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Environmental Assessment and Pollution Mitigation of Wind Power Generation in Indian

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Abstract - *Wind energy has the highest potential of pollution mitigation among all renewable energy sources. However, it is intermittent in nature and its availability varies from place to place and season to season. There is a remarkable change in wind turbine technology in the last few years. To enhance the efficiency of wind turbine various developments has been made in the technology such as power electronics, aerodynamics and mechanical drive train design. This paper presents the pollution mitigation assessment of wind power generation in India. The equivalent amount of energy generated through thermal power plant is replaced by the energy generated by the wind and the amount of pollution mitigated by the wind energy is being presented. Results, calculation, and discussion based on existing available data have been presented.*

Key Words: Environmental Assessment, Wind Power generation, Pollution Mitigation.

1. INTRODUCTION

Energy is the main component of economic growth and human development for any nation. India is 6th largest energy consumer in the word with the percentage of total global energy consumption is 3.4. Due to rising economy of India, the demand for energy has grown at an average of 3.6% per annum over the past 30 years [1]. The Electricity sector in India is growing rapidly to meet the electricity demand in various sectors. During the current year 2016-17 (up to 30.06.2016), the installed capacity is 304.50 GW with generation mix of Thermal (70%), Hydro (14%), Renewable (14%) and Nuclear (2%) as shown in figure1 [2].

India has enormous resources of new and renewable energy. It has one of the major programs in the world for deploying renewable energy technologies and products. Moreover, India has separate Ministry of New and Renewable Energy (MNRE) in the world. The significant progress is being made in power generation from renewable energy sources by the Ministry through launching a number of programs and promotional efforts. Total installed capacity of renewable energy is 44.2 GW with generation mix of the wind (61%), Solar (18%), SHP (10%) and Biomass (11%) as shown in figure 2 [2].

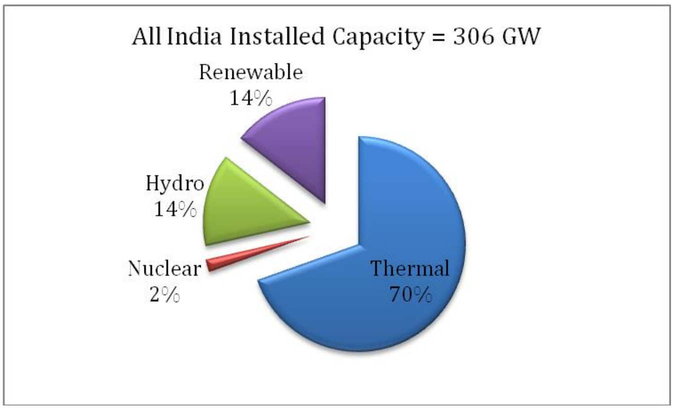

Figure 1: Total Installed Capacity in India as on 30.09.2016 [2]

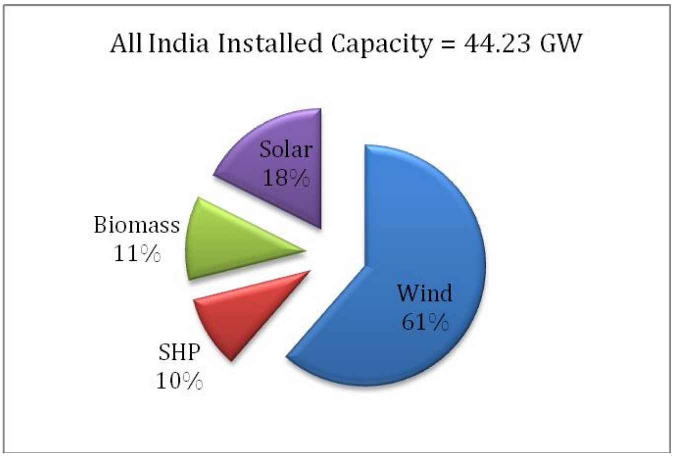

Figure 2: Total Installed Capacity in India as on 30.06.2016 [2]

2. WIND POWER IN INDIA

There is a huge increase in wind power generation in India. However, with good sunshine hours leading to the creation of commercially viable wind energy generation and 7517 km of the seashore and its territorial waters extending up to 12 nautical miles into the sea, India has very large wind energy potential. India is the fourth largest wind power producer in the world [3,4,5].

Table 1 presents a state wise gross wind power potential at 100 meters above ground level and installed capacity as on

31.03.2016 [6]. It reveals that Tamil Nadu is a leader in wind power generation followed by Maharashtra.

