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Technical and economic potential of concentrating solar thermal power generation in India

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ABSTRACT

This study aims to assess the technical and economic potential of concentrating solar power (CSP) generation in India. The potential of CSP systems is estimated on the basis of a detailed solar radiation and land resource assessment in 591 districts across the country. The land suitability, favorable solar resource conditions and wind power density over the vicinity have been considered key parameters for potential estimation. On the basis of a district-wise solar and land resource assessment, the technical potential of CSP systems is estimated over 1500 GW at an annual direct normal irradiance (DNI) over 1800 kWh/m^2 and wind power density (WPD) ≥150 W/m^2 after taking into accounts the viability of different CSP technologies and land suitability criteria. The economic potential of CSP is estimated at 571 GW at an annual DNI over 2000 kWh/m^2 and WPD≥150 W/m^2 in India. The technical evaluation of CSP technologies over the potential locations have been carried through System Advisor Model (SAM) Software using the Typical Meteorological Year data of Meteonorm 7.0 weather database. In near future, it is anticipated that locations with DNI values ≥1600–1800 kWh/m^2 could also become economically feasible with the development of new technologies, advancement of materials, efficient and cost-effective thermal energy storage, economy of scale, manufacturing capability along with the enhanced policy measures, etc. In the long-term, it is possible to exploit over 2700 GW solar power through CSP in India with an annual DNI ≥1600 kWh/m^2 and WPD≥150 W/m^2. The findings of this study can be used for identification of niche areas for CSP projects in India.

1. Introduction

Energy is the vital ingredient in the world economy. The global energy demand is steadily increasing due to the increasing world population and the rising living standards. The current world population of 7.2 billion is projected to increase by almost one billion people within the next twelve years, reaching 8.1 billion in 2025 and 9.6 billion in 2050 [1]. Moreover, rapid urbanization will bring with it changes in life styles and consumption patterns. Over 70% of the world's population is expected to be urban by 2050 [2]. Without any change in our current practice, the global primary energy demand increase in 2040 would be 45% higher than 2013 levels in the current policy and 32% under a more restrained scenario [3]. At the same time, over 1.2 billion people – 16% of the global population have no access to electricity and 2.7 billion people – 38% of the world's population rely on traditional biomass for cooking and heating [3]. With global energy demands on the increase, coupled with the depletion of natural resources and the negative impact of fossil-based energy sources on the environment, the issues of clean, sustainable energy and the importance thereof in economic development and global wellbeing

Abbreviations: AD, Accelerated Depreciation; AWS, Automatic Weather Stations; CEA, Central Electricity Authority; CERC, Central Electricity Regulatory Commission; CRS, Central Receiver Systems; CSP, Concentrated Solar Power; C-WET, Centre for Wind Energy Technology; CUF, Capacity Utilization Factor; DNI, Direct Normal Irradiance; DOLR, Department of Land Resources; ESIA, Environmental and Social Impact Assessment; FIT, Feed-in Tariff; GBI, Generation Based Incentives; GHI, Global Horizontal Irradiance; GoI, Government of India; HTF, Heat Transfer Fluid; IFC, International Finance Corporation; IMD, Indian Meteorological Department; IEA, International Energy Agency; ITC, Investment Tax Credit; JNNSM, Jawaharlal Nehru National Solar Mission; LCOE, Levelized Cost of Electricity; LFC, Linear Fresnel collectors; MNRE, Ministry of New and Renewable Energy; MoRD, Ministry of Rural Development; NAPCC, National Action Plan on Climate Change; NASA, National Aeronautics and Space Administration; NIWE, National Institute of Wind Energy; NREL, National Renewable Energy Laboratory; NTPC, National Thermal Power Corporation; NVVN, NTPC Vidyut Vyapar Nigam Limited (NVVN); PCM, Phase Change Material; PDS, Parabolic Dishes System; PPA, Power Purchase Agreement; PTC, Parabolic trough collector; RE, Renewable Energy; REC, Renewable Energy Certificates; REID, Renewable Energy Infrastructure Development Fund; RPO, Renewable Purchase Obligation; SEC, Solar Energy Centre; SECI, Solar Energy Corporation of India; SEGS, Solar Energy Generating Systems; SERC, State Electricity Regulatory Commission; SRRA, Solar Radiation Resource Assessment; TES, Thermal Energy Storage; TMY, Typical Meteorological Year; UWA, Usable Wasteland Area; TWA, Total Wasteland Area; UNFCCC, United Nations Framework Convention on Climate Change; VGF, Viability Gap Funding; WPD, Wind Power Density

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Nomenclature

Albedo Albedo is the fraction of solar energy (shortwave irradiance) reflected from the Earth back into space. It is a measure of the reflectivity of the earth's surface.
Capacity Utilization Factor (CUF) CUF is the ratio of the actual output from a solar plant over the year to the maximum possible output from it for a year under ideal conditions.
Direct Normal Irradiance (DNI) DNI is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.
Global Horizontal Irradiance (GHI) GHI is the total amount of shortwave radiation received from above by a surface horizontal to the ground.
Levelized Cost of Electricity (LCOE) LCOE is the price at which electricity must be generated from a specific source to break even over the lifetime of the project

have become a pressing reality worldwide [4–6]. The world needs another industrial revolution in which energy sources are affordable, accessible and sustainable [7]. Energy efficiency and conservation, as well as decarbonizing our energy systems, are essential to this revolution.

