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Mitigation of GHG Emissions with a 50 MW Wind Power Plant: A Case Study of Pakistan

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Abstract: The combustion of fossil fuels for power generation produces large amount of greenhouse gases (GHGs) which causes not only global warming and climate change but also indirectly affects the life of all living organisms and the environment. There are worldwide efforts by United Nations Framework Convention on Climate Change (UNFCCC) for the reduction of these GHGs by means of various methodologies for short to long term strategies. Renewable energy technologies and more significantly wind energy provide economical and sustainable solutions to the environmental and atmospheric issues. This study estimates the mitigation of GHGs by a 50 MW wind power plant on the basis of current baseline emission factor of national grid of Pakistan. The results specify that a 50 MW of wind energy plant in Pakistan can generate about 110 GWh of electricity annually which can mitigate or reduce about 63620 ton CO_2eq emissions of GHGs from the power generation annually.

Keywords: GHGs, air pollution, Mitigation, wind power, Renewables

1. INTRODUCTION

Fossil fuels during extraction, transportation, conversion and combustion produce large amount of GHGs which is a key environmental issue of today's developing era. The main components of these emissions like carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are considered as GHGs which are dominantly responsible for the serious environmental problems such as air pollutions, global warming and climate change (Harijan, *et al.*, 2011; Sonibare, 2010).

Because of increasing effects of global warming, climate change and environment degradation problems, the solutions to the reduction of GHGs have been felt globally. In order to handle this problem, nations around the world are making their efforts to stabilize GHGs or other pollutants concentrations level well below to prevent hazardous anthropogenic interference with the environment.(Dong *et al.*, 2012; UNFCCC, 2006; Zhou, 2015).

There are many approaches for reducing these emissions from the atmosphere like employing greater energy efficiency systems, energy conservation practices and capturing and storing carbon emissions from fossil based fuels. Another way is to switch from fossil-fueled power generation sources to emissions free sources like renewables (solar, wind, Hydro and biomass) and nuclear. Renewables particularly wind energy is considered as the best useful resource of energy for the mitigation of GHGs. It is reliable and abundantly available almost in every region of the world. The generation cost of wind energy is potentially decreasing and becoming cost-effective energy source than conventional fossil fueled sources.(Akorede, *et al.*, 2012; Liu, *et al.*, 2011; Mahesh *et al.*, 2013) In this study the national grid emission factor of Pakistan has been estimated to evaluate GHG emissions reduction though the proposed 50 MW wind power plant to counter the effects of climate change and global warming.

2. POWER GENERATION AND GHG EMISSIONS IN PAKISTAN

Power generation system of Pakistan comprise of both government owned units and private power generation units. The public generation companies are Water & Development Authority (WAPDA), Pakistan Electric Power Company (PEPCO), Pakistan Atomic Energy Commission (PAEC), while privately electricity is generated by Independent power producers (IPPs) and Karachi Electric (K-Electric). IPPs contribute significantly in electricity generation by supplying around 42% of total electricity generation in the country. The major consumption of electricity is in the, domestic, commercial, industrial and agricultural sectors (ICCI, 2011).

The power generation in Pakistan is dominated by the fossil fuels and mostly comprises of imported oil, indigenous natural gas and a minimum amount from

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local coal. Total installed capacity increased at a meager growth of 14.86% from 19420 MW in 2008 to 22812MW in 2013. The major increase (75%) was in thermal capacity by IPPs, (NEPRA, 2013). The total installed capacity for power generation in Pakistan from 2008 to 2013 is shown in **(Fig-1)** (HDIP, 2013).

