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Techno-economic evaluation of concentrating solar power generation in India

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ABSTRACT

The Jawaharlal Nehru National Solar Mission (JNNSM) of the recently announced National Action Plan on Climate Change (NAPCC) by the Government of India aims to promote the development and use of solar energy for power generation and other uses with the ultimate objective of making solar competitive with fossil-based energy options. The plan includes specific goals to (a) create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022; (b) create favourable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership; (c) promote programmes for off grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022, (d) achieve 15 million m^2 solar thermal collector area by 2017 and 20 million by 2022, and (e) deploy 20 million solar lighting systems for rural areas by 2022. The installed capacity of grid interactive solar power projects were 6 MW until October 2009 that is far below from their respective potential.

In this study, a preliminary attempt towards the technical and economic assessment of concentrating solar power (CSP) technologies in India has been made. To analyze the techno-economic feasibility of CSP technologies in Indian conditions two projects namely PS-10 (based on power tower technology) and ANDASOL-1 (based on parabolic trough collector technology) have been taken as reference cases for this study. These two systems have been simulated at several Indian locations. The preliminary results indicate that the use of CSP technologies in India make financial sense for the north-western part of the country (particularly in Rajasthan and Gujarat states). Moreover, internalization of secondary benefits of carbon trading under clean development mechanism of the Kyoto Protocol further improves the financial feasibility of CSP systems at other locations considered in this study. It may be noted that the locations blessed with annual direct solar radiation more than 1800 kWh/m^2 are best recommended for installation of CSP systems. The results obtained can be used as preliminary indicators for identifying niche areas for immediate/short-term utilization of solar energy for concentrating solar power generation in India.

1. Introduction

Energy is a vital ingredient in economic development. With the increasing world population and the rising living standards, the global energy demand is steadily increasing (EIA, 2006). Moreover, developing countries are facing the challenge of sustaining economic growth, achieving social development and ensuring environmental protection (Beg et al., 2002). Therefore, the energy exploitation and utilization should be based on the sustainable development and better ecological environment in developing countries, so that we can attain the objective of coordinating the relationships among society, economy, energy, and sustainable environment that meets the needs of the present without compromising the ability of future generations to meet their own needs (Dincer, 1998; Wang and Feng, 2003). At present, India faces formidable challenges in meeting its energy needs and in providing adequate energy of desired quality in a sustainable manner and at competitive prices (GOI, 2006). The cumulative installed capacity of electric power plants in India under utilities was 1,56,092.23 MW till December 2009. Out of this 52.3% is generating through coal, 10.9% by gas, 0.8% by oil and 2.6% from nuclear. The share of hydropower is 23.8% followed by 9.8% through renewable energy resources (see http://www.powermin.nic.in). However, in the electricity sector India is facing acute shortage. In December 2009, all India power deficit of 10.2% and peak shortage of 11.8% is observed (CEA, 2009).

Renewable energy sources are indigenous and can contribute towards energy sufficiency as well as reduction in dependency on

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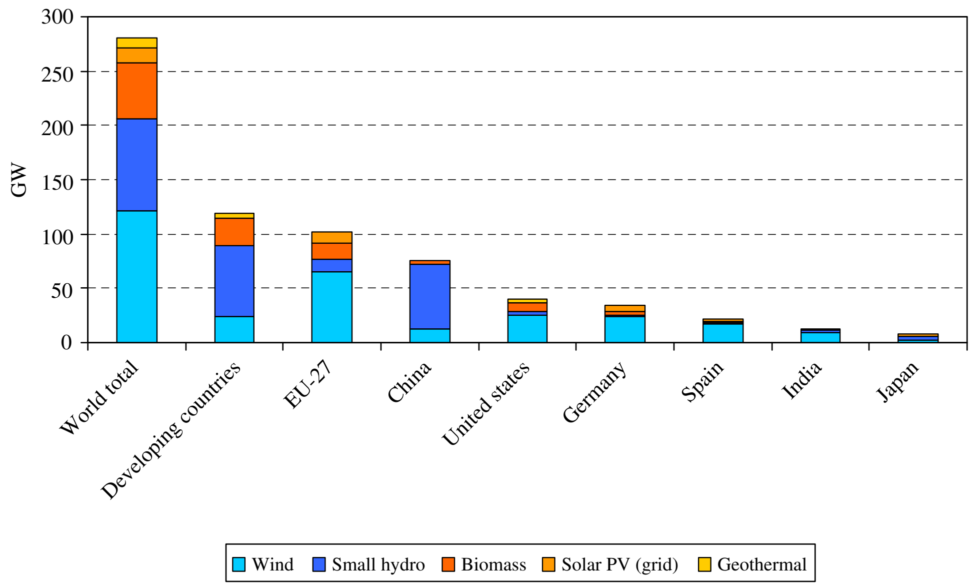