Table 1: State wise gross wind power potential and cumulative installed capacity in India as on 31.03.2016 [6]

S.NO.	State	Gross wind power potential at 100 meter above ground level (MW)	Installed Capacity (MW)
1.	Andhra Pradesh	44229	1431.45
2.	Gujarat	84431	3948.61
3.	Karnataka	55857	2869.15
4.	Kerala	1700	43.50
5.	Madhya Pradesh	10484	2141.10
6.	Maharashtra	45394	4653.83
7.	Rajasthan	18770	3993.95
8.	Tamil Nadu	33800	7613.86
9.	Telangana	4244	77.70
10.	Others	3342	4.30
Total (All India)		**302251**	**26777.45**

The electrical power generation based on fossil fuels has been associated with adverse environmental impacts such as land degradation, deforestation, and water and air pollution. Furthermore, there are great concerns about the release of greenhouse gas (GHG) emissions mainly from fossil fuels based power generation [7, 8]. The key component of greenhouse gas is carbon dioxide (CO_2). To address these environmental issues, development and promotion of renewable energy technologies (RETs) have been made towards large-scale dissemination in India. Renewable energy technologies are considered as the best potential option for mitigation of CO_2 emissions into the atmosphere due to fossil fuel-based power generation.

3. METHODOLOGY

Wind power has the largest installed capacity amongst all renewable energy in India. Therefore, CO_2 emission mitigation through wind power generation is considered in this paper. In recent past years, the effort has been made to study the CO_2 emission mitigation potential through renewable energy sources [9,10,11]. In this perspective, the development of a framework for the assessment of CO_2 emission mitigation potential through wind power generation has been discussed. The result of calculations has been made on the basis of available data is also presented and discussed.

Potential of CO_2 emissions mitigation by wind power generation would essentially depend on the amount of fuel saved by its use. The amount of fuel saved would directly depend on annual useful energy provided by the wind power generation and the efficiency of utilization of fuel being saved in the existing fossil fuel based power plant.

3.1 Annual CO_2 emission mitigation potential through wind power generation

The wind turbine converts the kinetic energy of the wind through a rotor consists of two or more blades mechanically coupled to an electric generator. The output power of a wind turbine depends on the site-specific parameters which include wind speed and air density and design parameters consisting of “coefficient of performance” of the wind rotor, swept area of the rotor, cut-in, cut-out and rated wind speed of the rotor. Hence, the annual useful energy, AUE_{wind}, generated by a wind generator can be expressed as [12].

$$AUE_{wind} = 8760\gamma \int_{v_{c_i}}^{v_{c_o}} P(v)F(v)dv \quad (1)$$

Where,
γ = wind turbine mechanical availability factor for downtime during maintenance etc.
P(v) = power generated by the wind generator at wind speed v
F(v) = Weibull probability distribution function
v_{ci} = cut-in wind speed (m/s)
v_{co} = cut-out wind speed (m/s)

The power generated by the wind generator at wind speed v can be given as [13]

$$P(v) = \frac{1}{2} C_p \rho_\alpha A v^3 \quad (2)$$

Where,
Cp = coefficient of performance of the wind rotor
ρ_a = air density (kg/m^3)
A = area swept by the rotor blades (m^2)
V = velocity of the air (wind speed)(m/sec)

The variation in wind speed at a location is often described by the Weibull probability distribution function F(v) and is given by the following equation [14].

$$F(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} e^{-\left(\frac{v}{c}\right)^k} \quad (3)$$

Where, k represents the shape parameter and c the scale parameter.

From equations (1), (2) and (3) the annual useful energy (in kWh) generated by the wind generator can be calculated as [12].

$$AUE_{wind} = 4.38\left(\frac{\gamma C_p \rho_a A k}{c^k}\right) \int_{v_{c_i}}^{v_{c_o}} v^{(k+2)} e^{-\left(\frac{v}{c}\right)^k} dv \quad (4)$$

The annual gross CO_2 mitigation potential of a wind generator depends on the annual electricity saved by the wind generator and the CO_2 emission factor (CEF_e) for electricity [12].

$$GCE_{wind} = 4.38\left(\frac{\gamma C_p \rho_a A k}{c^k (1-l)}\right)\left[\int_{v_{c_i}}^{v_{c_o}} v^{(k+2)} e^{-\left(\frac{v}{c}\right)^k} dv\right] CEF_e \quad (5)$$

Where, l represents the transmission and distribution losses of electrical power (*in fraction*) and CEF_e the baseline CO_2 emission factor (kg/kWh).

For a given capacity of a wind generator the gross annual CO_2 emissions mitigation potential can be given as [12].

$$GCE_{wind} = (8760\, PLF_{wind}\ P_{wind})CEF_e \quad (6)$$

Where,

P_{wind} = capacity of wind generator (in MW)
PLF_{wind} = plant load factor of the wind generator

The term $(8760\, PLF_{wind}\ P_{wind})$ of equation (6) is the annual amount of electricity saved by the wind power generation.