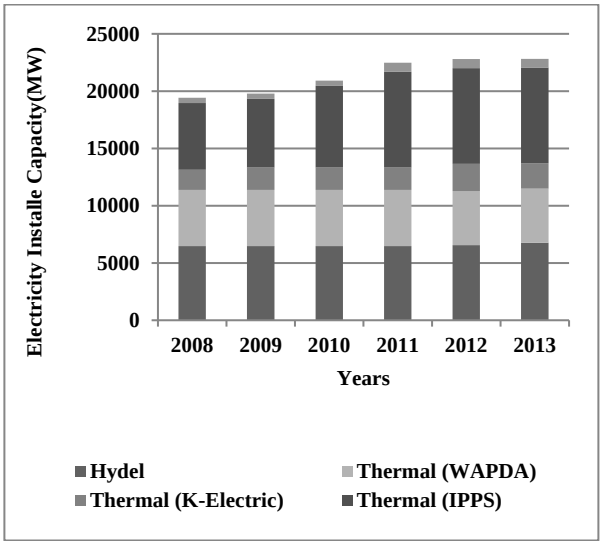

Fig-1 Total installed capacity from 2008 to 2014

According to the data from the energy year book 2013, the total electricity generated in the country during financial year 2012-13 was 96,122GWh. The contribution from fossil fuels for power generation was the highest at 64.2% of which the share of natural gas and furnace oil was 36% and 28% respectively. Next to the fossil fuels are hydropower and nuclear power generation having shares of 31% and 5% respectively (HDIP, 2013) in overall generation. The share of electricity generation from each fuel source for the period 2012-13 is shown in the **(Fig-2)**.

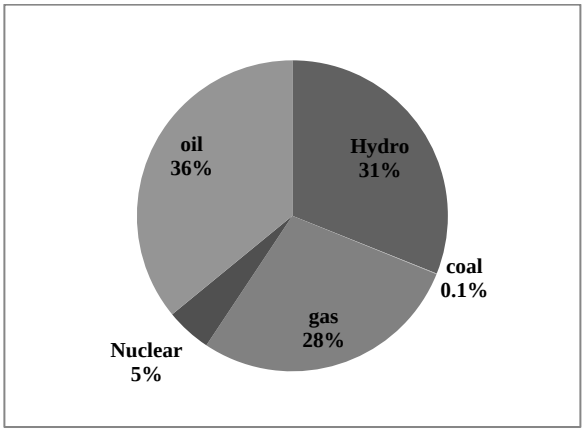

Fig-2 Total electricity generation during financial year 2012-13

Since the fossil is major source of power generation, therefore, power sector stands to be the foremost contributors of the GHGs particularly CO_2 emissions (make up the 50 % of all energy consumes in the country) due to the heavy reliance on the thermal power. The CO_2 emissions in Pakistan have increased from 14 million tons in 1960 to 174 million tons in 2013 (WB, 2016). The main sources of these emissions are power generation, transportation and cement manufacturing industries, in which power generation contributes more than the other sectors. Further, it is apparent from the future power expansion plans of government that a considerable share of power generation would be from local coal (Thar) and imported coal which will further increase these emissions.

Pakistan has about 1050 km long coastline, extending in the east from Indian border to the west with Iranian border. This coastline is blessed with huge wind energy potential. In addition to the coastal areas in the country some isolated areas of Balochistan, Khyber Pakhtunkhwa, Punjab provinces and northern areas have also the significant wind potential to generate power (Mengal, *et al.,* 2014; Mirza, *et al.,* 2007). The current map of wind potential was build up by National Renewable Energy Laboratory (NREL) USA in collaboration with USAID. According their reports Pakistan has an resourceful wind energy potential of 346 GW out of which more than 50 GW is technically exploitable alone from wind corridor in Sindh Province (NREL, 2007).

3. MATERIALS AND METHODS

The baseline grid emission factor is an essential parameter for the mitigation of GHGs owing to fossil fuel based power generation, as such, should be estimated first. Following sub-sections elaborate the calculation procedure for estimating the grid emission factor.

3.1 Baseline grid emission factor estimation

The baseline grid emission factor is employed to determine the baseline emissions of the grids that supply electricity to a country. The volume of emissions which are released from fossil fuel based power plants connected to national grid in absence of the (proposed) renewable power project is described as baseline emissions. As such, the difference of baseline emissions and project emissions is the reduction in emissions. In this study the baseline emission factor is found with help of approved baseline methodology for electricity generation from renewable energy ACM0002 (version 16) by UNFCCC. According to this methodological tool baseline emission factor is estimated by combine margin (CM) emission factor which is referred as the weighted average of both operating margin (OM) as well as the build margin (BM) emission factors for the

displacement of electricity generated by the power plants in electricity generation systems (UNFCCC, 2014a).