Fig. 1. Installed capacities of renewables in developing world, EU and top 6 countries (*source*: REN21, 2009).

fossil fuels. As per the updates of Renewables Global Status Report 2009 (REN21) the renewable power capacity expanded to 280 GW in 2008, a 75% increase from 160 GW in 2004, excluding large hydropower (see Fig. 1). The top six countries were China (76 GW), the United States (40 GW), Germany (34 GW), Spain (22 GW), India (13 GW), and Japan (8 GW). Fig. 1 presents the installed capacities of renewable power in developing world, European Union (EU) and top 6 countries (REN21, 2009). The capacity in developing countries grew to 119 GW, or 43% of the total, with China (small hydro and wind) and India (wind) leading the increase.

The 11th 5 year plan target of the Government of India is to add 1,00,000 MW by 2012 and the Ministry of New and Renewable Energy (MNRE) of the Government of India has set up target to add 14,500 MW by 2012 from new and renewable energy resources out of which 50 MW would be from solar energy (see http://www.mnre.gov.in). The Integrated Energy Policy of India envisages electricity generation installed capacity of 8,00,000 MW by 2030 and a substantial contribution would be from renewable energy (GOI, 2006). Recognizing both the environmental and climatic hazards to be faced in the coming decades and the continued depletion of the world's most valuable fossil energy resources concentrating solar power (CSP) can provide critical solutions to global energy problem within a relatively short time-frame and is capable of contributing substantially to greenhouse gas emissions mitigation efforts (Quaschning, 2004; European Commission, 2007; Hang et al., 2008; Li, 2009). Solar thermal electricity generating systems are emerging renewable energy technologies (Mills, 2004) and can be developed as viable option for electricity generation in near future (Muneer et al., 2005; Poullikkas, 2009).

Solar thermal electricity may be defined as the result of a process by which directly collected solar energy is converted to electricity through the use of some sort of heat to electricity conversion device (Mills, 2004). At present, there is rapid development occurring both in the basic technology (El-Sayed, 2005) and the market strategy and prospects for rapid growth of solar thermal power (Tsoutsos et al., 2003; Brakmann et al., 2005; McKinsey, 2008; Fthenakis et al., 2009). Large scale solar concentrating systems have been developed for about 30 years (Yogev et al., 1998; Segal and Epstein, 1999; Kodama, 2003). In United States, more than 350 MW of CSP systems were installed in California in the 1980s. New plants have been constructed in the last years, such as the 65 MW plant of the Spanish company Acciona in Nevada (USA) and another 280 MW plant is planned in Arizona owned by the Spanish company Abengoa.

In Europe, around 300 MW of solar thermal power plants are either operating or under construction. According to the European Solar Thermal Electricity Association (ESTELA), the installed capacity in Europe is expected to be of 500–1000 MW by 2010 and an amount of more than 20,000 MW by 2020 is reasonable. The technical potential in Europe in the long run can be estimated at least at 20 times that figure within reasonable generation costs. In addition, two plants in Algeria and Morocco of 50 MW electrical equivalent power for two solar bottomed combined cycles have been awarded to Spanish companies as a result of an international tender and a 20 MW plant is under construction in Egypt. A prequalification request for a 100 MW plant has been received from Abu-Dhabi as well as additional expressions of interest from Middle East, China and other sunny countries (see http://www.estelasolar.eu/). Fig. 2 presents the most promising areas for CSP plants (Pharabod and Philibert, 1991). It is observed that the Middle East, North Africa, South Africa, Australia, south-western United States, parts of South America, and central Asian countries from Turkey to parts of India and China figure among the most promising areas. Large engineering and industry groups, notably in Germany (e.g. Flabeg, Fichtner, Schott) and Spain (e.g. Abengoa, Acciona, ACS Cobra, Iberdrola), are now active in these markets (IEA, 2008).

India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. The India Meteorological Department (IMD) maintains a nationwide network of radiation stations which measure solar radiation and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced 250–300 days a year (Purohit and Michaelowa, 2008). The annual global radiation varies from 1600 to 2200 kWh/m^2 which is comparable with radiation received in the tropical and sub-tropical regions (Mani and Rangrajan, 1982). Fig. 3 (a) and (b) presents the distribution of annual global solar radiation and annual diffuse solar radiation in India. The equivalent energy potential is about 6000 million GWh of energy per year (Kumar, 2008). The highest annual global radiation ($\geq$2400 kWh/m^2) is received in Rajasthan and northern Gujarat (Purohit and Garud, 2007). MNRE is implementing a