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The role of storage technologies in energy transition pathways towards achieving a fully sustainable energy system for India

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ABSTRACT

In this work, a 100% renewable energy (RE) transition pathway based on an hourly resolved model till 2050 is simulated for India, covering demand by the power, desalination and non-energetic industrial gas sectors. Energy storage technologies: batteries, pumped hydro storage (PHS), adiabatic compressed air energy storage, thermal energy storage and power-to-gas technology are used in the modelling to provide flexibility to the system and balance demand. The optimisation for each time period (transition is modeled in 5 year steps) is carried out on an assumed costs and technological status of all energy technologies involved. Results indicate that a 100% renewable based energy system is achievable in 2050 with the levelised cost of electricity falling from a current level of 58 €/MWh_e to 52 €/MWh_e in 2050 in the power scenario. With large scale intermittent renewable energy sources in the system, the demand for storage technologies increases from the current level to 2050. Batteries provide 2596 TWh, PHS provides 12 TWh and gas storage provides 197 TWh of electricity to the total electricity demand. Most of the storage demand will be based on batteries, which provide as much as 42% of the total electricity demand. The synchronised discharging of batteries in the night time and charging of power-to-gas in the early summer and summer months reduces curtailment on the following day, and thus is a part of a least cost solution. The combination of solar photovoltaics (PV) and battery storage evolves as the low-cost backbone of Indian energy supply, resulting in 3.2–4.3 TWp of installed PV capacities, depending on the applied scenario in 2050. During the monsoon period, complementarity of storage technologies and the transmission grid help to achieve uninterrupted power supply. The above results clearly prove that renewable energy options are the most competitive and a least-cost solution for achieving a net zero emission energy system. This is the first study of its kind in full hourly resolution for India.

1. Introduction

In the next few decades, the role of India in transitioning to a net zero emission based energy system till 2050 as agreed in COP21 will be keenly observed by the world. In turn, its success will be a major step in restricting the global temperature rise to 2 °C. Working towards the COP21 agreement, various changes have been initiated by the government in the power generation sector, especially power generation from renewable energy sources [1]. India is endowed with an abundant renewable energy potential, especially solar, with average solar radiation varying from 1460 kWh/(m^2·a) to 2555 kWh/(m^2·a) over India [2]. The cost of power produced from solar energy dropped drastically in the last decade to 2.44 INR/kWh (0.035 €/kWh[1]) in May 2017 [3]. Realising the abundant potential of low cost solar, the government has set an ambitious target of installing 100 GW of solar by 2022 and further up to 250 GW by 2030 [4,5]. With a rapid decrease in solar cost, producing power from a new solar plant is cheaper than a new coal fired power plant [6]. The recent trends in installed capacities of solar photovoltaics (PV) validate the initiatives taken by the government to harness the massive solar potential in the country, with an installed capacity reaching 13 GW as of June 2017 [7]. Also during COP21, India launched the International Solar Alliance, which is a coalition of the countries located between the Tropic of Cancer and the Tropic of Capricorn, to help transfer and collaborate on solar energy [8].

In India, population growth, access to modern services, increasing electrification rates and a rapid growth in gross domestic product (GDP) in the last decade have driven a large increase in energy demand and put pressure on the security, reliability and affordability of energy supply, all of which are strongly linked to economic stability and development [9]. To keep

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up with increasing electricity consumption, the electricity generation in India has grown at a 6% compound annual growth rate (CAGR) from 2012 to 2016 [4]. As of today, imports of oil, gas and coal form a substantial part in meeting the energy demand, and high dependence on imports of fossil fuels has created a serious threat to the energy security and environment of the country [10]. To keep up with economic development and improve the living conditions of the poor, a rapid increase in installed capacities of power generation sources would be needed without additional greenhouse gas emissions [11]. Coal has been the dominating fossil fuel in the energy mix of India [12]. Coal-fired power plants are associated with high health costs and heavy metal emissions [13–16], which are rarely taken into account in optimising the societal cost of energy supply in a region. In 2014, 240 million people in India did not have access to electricity, while 840 million people relied on wood, crop waste, dung and biomass to cook in traditional cook stoves, which are the major causes of indoor air pollution and premature deaths [12]. Climate change will affect most Indians due to flooding, change in the monsoon cycle and water scarcity [17,18]. Therefore, in the future India will hold the key to minimizing the impacts of climate change.