3.1.1. Operating Margin (OM) Emission Factor

The Operating Margin (OM) emission factor referred as the weighted average emission factors of existing power plants in a grid system not considering the low cost/must-run (LC/MR) sources whose present electricity generation would affect the proposed new renewable projects. It can be estimated by many approaches like simple, simple adjusted and dispatch according to the available data of the national grid of a country.

Hydro and Nuclear powers are considered as the LC/MR generation resources in Pakistan. The average of total LC/MR electricity generation data of recent five years is 34.6% which constitutes less than threshold limit of 50%, therefore, for Pakistan simple OM emission factor approach is used. The equation used for the estimation of simple OM emission factor is given as under (UNFCCC, 2014a):

$$\mathbf{EF_{grid,OM\ simple,\ y}} = \frac{\sum_i (\mathbf{FC_{i,y}} \times \mathbf{NCV_{i,y}} \times \mathbf{EF_{CO_2,i,y}})}{\mathbf{EG_y}} \quad \textbf{(1)}$$

Where

$\mathbf{EF_{grid\ OM\ simple,\ y,}}$	**Simple grid OM emission factor in year y (tone emissions/MWh)**
$\mathbf{FC_{i,y}}$	**Quantity of fossil fuel type i utilized for the electricity generation system in year y (unit mass)**
$\mathbf{NCV_{i,y}}$	**Net calorific value of fossil fuel type i in year y (GJ/ unit mass)**
$\mathbf{EF_{CO2,i,y}}$	**Emission factor of fossil fuel type i in year y (tone of emissions/GJ)**
$\mathbf{EG_y}$	**Net amount of electricity produced and supplied to the grid by all power plants in the grid system, not considering LC/MR plants/units, in year y (MWh)**
i	**Type of fossil fuel utilized in power plant for the electricity generation system in year y**
y	**The relevant year**

For the calculation of OM emission factor, the data pertaining to the fuel consumption ($FC_{i,y}$) and ($NCV_{i,y}$) were taken from the Pakistan energy year book 2013(HDIP, 2013). The values of emission factors ($EF_{CO2,i,y}$) of all the fuels that use for power generation were taken from the greenhouse gas inventory guidelines of IPCC (IPCC, 2006). The values of Net Calorific Value and emission factor are given **(Table-1)**.

It is pertinent to mention that Global Warming Potential (GWP) is the measurement of impacts of the greenhouse gases in the atmosphere. Each greenhouse gas has different intensity of effect on the atmosphere which measures how much heat one tone of a gas will entrap into the atmosphere over a given period of time compared to CO_2 over the same time. The main greenhouse gases release from the combustion of fossil fuels as mentioned already in this study are CO_2, CH_4 and N_2O and their relevant GWP at 100 years are 1, 21 and 310 respectively (UNFCCC, 2014b).

Further, Carbon dioxide equivalent (CO_2e) is a standard unit which states the impact of each particular GHG in terms of amount of CO_2 which produce the same amount of warming. The CO_2e emission factor is calculated using emission factors of all fuels given in (Table 1) and the GWP of each respective GHG. The calculated results of emission factors are given in **(Table-2)**.

Table-1 Net calorific value of fuels and Emission factors of GHGs

Fuel type	Net calorific value (GJ/ton)	GHG Emission factors (Kg/TJ)		
		CO_2	CH_4	N_2O
Coal (lignite)	19.8	101000	1	1.5
Furnace Oil	42.3	77400	3	0.6
Diesel Oil	43	74100	3	0.6
Gas	48	56100	1	0.1

Table-2 Emission factors of CO_2e for the electricity generation fuels

Fuel type	CO_2e (ton/TJ)
Coal (lignite)	101.49
Furnace Oil	77.649
Diesel Oil	74.29
Gas	56.152

3.1.2. Build Margin (BM) Emission Factor

The BM emission factor refers to the weighted average emission factor of the power plants whose construction and future operation would affect the new renewable power projects. It is estimated on the basis of average effect of emission factors of a sample group of power generation units and consists either of the group of five power plants which are newly built or the group of power units in the total electricity generation system that consists of 20% of total electricity generation system (in MWh) which have been most newly built.

