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A geospatial assessment of the techno-economic wind power potential in India using geographical restrictions

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ABSTRACT

India is a privileged country in terms of wind resource regime. However, most of it remains untapped at the same time as ca 240 million people lack access to electricity in the country (19% of the total population). This calls for a thorough estimation of the amount of wind energy that could be technically and economically seized to assess the potential penetration of wind power into the country's energy system. The utilization of wind energy is associated with a plethora of localization criteria and thus it should be systematically addressed by spatial assessments to guarantee its harmonization with socio-economic systems, infrastructure and ecosystems. This study focuses on onshore wind power and strives to provide with estimates of techno economic potential based on state of the art wind power technology. Socio-economic, geographical and technical criteria regarding the localization of wind farms are outlined and implemented through a detailed a Geographic Information Systems (GIS) analysis. The levelized cost of wind generated electricity is then calculated geospatially. According to this assessment there are several states that signify high yearly wind energy yield, such as Rajasthan, Andhra Pradesh and Gujarat, whilst Goa and other states indicate the least or negligible wind power potential. The levelized cost of generating electricity ranges between 57 and 100 USD/MWh, which places wind power in a competitive position in the Indian electricity market.

1. Introduction

In India, most of the electric power is generated by conventional energy sources, e.g. coal, gas and other fossil fuels, the combustion of which generates greenhouse gas (GHG) emissions and exacerbates global warming [1]. The total population of India reaches approximately 1.3 billion, whilst around 240 million (19%) people lack access to electricity [2]. Additionally, India stood as the fourth larger energy consumer globally during 2011. The country depends heavily on imported fossil fuels (38% import dependence in 2012 [3]), a fact that might cause energy crises due to unpredicted geopolitical circumstances and potentially deteriorate economic development [4]. This calls for a comprehensive assessment of the local renewable resources (such as solar and wind energy) to estimate the extent that these would penetrate to the national energy system. Notwithstanding the plethora of wind energy's advantages, such as: very low levels of greenhouse gas emissions, cost competitiveness to other fuels, decentralized job creation [5] and high energy potential, it produces just about 3% of the country's electricity [6]. Large-scale implementation of wind power has been hindered mainly due to its variable nature [7], and the difficulty in identifying locations with fair wind power potential, especially in developing countries [8].

1.1. Present energy system

At present the total installed power capacity of India accounts for approximately 233 GW, which is planned to increase to 755 GW by 2030. Furthermore, the power sector of the country relies primarily on fossil fuels as shown in Fig. 1 [9], with a total share of approximately 68%, whereas the share of renewable energy (hydro, solar, wind and bio-energy) and nuclear stand at around 30% and 2% respectively. The conventional power plants emit a great deal of greenhouse gases. In fact, the total absolute CO_2 emissions associated with the power sector raised from 470 million tonnes in 2006 to 637 million tonnes in 2012; i.e. a 6% annual increase [10]. The emissions of CO_2 and other greenhouse gases generated by fossil fuel combustion in conventional power plants have high impact on environmental degradation as well as on health condition of the

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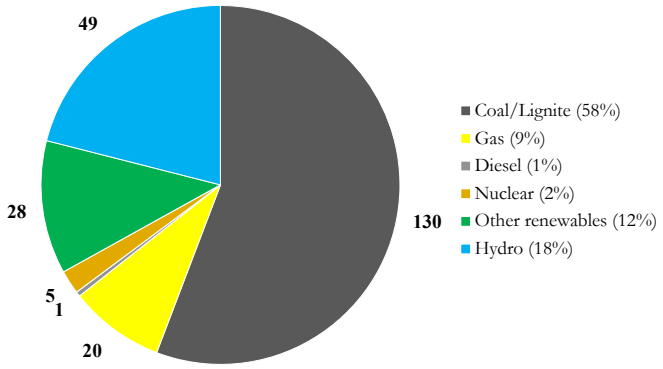

Fig. 1. Total installed power in India by type (total 233 GW).

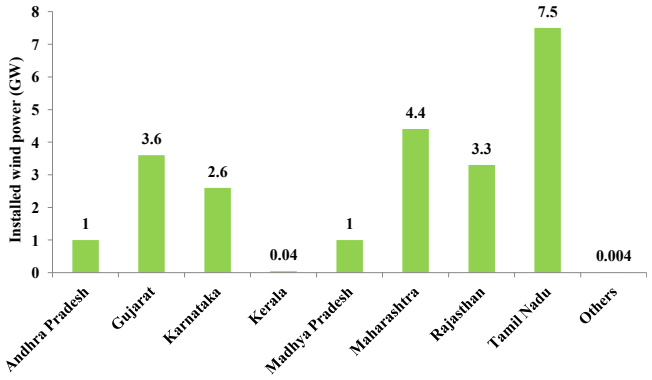

Fig. 3. Installed wind power capacity by state in India in 2015 (total 23.4GW).

population.

