different groups of states with varying levels of economic freedom. Since, economic freedom indices range between the lowest value of 0.2 to the highest value of 0.6, 0.4 is considered the mid value and grouping is carried out considering the mid-value. States having economic freedom value of 0.4 or above are categorized into one group and states with values below 0.4 are categorized into another group. Table 7 presents the grouping of states on the above-mentioned basis.

The results are presented on a comparative basis between two groups, for each dimension of sustainability sector outcomes. Under the category based on reforms, it is shown in the figure that groupings do not really reflect any significant differences (Fig. 18). However, there exist some degree of differences between the early and late reforming states, as far as the performances under economic and environmental dimensions of sustainability outcomes are concerned. Second type of grouping is done on the basis of human development achieved by the states (Fig. 19). Here as well, no significant differences can be observed between the two groups named as High Human Development Index States and Low Human Development Index States. However, some variations could be observed in the field of the economic dimension of sector outcomes. Third type of grouping is done on the basis of economic freedom achieved by the states under considerations (Fig. 20). The average performance of the high economic freedom states and low economic freedom states in all the dimensions reveals that except the social dimension, there is a large degree of similarity in performances between these two groups of states.

5. Does electricity sector sustainability enhance energy security? What policy learnings could be drawn?

The empirical assessment carried out in this study has clear policy implications connecting energy security and electricity sector sustainability of the country. This connection gets echoed in a policy sphere,

[3] Economic freedom is measured by considering three important dimensions where state governments have powers such as size of government characterized by expenditures, taxes and enterprises, legal structures and security of property rights, and regulation of labour and business (Debroy et al., 2012).