According to the above, the first criteria of group of five power generation plants (SET5-Units) were identified which started supplying electricity generation to the national grid and are mostly new and their annual electricity generation in 2013 was 4429 GWh refers as ($AEG_{SET\text{-}5\text{-}units,}$ in MWh).

Further, according to the above second criteria; annual electricity generation of total system is referred as ($AEG_{total,}$ in MWh). From the total electricity generation system, a group of power plants was identified which supply electricity to the national grid

and are mostly new and consists of 20% of (AEG_{total} in MWh). Then, the annual electricity generation ($AEG_{SET-20\%}$ in MWh) of this group of power plants was estimated. The estimated results of total annual electricity generation ($AEG_{total,}$ in MWh) and ($AEG_{SET-20\%}$ in MWh) are presented in **(Table-3).**

Table-3 Total annual electricity generation in Pakistan in 2013

Total annual electricity generation (AEG_{total}) in Pakistan in 2013		
Electricity generation	**Units**	**2013**
Total Generation [AEG_{total}]	**GWh**	**96122**
20% of [AEG_{total}]	**GWh**	**19224**

According to the procedure adopted above, from the two groups of power plants the one with highest output will be selected for estimation of BM emission factor. It is found that SET≥20% consists highest annual electricity generation system than SET5-units, therefore, it was selected as (SET sample) for BM emission factor estimation. The BM emission factor is estimated by the following equation (UNFCCC, 2014a).

$$EF_{grid,BM,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}} \quad (2)$$

Where

$EF_{grid,\ BM,\ y}$	**BM CO_2eq emission factor in the year "y" (tCO_2eq/GWh)**
$EG_{m,y}$	**Net amount of electricity generated and supplied to the national grid by the power plants "m" in year "y" (GWh)**
$EF_{EL,\ m,y}$	**CO_2eq emission factor for power plants "m" in year "y" ($tonCO_2eq/GWh$)**

The net amount of electricity generation data for power plants "m" in year "y" as in (SET sample) was taken from the Pakistan energy year book 2013 (HDIP, 2013) while, for the CO_2eq,the emission factor data for each power plant was taken from IPCC guidelines (IPCC, 2006).

3.1.3. Combine Margin (CM) Emission Factor

CM grid emission factor is the average effect value of the OM and the BM emission factors and is used for the estimation of baseline emissions from grid of a country. The CM emission factor is calculated as under (UNFCCC, 2014a):

$$EF_{grid,CM,y} = EF_{grid,OM,y} \times W_{OM} + EF_{grid,BM,y} \times W_{BM} \quad (3)$$

Where

$EF_{grid,CM,y}$	**CM emission factor in year *y* (tCO_2eq/MWh)**
$EF_{grid,OM,y}$	**OM emission factor in year *y* (tCO_2eq/MWh)**
$EF_{grid,BM,y}$	**BM emission factor in year *y* (tCO_2eq/MWh)**
W_{OM}	**Weight of the OM emission factor**
W_{BM}	**Weight of the BM emission factor**

3.2. Wind power generation and GHGs Mitigation

The assessment of power generated from wind system involves various terms, criteria's and parameters observed appropriately. The rated power of a wind energy plant is the highest power output from it that can be generated in terms of ideal wind conditions. The capacity factor or load factor is the ratio between real electricity generations from the wind energy plant to the electricity generation from it at its rated capacity. The plant load factor is the ratio between number of hours for power generation to the total no of hours in year. The annual electricity generation output from wind energy plant can be estimated from the following expression (Parmal 2013).

$$AE_{Output} = \text{Capacity (MW)} \times \text{Capacity factor (\%)} \times 8760 \quad (4)$$

Where, the AE_{output} is the annual electricity output from wind energy plant in MWh, total plant capacity in MW, the capacity factor in (%) and 8760 are total number of hours in year.