Hence the government is determined to achieve a sustainable electricity sector by utilizing local renewable energy resources [11]. According to the Indian Wind Energy Association (InWEA), India is one of the most endowed countries with significant wind energy potential [12]. As of 2015 [13], the wind power installed capacity has reached 23.4 GW, with Tamil Nadu and Maharashtra being the leading states (see Fig. 3). In terms of installed wind power capacity, India is ranked fifth in the world and constitutes a major player in the global wind energy market, see Fig. 2 [11]. However, the potential is far from exhausted.

1.2. Yet to come wind power targets

India has ambitious plans regarding the expansion of the power sector using local renewable energy resources [14]. According to [15], due to increasing electricity demand, about 372 GW of total power capacity should be installed by 2022. Regarding wind power, government plans 60 GW of total installed wind power capacity by 2022 [15,16].

It is therefore of outmost importance to analyse the wind resource potential and provide indicators regarding the degree that wind power would be economically competitive to other sources of energy and indicate potential suitable sites. Due to the spatial nature of wind energy, GIS based systems should be used for such an analysis. Further, GIS offer the possibility to utilize remote sensing data [17] to carry out a spatial wind energy assessment and visualize results in an informative way to bridge the science and technology, and policy gap [18,19].

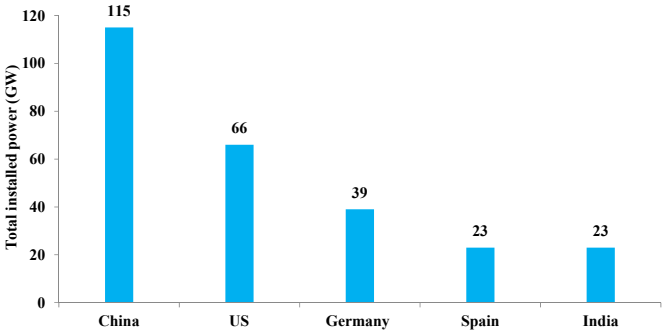

Fig. 2. India's position in the global wind energy market in terms of installed wind power capacity in 2015 (GW).

1.3. Literature review

GIS applications for the assessment of energy resources started in the 1990s and have made a reasonable progress since then; examples of such GIS-based studies are available at [20–22]. GIS software can be used to locate energy resources such as solar, biomass, wind, hydropower etc. on local and national level. In recent years GIS have been widely deployed as a decision support system to assist in locating suitable sites for wind farms in different scales; from local assessments [20,23–25] to national [22,26–28] and regional analyses [29,30]. However, there is a shortage of recent studies regarding wind resource estimations in India. Hossain et al. [31] have assessed the wind energy potential considering that the entire country (apart from urban and the Himalayan areas) is covered with wind farms. They carry out a geospatial analysis to indicate the potential in terms of plant load factor throughout the country and conclude that the potential for wind farms in India is significantly higher than assumed in earlier studies. However, several land restrictions considering other socio economic and geographical limitations are not looked at.

Another essential effort is conducted by Ref. [32] in order to quantify the wind power potential in the country using GIS. They implemented restriction criteria regarding wind farm localization and estimate that 1549 GW of onshore wind farms could be installed in the country. Nonetheless, neither wind energy yield values nor any cost related figures in geospatial basis were depicted.

1.4. Statement of the objectives

This study aims to accommodate the limitations of the above mentioned studies and provide wind energy yield figures and associated economic indicators. More specifically, the main objectives of this paper are to use a GIS based analysis in order to:

- Quantify India's onshore technical wind energy potential using wind power technical parameters, land use restrictions, and wind farm siting criteria.[1]
- Estimate the economic wind energy potential by providing relevant economic indicators such as the spatial levelized cost of

[1] According to [27], *Geographical potential* is the total amount of land area available for wind turbine installation taking geographical constraints into account. *Technical potential* is the wind power generated at the geographical potential including energy losses due to the power density of the wind turbines and the process of generating electricity using wind turbines and *Economic* potential is the technical potential that can be realized economically given the cost of alternative energy sources.