Table 2 present the assessment of annual CO_2 emission mitigation potential through estimated gross potential and installed capacity of wind power generation on the basis of state wise baseline CO_2 emission factor (kg/kWh).

Table 2: Annual CO_2 mitigation potential through gross and installed wind power generation in India

S. No.	State	*Baseline (kg CO_2 /kWh)	Annual electricity generation (TWh)		Annual CO_2 emissions mitigation Potential (million tonnes)	
			Gross	Installed	Gross	Installed
1	A. P.	0.86	96.8	3.13	83.30	2.69
2	Gujarat	0.89	184.9	8.64	163.76	7.69
3	Karnataka	0.86	122.3	6.28	105.17	5.40
4	Kerala	0.86	3.7	0.09	03.18	0.08
5	M. P.	0.89	22.9	4.68	20.38	4.16
6	Maharashtra	0.89	99.4	10.19	88.46	9.07
7	Rajasthan	0.75	41.1	8.74	30.82	6.56
8	Tamil Nadu	0.86	74.0	16.67	63.64	14.34
9	Telangana	0.86	9.2	0.16	07.91	0.14
10	Others	0.86	7.3	0.009	06.28	7.74×10^{-3}
All India			**661.6**	**58.58**	**572.90**	**50.13**

*Source: [12]

5. RESULTS AND DISCUSSION

Annual CO_2 emission mitigation potential through the gross potential of wind power in India has been estimated as 572.90 million tonne. Amongst all Indian states, Gujarat has the largest CO_2 emissions mitigation potential through gross wind power potential (163.76 million tonne) followed by Karnataka (105.17 million tonne), Maharashtra (88.46 million tonne), Andhra Pradesh (83.30 million tonne), Tamil Nadu (63.64 million tonne), and so on as shown in Table 2 and figure 3.

The annual electricity generation in India by wind power with 25% PLF based on the gross potential and installed capacity is 661.60 TWh and 58.58 TWh respectively as given in Table 2.

6. CONCLUSIONS

In this paper, the assessment reveals that there is a huge potential of CO_2 emission mitigation by the use of wind energy in India. Based on available data the gross potential of wind power is more than 3, 00,000 MW and the existing installed capacity is around 26500 MW in India. The final annually estimated CO_2 emission mitigation potential through gross potential and installed wind power capacity in India is 572.90 million tonne and 50.13 million tonne respectively.

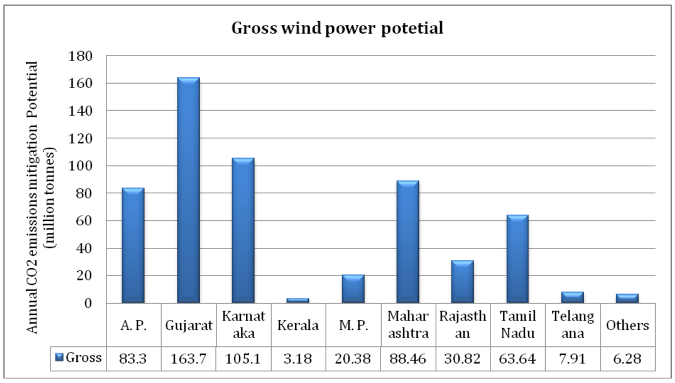

Fig. 3: Annual CO_2 emissions mitigation potential through gross wind power potential in India.

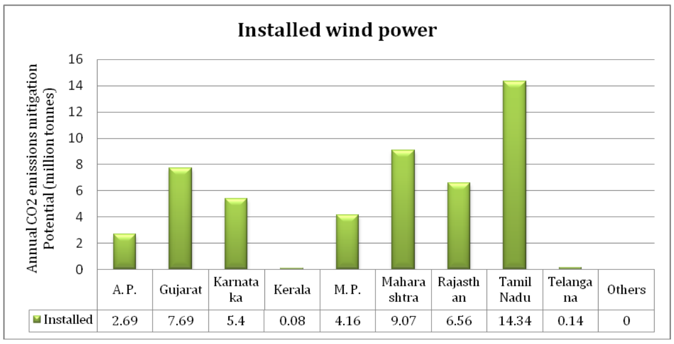

Fig. 4: Annual CO_2 emissions mitigation potential through installed wind power generation in India.

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BIOGRAPHY

Imdadullah received the B.Tech. Degree in electrical engineering and the M.Tech. Degree in power systems and drives from Aligarh Muslim University (AMU), Aligarh, India, in 2003 and 2006. He is currently an Assistant Professor in electrical engineering with the University Polytechnic, AMU, Aligarh, India. His areas of interests are renewable energy and power systems and drives.