Since the wind energy plant is emission free power generation system, therefore, the annual plant emissions for electricity generation output will be zero. The annual baseline GHG emissions for the proposed wind energy plant can be estimated considering the calculated grid emission factor (Grid EF) of Pakistan (Parmal *et al.*, 2013).

$$\text{Baseline GHG emissions} = \text{Electricity output (MWh)} \times \text{GridEF(tonCO2 eq/MWh)} \quad (5)$$

Where, the electricity output is annual electricity generation from wind energy plant and Grid EF is the baseline grid emission factor.

4. RESULTS AND DISCUSSION

Using the data from the Tables 1 and 2 in Eq (1) the OM grid emission factor ($EF_{grid,\ OM\ simple,\ y}$) was estimated. The results for grid emission factor based on the data of recent years i.e. 2013, 2012 and 2011 and their average value of grid emission factor are listed in **(Table-4)**.

Table-4 Estimated Results of OM Emission factors ($ton\ CO_2e/MWh$)

2013	2012	2011	Average
0.665	**0.649**	**0.693**	**0.668**

Further, using the data of net amount of electricity generation ($EG_{m,\ y}$) of 2013 in GWh from each power plant and the CO_2eq emission factor of fuel utilized for power generation in the Eq (2), the BM emission factor for 2013 was estimated which is found to be 0.315 ton CO_2eq/MWh.

As per the guidelines of ACM0002 by the UNFCCC for wind power projects, the weighted effects of OM and BM emissions factors are 0.75 and 0.25 respectively, therefore, CM grid emission factor (baseline emission factor) can be calculated by the Eq (3). The calculated results of OM, BM and CM emissions factor are presented in **(Table-5)**.

Table-5 Base line grid emission factor for Pakistan 2013

Emission factor	Unit	Result
OM (EF grid, OM, y)	(ton CO2e/MWh)	0.669`
BM (EF grid, BM, y)	(ton CO2e/MWh)	0.315
CM (EF grid, CM, y)	(ton CO2e/MWh)	0.581

The literature available on the wind potential estimation in Pakistan suggests that the 25% average capacity factor of wind energy plant exists in wind potential areas of the country (Bhutto, *et al.*, 2013; Harijan *et al.*, 2011). The total power generation hours in a year assumed in this study are 8760. Using the all values of the above parameters in the Eq (4) the annual electricity output from proposed wind energy plant was found to be 110 GWh.

Finally, using the values of annual electricity output from wind energy plant and baseline Grid EF (CM grid EF) in Eq (5), the baseline grid emissions were estimated to be 63620 ton CO_2eq emissions of GHG annually. The wind energy based electricity generation has zero emissions. As such, the reduction or mitigation in emissions is the difference of baseline emissions and the emissions from a wind plant for electricity generation. Since, the wind energy plant emission are zero, therefore, baseline grid emissions are equal to mitigation or reduction of GHG emissions.

The above results illustrate that a 50 MW of wind energy plant in Pakistan can generate about 110 GWh of electricity annually which can mitigate or reduce about 63620 ton CO_2eq emissions of GHG from the national grid annually. This reduction in emissions can put a significant impact on the environment by minimize the global warming and climate change.

5. CONCLUSION

Power sector in Pakistan is dominated by the thermal electricity generation based on fossil fuels and contributing a large amount of GHGs particularly CO_2 emissions. These GHG emissions are the big challenges for the environment as well as the main source of climate change and global warming. The electricity generation fuel mix of the country needs to be improved by increasing the share of cleaner and emissions free fuels. The exploitation of available renewable resources such as wind energy has emerged to be one of the most efficient and effective means of achieving this goal. The results of this study indicate that a 50 MW of wind energy plant in Pakistan can generate about 110 GWh of electricity annually which can mitigate or reduce about 63620 ton CO_2eq emissions of GHGs from the national grid. Therefore, government should offer worthwhile incentives for the investors to attract them to invest in the wind energy plants.