The government is going in the right direction to curb the effects of climate change and provide electricity for all in a sustainable way by taking initiatives in renewable power generation and particularly utilizing the abundant solar potential. According to research by KPMG [19], electricity generation from solar power will find a breakeven to the price of electricity from imported coal in 2015 and domestic coal in 2019. However, large scale deployment of renewables in the future would require various storage solutions to balance intermittency and to create a more reliable and flexible electricity distribution system. According to the IEA [20], energy storage offers the required flexibility for the energy systems of the future as they are capable of overcoming the problem of intermittent supply of the resources. For India energy storage technologies could bring reliable and uninterrupted basic energy services to remote areas [21].

The Indian storage market is gearing up with large-scale pilot projects and has the potential to become one of the largest markets for energy storage technologies [22]. Energy storage will play an important role in achieving the ambitious renewable energy targets of the government by reducing the curtailment of the intermittent renewable resources. In the financial year 2016–17, India has already started about 46 MW of large-scale energy storage projects. The years 2017–18 have already seen the introduction of 64 MWh of new Request for proposals (RFPs) and about 100 MW of projects will be announced. Also, new project tenders by SECI (Solar Energy Corporation of India) that include solar + energy storage were launched for the states of Karnataka and Andhra Pradesh. The government is planning to set up solar PV power plants with energy storage at two sites in Andaman and Nicobar Islands to replace 47 MW of diesel-run generation capacity [22].

This work on the sustainable energy transition pathways towards 2050 integrates all aspects in the required manner, including storage technologies. The methodology used in this study is more comprehensive, such as an hourly based model that guarantees that the total power supply in a year in the sub-regions covers the local demand from all sectors (which is most relevant during the monsoon season); a transmission grid connecting different regions that is able to reduce the need of energy storage and total costs; and an integrated scenario that assumes demand by the power, water desalination and non-energetic industrial gas sectors.

2. Methodology

2.1. Overview of the model

The transition of the Indian power system from 2015 to 2050 in 5-year time steps was modelled with the LUT Energy System Transition modelling tool (LUT model). Bogdanov and Breyer [23] describe the model in detail, giving equations and constraints used in the modelling. The LUT model is based on a linear optimisation with hourly resolution for an entire year of the energy system parameters under previously defined constraints, applied to the system with the assumptions for the future RE power generation and demand. The flow diagram of the main input parameters and outputs of the model can be found in Fig. 1. All the technical and financial assumptions used in the modelling of the Indian energy transition can be found in the Supplementary Material (Table 1). The main aim of the system optimisation is to minimise the total annual energy system cost, which is calculated as the sum of the

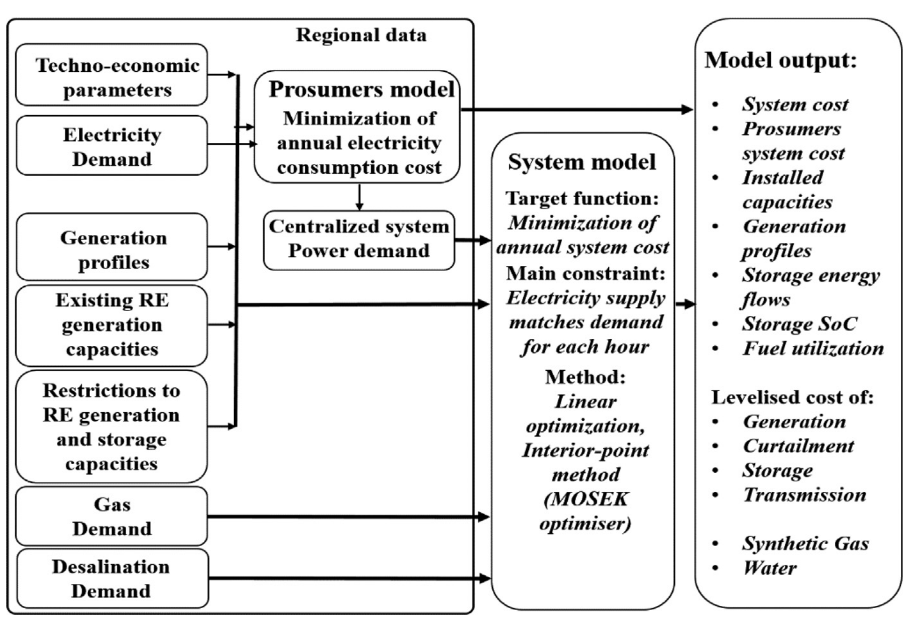

Fig. 1. The flow diagram of the LUT Energy System model from inputs parameters to outputs [24].