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Benchmarking sustainability of Indian electricity system: An indicator approach

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HIGHLIGHTS

- Hierarchical indicator framework for sustainability assessment of electricity system.
- Prioritized and quantified 85 indicators under four dimensions of sustainability.
- Evaluated electricity system sustainability indices of India with benchmark values.
- National electricity system sustainability index (NESSI) for India is 0.48.
- A hypothetical NESSI benchmark was developed for assessing electricity systems.

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ABSTRACT

India needs to significantly increase its electricity consumption levels, in a sustainable manner, if it has to ensure rapid economic development, a goal that remains the most potent tool for delivering adaptation capacity to its poor who will suffer the worst consequences of climate change. Resource/supply constraints faced by conventional energy sources, techno-economic constraints faced by renewable energy sources, and the bounds imposed by climate change on fossil fuel use are likely to undermine India's quest for having a robust electricity system that can effectively contribute to achieving accelerated, sustainable and inclusive economic growth. One possible way out could be transitioning into a sustainable electricity system, which is a trade-off solution having taken into account the economic, social and environmental concerns. As a first step toward understanding this transition, we contribute an indicator based hierarchical multidimensional framework as an analytical tool for sustainability assessment of electricity systems, and validate it for India's national electricity system. We evaluate Indian electricity system using this framework by comparing it with a hypothetical benchmark sustainable electrical system, which was created using best indicator values realized across national electricity systems in the world. This framework, we believe, can be used to examine the social, economic and environmental implications of the current Indian electricity system as well as setting targets for future development. The analysis with the indicator framework provides a deeper understanding of the system, identify and quantify the prevailing sustainability gaps and generate specific targets for interventions. We use this framework to compute national electricity system sustainability index (NESSI) for India.

1. Introduction

India needs to significantly increase the levels of electricity production and consumption, in a sustainable manner, if it has to ensure rapid economic development – a goal that remains the most potent tool for delivering adaptation capacity to its large number of poor who will suffer the worst consequences of extreme events induced either by human or natural systems. It is because the income poor in India are also energy poor [1]. Several other indicators suggest India has a lot to achieve to have a robust and adequate electricity system. Household electricity access level of 67.2% [2] and low per capita electricity consumption of 644 kW h [3] for India in 2011 compares unfavorably with two benchmark countries, USA and China, which have achieved 100% electricity access levels and have per capita consumption levels of 13,227 kW h and 3,298 kW h respectively [3]. Another aspect that

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is threatening the sustainability of India's energy system is its over dependence on fossil fuels for power generation. Greenhouse gas (GHG) emissions from the electricity system constituted 65.4% of the total 1100 million tCO_{2e} from energy sector in 2007 [4]. Although the annual per capita emission of 0.72 tCO_{2e} from electricity generation is lower than the 2010 global average per capita emissions of 1.71 tCO_{2e}, considering the magnitude of its total emissions, India needs to initiate measures to reduce the emissions. Third, India has an ambitious target of achieving installed capacity to the tune of 800 GW from the existing 200 GW by 2032, to support and maintain the economic growth [5].

The diagnosis in the preceding paragraph provides a glimpse of conflicting and hence contentious impacts of national electricity system. The conflicts are due to the prevailing gaps in the electricity system viz. lack of access, slower growth, need for low carbon electricity, and significant infrastructure gaps. The solution lies in adopting the principles of sustainability taking into account the conflicting objectives and dimensions, as stated above, by including the aspirations of all stakeholders in planning the national electricity system of the future. Adopting this approach raises several questions. What constitutes the sustainability of national electricity system and how it is measured? Which framework is to be used to assess the sustainability of the electricity system? How India's electricity system perform on sustainability benchmark? We want to respond to these questions and use a quantitative approach for this purpose. To do this, it is important to be able to measure the sustainability status of India's electricity system development and to monitor its achievement or lack of it toward sustainability.