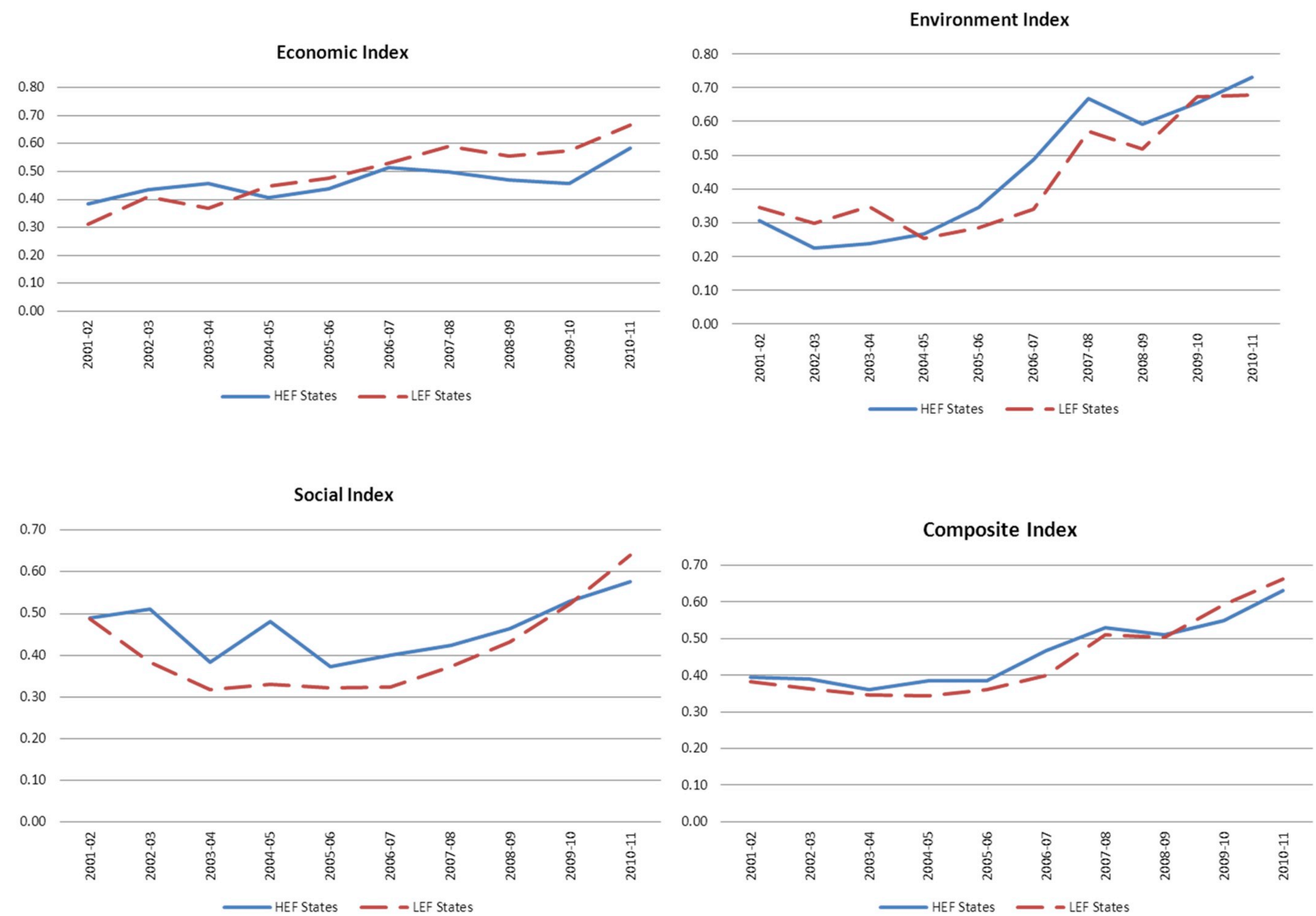

Fig. 20. Comparison based on status of economic freedom achieved (HEFS: High Economic Freedom States, LEFS: Low Economic Freedom States).

where cross-sectoral integrations across various sectors is emphasized and increasingly being viewed as mode to achieve sustainability. For instance, thrust on promoting renewables has led to establishing new linkages and integration between energy sector and transport sectors. The e-mobility plan of the Government of India is a clear manifestation of such sectoral integration and is built around the effort to promote renewables. This integration is aimed at arresting transport related emissions. The economic benefits of such integrated approach to policy making is to significantly minimise the current crude oil import and hence can significantly contribute to the state of country's energy security. This becomes meaningful strategy as projections reveal that oil import bill would surge and would be 42 % higher in this fiscal (2018–19) compared to last fiscal (2017–18).

This study, brings out a set of very interesting findings and hence, contributes significantly to the existing literature on sustainability assessment of energy sector in general and sustainability assessment of Indian electricity sector in specific. The Indian electricity sector appears to be moving on sustainable development trajectory though some deviations exist in the performance of individual states as well as e individual dimensions of the sustainability of the electricity sector. The economic dimension shows a non-linear trend with multiple ups and downs throughout the study period. The environmental dimension indicates first a falling trend up to 2005-06 and rising sharply thereafter. The probable reason for the sharp rise in the environmental index values after 2005-o6 could be linked to the introduction of feed-in-tariff mechanisms in 2005-06 designed to promote renewable energy in the country. The social dimension exhibits a declining trend during the initial periods of the study and picking up in the last few years.

Interesting patterns emerge when the sustainability of each state is analysed. In states like Gujarat, Punjab and UP, all the three dimensions of the sustainability of the sector demonstrate an upward moving trend. In several other states, a fluctuating pattern appears. Interestingly, the environmental dimension shows a very disturbing pattern for most of the states. It emerged from the further research that fluctuations in the environmental dimension in individual states are largely caused by a change in the energy mix due to an increase in the share of renewable energy and a sudden spurt of decline in the share of hydro energy in some states. For instance, a sudden drop in the environmental dimension of Odisha in 2002-03 is due to a drastic fall in hydro-power generation in the state. Similarly, Punjab also experienced a sudden fall in the environmental dimension in 2004-05 due to similar reasons. In some other states, a sudden spurt in the environmental dimension could be attributed to the rise in renewable energy share in the total energy mix. For example, in Gujarat and Madhya Pradesh, the rise in share of renewable energy led to a sudden spurt in the environmental dimension. A comparison based on grouping of states does not reveal any clear pattern as such. One of the limitations of this paper is that the analysis is up to 2010, as Indian electricity sector experienced an upheaval after 2010 due to declaration of Jawaharlal Nehru National Solar Mission, hence, logically could not extended. This creates scope for further research in this.

Acknowledgements

Authors are grateful to Waseda University for providing the funding for making this paper Gold Open Access through the "Support Program for Publication in High Impact Journals" of Waseda University. Authors are grateful to the Asian Development Bank Institute for sponsoring and supporting this research.

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