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REFERENCES:

Akorede, M. F., H. Hizam, M. Z. A. Ab. Kadir, I. Aris, S. D. Buba, (2012). Mitigating the anthropogenic global warming in the electric power industry. Renewable and Sustainable Energy Reviews, 16(5), 2747-2761. doi: 10.1016/j.rser.2012.02.037

Bhutto, A. W., A. A. Bazmi, G. Zahedi, (2013). Greener energy: Issues and challenges for Pakistan—wind power prospective. Renewable and Sustainable Energy Reviews, 20, 519-538. doi: 10.1016/j.rser.2012.12.010

Dong, G., X. Jia, C. An, F. Chen, Y. Zhao, S. Tao, M. Ma, (2012). Mid-Holocene climate change and its effect on prehistoric cultural evolution in eastern Qinghai Province, China. Quaternary Research, 77(1), 23-30. doi: 10.1016/j.yqres.2011.10.004

Harijan, K., M. A. Uqaili, M. Memon, U. K. Mirza, (2011). Forecasting the diffusion of wind power in Pakistan. Energy, 36(10), 6068-6073. doi: 10.1016/j.energy.2011.08.009

HDIP., (2013). Pakistan Energy Yearbook 2013: Hydrocarbon Development Institute of Pakistan, Ministry of Petroleum and Natural Resources, Government of Pakistan.

ICCI., (2011). An Overview of Electricity Sector In Pakistan. Islamabad chamber of commerce & industry.

IPCC., (2006). Guidelines for National Greenhouse Gas Inventories; Chapter 2, Stationary combustion: Intergovernmental panel on climate change

Liu, T., G. Xu, P. Cai, L. Tian, Q. Huang, (2011). Development forecast of renewable energy power generation in China and its influence on the GHG control strategy of the country. Renewable Energy, 36(4), 1284-1292. doi: 10.1016/j.renene.2010.09.020

Mahesh, A., S. Jasmin, (2013). Role of renewable energy investment in India: An alternative to CO2 mitigation. Renewable and Sustainable Energy Reviews, 26, 414-424. doi: 10.1016/j.rser.2013.05.069

Mengal, A., M. A. Uqaili, K. Harijan, A. G. Memon, (2014). Competitiveness of Wind Power with the Conventional Thermal Power Plants Using Oil and Natural Gas as Fuel in Pakistan. Energy Procedia, 52, 59-67. doi: 10.1016/j.egypro.2014.07.054

Mirza, U., N. Ahmad, T. Majeed, K. Harijan, (2007). Wind energy development in Pakistan. Renewable and Sustainable Energy Reviews, 11(9), 2179-2190. doi: 10.1016/j.rser.2006.03.003

NEPRA., (2013). State of Industry Report 2013: National Electric Power Regulatory Authority.

NREL., (2007). Wind Resource Assessment and Mapping for Afghanistan and Pakistan, National Renewable Energy Laboratory Golden, Colorado USA. Colorado USA: National Renewable Energy Laboratory Golden, Colorado USA.

Solanki1, P. S., C. Zhou, (2013). Estimation and diminution of CO2 emissions by clean development mechanism option at power sector in Oman. International journal of energy and environment, 4(4), 641-652.

Sonibare, J. A., (2010). Air pollution implications of Nigeria's present strategy on improved electricity generation. Energy Policy, 38(10), 5783-5789. doi: 10.1016/j.enpol.2010.05.029

UNFCCC., (2006). Hand Book, United Nations Framework Convention on Climate Change: United Nations Framework Convention on Climate Change.

UNFCCC., (2014a). ACM0002: Grid-connected electricity generation from renewable sources --- Version 16.0, The United Nations Framework Convention on Climate Change Retrieved 3rd March 2016, from https://cdm.unfccc.int/methodologies/DB/EY2CL7RTEHRC9V6YQHLAR6MJ6VEU83

UNFCCC., (2014b). Global Warming Potentials. Retrieved 24 Jully 2016, from http://unfccc.int/ghg_data/items/3825.php

WB., (2016). The World Bank, CO2 emissions in pakistan. Retrieved 27 September, from http://data.worldbank.org/indicator/EN.ATM.CO2E.KT?locations=PK&year_high_desc=false

Zhou, Z. Q., (2015). Effects of Climatological Model Biases on the Projection of Tropical Climate Change. Journal of Climate Change, 34(2).