At present, India faces insurmountable challenges to its economy, environment and energy security [8,9]. India today is home to one-sixth of the world's population and its third-largest economy, but accounts for only 6% of global energy use and one in five of the population– 240 million people– still lacks access to electricity [3]. Nearly, 30% of the households classified as below the poverty line as per recent estimates [10]. Over 80% of the total oil requirement in India is imported [11] and more than 60% coal thermal power generation is based on fast depleting coal reserves [12]. Increased import dependence also exposes the country to greater geopolitical risks and international price volatility. The Government of India (GoI) has voluntarily agreed to reduce the emissions intensity of its gross domestic product (GDP) by 33–35% from 2005 levels by 2030 [13] as per the Intended Nationally Determined Contributions (INDCs) submitted by GoI to the UNFCCC in preparation of the Paris Agreement, although overcoming energy poverty and ensuring economic and social development remains a top priority. India needs economic growth for sustainable development, which in turn requires access to clean, convenient and reliable energy for all. Renewable energy (RE) sources offer a viable option to address the key energy policy issues of the country in providing energy services in a sustainable manner and, in particular, in mitigating climate change [14].

1.1. Overview of Indian power sector

The electricity sector in India had an installed capacity of 310 GW as of end December 2016 [12]. India became the world's third largest producer of electricity in the year 2013 with 4.8% global share in electricity generation surpassing Japan and Russia [15,16]. Captive power plants have an additional 47 GW capacity as on 31st March 2015 [17]. Out of 310 GW installed capacity, 189 GW is generating through coal, 25.3 GW by gas, 0.9 GW by oil and 5.8 GW from nuclear. The share of hydropower is 13.9% (43.1 GW) followed by 14.8% (45.9 GW) through RE resources. During the 11th Five Year Plan (FYP) from 2007–12, nearly 55 GW of new generation capacity was created whereas the 12th FYP (2012-17) aims to add another 88 GW [18]. For 2015–16 fiscal year, a base load energy deficit and peaking shortage anticipated at 2.1% and 2.6% respectively [19]. This has also accentuated by non-decentralized nature of power generation with vast areas in the rural segment which are not connected by the grid for reliable and quality power. As on 31st December 2016, total RE based electricity generation capacity in the country is estimated to be 51,447 MW including 1429 MW off-grid capacities [20]. Approximately, 57% of the RE capacity is accounted by wind (Fig. 1) followed by solar (18%), small hydro (9%) and biomass power/bagasse cogeneration (16%). The rate of growth has been particularly significant for solar over the last six years (2010–2016), which grew from less than 20 MW in early 2010 to more than 9000 MW by December 2016. The share of concentrating solar power (CSP) is relatively small (0.5%) in the RE mix of the country as compared to solar PV (17.5%), wind (57.4%) and other RE technologies (24.6%) in spite of having several advantages (dispatchability, thermal energy storage, hybridization, etc.) and huge potential across the country.

1.2. Global status of CSP technologies

At the global level, renewables represented approximately 58.5% of net additions to global power capacity in 2014, with significant growth in all regions [21,22]. In 2014, solar PV marked another record year for growth, with an estimated 40 GW installed for a total global capacity of about 177 GW [22]. However, CSP market remains less established than most other RE markets despite far greater potential for CSP systems to meet global electricity demand [22,23]. With advanced industry development and high levels of energy efficiency, solar thermal electricity could meet up to 6% of the world's power needs by 2030 and 12% by 2050 [24]. As of February 2016, the CSP market has a total capacity of 7.4 GW worldwide, among which 5 GW is operational and 2.4 GW is under construction [25]. Spain and the United States lead the world in terms of the installed capacity of CSP projects followed by India, South Africa and Morocco. Nevertheless, in terms of CSP projects under construction Oman leads with about 1 GW followed by China (430 MW), Morocco (350 MW), Israel (121 MW), Chile (110 MW) and South Africa (100 MW). Miraah (translated as 'mirror' in Arabic), a proposed 1021 MW CSP facility to be located in South Oman, is expected to be one of the world's largest CSP plants. Construction of the plant is started in late 2015, while operations are scheduled to begin in 2017.

1.3. CSP in Indian context

The Jawaharlal Nehru National Solar Mission (JNNSM) under the National Action Plan on Climate Change (NAPCC) of India was launched in 2010 with the objective of achieving grid parity by the year 2022. It aimed at the deployment of 20 GW of grid connected and 2000 MW of off-grid solar power during the three phases of its operative period [26]. However, given the progress that has been achieved thus far in the form of grid-interactive power (Fig. 1) and off-grid/captive power (406 MW) [12], GoI has raised the target of the JNNSM to 100 GW [13] to be achieved through grid connected projects, off-grid projects and solar parks by 2022. The idea in the first phase of the JNNSM (2010-13) was to give equal emphasis to both solar photovoltaic (PV) as well as CSP technologies. Therefore, 500 MW each was allocated to solar PV as well as CSP technologies in Phase-I. For CSP, 7 projects (470 MW) were awarded out of which only 225 MW capacities is implemented by end 2015 [27]. Further three projects of 10 MW capacities each were awarded through migration scheme of the Indian Ministry of New and Renewable