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Contribution of 5.1 MW Ngong Wind Farm to Reduction of CO_2 Emissions in the Power Generation Activity in Kenya

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Abstract : ***This study was carried out to determine the contribution of 5.1MW Ngong wind farm to reduction of Carbon Dioxide (CO_2) emissions in the power generation activity in Kenya. In this study six (6) years of data was collected and Tier 1 approach of 2006 Intergovernmental Panel on Climate Change (IPCC) was applied to derive the average monthly emissions. Plant utilization factor was used to adjust for penetration of each of the fossil thermal generation technology. Analysis of the data showed that on average 0.702 Metric Tonnes of CO_2 was avoided for every MWh of wind power generated.***

Keywords-CO_2 Emissions, Wind generation, Fossil thermal generation, Fuel consumption, Plant emission factor, Plant availability.

1. Introduction

One of the positive effects of wind generation is the displacement of fossil fuel consumption in power generation. China was reducing CO_2 emissions by 741 g/kWh of wind energy generated by 2014 while USA reduced 125 Million Metric Tonnes of CO_2 emissions annually by the same year, (IEA, 2014). For the period from Nov 2008 to June 2013, the entire fleet of wind farms in Great Britain was responsible for a net emissions reduction of approximately 19MT CO_2 equivalent, (Thomson, 2014).

Carbon emissions avoided by wind energy would be determined by the carbon emissions of the marginal Plant (that which is regarded as reducing its output as a result of the additional unit of production from wind). However, there is a debate on the extent to which the variability of wind affects these reductions. Fluctuations in wind energy output will require other types of generator to be called on to balance demand; some at only part load, which result in lower efficiencies and higher greenhouse gas emissions per unit output and others by operating as very fast response peaking plant, with inherently high emissions, (Royal Academy of Engineering, 2014).

A number of studies have confirmed that wind power displaces a combination of gas and coal fired generation and the impact of part loading efficiency penalties is significant, (Thomson, 2014). However, estimates of how much wind farms reduce emissions vary widely and depend on the electricity generation mix in a region, (Nordman, 2014).

The 5.1MW Ngong wind farm was commissioned in August 2009, comprising of six (6) Vestas 850Kw wind turbines and is located on the Ngong hills, approximately 20 km from Nairobi. The wind power generation is fed into the distribution end of the electric system within the Nairobi region which because of its high population density with numerous commercial and industrial activities is also the largest electric load centre in the country. Nairobi region is also supplied with power from a combination of sources including hydro, geothermal and fossil thermal. The wind and fossil thermal generation are located within the Nairobi region while the geothermal and hydro sources are at distant locations outside the region. Owing to constraints on the electric transmission network and the need for system stability, thermal generation in Nairobi has been required to run throughout though at different dispatch levels depending on prevailing demand. Wind generation fed from the distribution end reduces the demand for thermal generation and is relatively low compared with the thermal generation. Its effect has been a small reduction on loading of various units of the thermal Plants whose capacity range from 1MW to 27MW. The effect is distributed across the various thermal Plants in Nairobi. Whereas wind power penetration is not high enough to cause a complete thermal unit shut down it resulted to thermal units operating slightly below their maximum but within their optimum efficiency range.

This study aimed at establishing the amount of CO_2 emissions avoided owing to 5.1MW Ngong wind farm power generation.

2. Materials and methods

Data for a period of six years from September 2009 to August 2015 on Plant availability, fossil thermal generation, fuel types, fuel consumption and corresponding Net Calorific Values for the thermal Plants in Nairobi region and wind generation was collected. Tier 1 approach of 2006 IPCC Guidelines for National Greenhouse Gas inventories for stationary combustion was applied to derive the monthly emissions emitted from each of the Plants, (Inter-Governmental Panel on Climate Change, 2006). The IPCC methodology approach was adjusted for penetration (Plant utilization) of each thermal Plant.