To respond to the above questions, we have developed an indicator based hierarchical multi-dimensional framework to evaluate, compare and benchmark the Indian electricity system for sustainability. This framework is built upon the indicator literature in this domain. Literature reports several attempts at classifying and listing of large number of indicators ranging between 93 and 372 [6,7], however, the analysis using indicators, as evident from the empirical articles, is done with relatively lesser number of indicators, i.e., between 6 and 19 [8–12]. Even though there are studies discussing the attempts at classification/categorization of energy indicators into themes and sub-themes at different levels [8,13–16], such attempts are lacking in the context of sustainability assessment of national electricity systems. The literature has largely focused on developing theoretical and conceptual understanding of the indicator-based approaches for sustainability assessment and not on empirical validations. Given these research gaps, first, the present study contributes to bridging the methodological gap by proposing a multi-level hierarchical indicator framework with system sustainability index at the top followed by dimensions, themes, sub-themes, composite indicators and the measurable indicators as the next five levels. Next, this framework was empirically validated for the national electricity system of India by quantifying 85 indicators under different dimensions, establishing a sustainability benchmark for comparison, and developing a national electricity system sustainability index (NESSI).

2. Literature review

Energy must be an instrument for advancing economically viable, need oriented, self-reliant and environmentally sound development, which is now referred to as sustainable development [17]. The emphasis on sustainable development, in the context of energy, means that the focus must be on the end use of the energy and the services that energy provides for the welfare of human beings. In other words, energy is important for creating conditions of livability and economic development. In this paradigm, the emphasis is on human beings as ends in themselves and not so much as means of development. The idea is that these requirements of energy services can be satisfied by scrutinizing how energy is used, and by whom and for what purpose, that is by taking an end use approach [17]. Sustainable development of a country, in the context of electricity system, can only be achieved by responding to these questions and providing solutions to them. With sustainable development, as a process as well as an outcome, gaining importance, more studies are being carried out to gain deeper understanding of the whole gamut of issues. Sustainable development is a multidimensional concept, and needs both quantitative and qualitative assessments to derive deeper insights. Indicator-based approaches appears to be the most popular tool being employed to analyze the complexities around sustainable development. There are a number of studies which analyze sustainable development within the energy sector based on a set of measurable energy indicators for several countries and regions [8,9,18]. Researchers have also explored sustainability assessment of renewable energy systems using indicators [10,19–21]. In addition, there are attempts at developing indicators for the assessment of energy systems at a national level [6,8,9,22]. There is also evidence of using indicator approaches for studying the effectiveness of electricity systems by capturing the variations in the reliability levels, and price changes due to market factors and capacity constraints [23–25]. However such studies, with the exception of papers by Dimitrijevic and Salihbegovic [10] and Vithayasrichareon et al. [11], do not focus on assessment of sustainability in the context of national electricity system. Energy indicators for sustainable development [13] constructed by the International Atomic Energy Agency are widely used for assessing the energy systems [8,14–16].

Organization for Economic Cooperation and Development (OECD) defines an indicator as "a parameter which provides information about the state of a phenomenon" [26]. An indicator or group of indicators is used to judge the health of the system. According to the United Nations, indicators translate physical and social science knowledge into a few numbers, which are easy to understand and facilitate decision making [27,28].

Sustainability analyses of systems are successful when one can ascertain unambiguously overall superiority of the state of a system compared to alternative states. These alternative states can be the system's conditions over time intervals or alternative products or processes for the same function [29]. In such analyses, indicators or metrics that satisfactorily characterize the system can be used to obtain an aggregate index for easy decision making. The goal of sustainability analysis has two objectives – (i) to gain knowledge on the sensitivities of these indicators and their underlying control variables to overall sustainability performance, and (ii) to make continuous improvement by adjusting the control variables [29]. The indicators can assist countries in their efforts to assess the progress made in implementing sustainable development strategies in the area of energy, and can further identify specific areas in which focused measures and policies should be directed.

Measurement of sustainable development is crucial for operationalizing it. Different approaches for measuring sustainable development have led to detailed frameworks, from which indicators have been derived [30]. They help focus on what to measure, what to expect from measurement and which data to use [31]. These efforts received a major boost following the adoption of Agenda 21 at the earth summit in 1992, which specifically asks countries, international and nongovernmental organizations to develop the concept of indicators of sustainable development and to harmonize them at the national, regional and global levels [32]. Frameworks differentiate the ways in which the main dimensions of sustainable development are conceptualized, the inter linkages between these dimensions are established, and the