Avoided CO_2 emissions for the period of study = $\sum_{y=1}^{y=n} \textit{Annual avoided } co_2 \textit{ emissions}$.................. (Eq.1)

On basis of the consideration that penetration of wind generation is relatively low ,causing a small reduction of fossil thermal generation distributed across the various thermal Plants, whose magnitude is not adequate to cause part loading of thermal units below their optimum efficiency load levels then;

Annual avoided CO_2 emissions (MT) =

$\sum_{m=1}^{m=12}(NEO_W \times Monthly\ CO_2\ emission\ factor)\ldots$ (Eq.2)

Monthly CO_2 emission factor =

$$\sum_{tp=1}^{tp=n}\left[\frac{(F_{qty}\times NCV_{i,m}\times EF_{co2,i,m})}{NEO_{tp}}\times\frac{(NEO_{tp}/AMA_{tp})}{\sum_{tp=1}^{tp=n}\left(\frac{NEO_{tp}}{AMA_{tp}}\right)}\right]$$ .. .(Eq.3)

Where;

NEO_w = Monthly net electrical output for the wind Plant

F_{qty} = Quantity of fuel in MT consumed/burnt in thermal Power Plant tp in month m

$NCV_{i,\ m}$ =Net Calorific Value for fuel type i consumed in thermal Power Plant tp in month m in GJ/MT

$EF_{co2,\ i,\ m}$ = CO_2 emission factor of fuel type i in month m in T/GJ

NEO_{tp} = Monthly Net Electrical Output of a thermal Power Plant

AMA_{tp} = Machine Availability of thermal Power Plant tp in month m

3. Results and Discussion

3.1 Fuel consumption in power generation within Nairobi Region

The study found that for the period September 2009 to August 2015, 878,780 Metric Tonnes of Heavy Fuel Oil (HFO), and 332,668 Metric Tonnes of Automotive Gasoline Oil (AGO) and 30,716 Metric Tonnes of Jet A1 Dual Purpose Kerosene (DPK) were used in thermal generation to meet part of electric load in the Nairobi region (Figure 1).

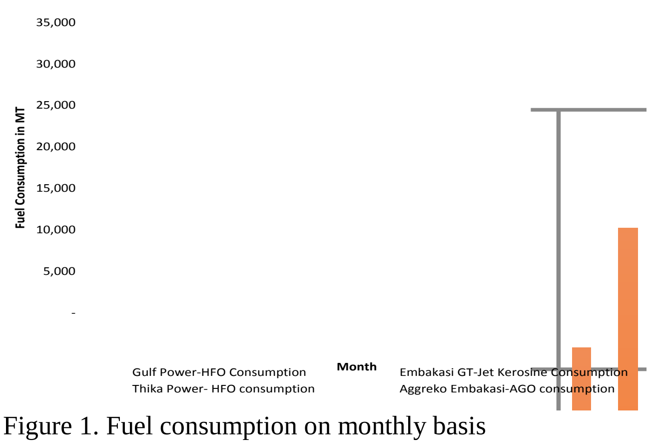

Figure 1. Fuel consumption on monthly basis

Consumption was observed to be in tandem with the Net electrical output of each respective Plant as shown on Figure 2. High consumption was observed on Iberafrica Plant which had the highest Net Electrical Output over the study period.

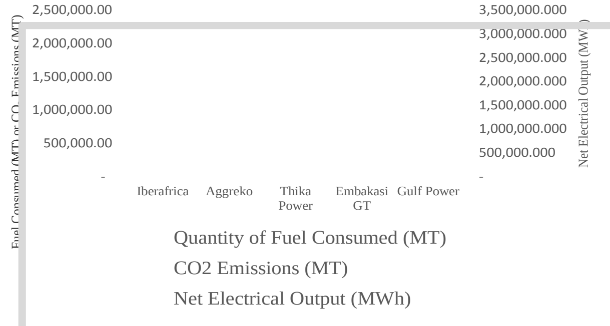

Figure 2. Fossil thermal Power Plants Fuel consumption, Co_2 Emissions and Net Electrical Output

3.2 Plant CO_2 Emission Factors

The average Plant CO_2 emission factors for the thermal plants which operated in Nairobi region over the period were obtained as shown on Figure 3. The three Power Plants exhibited different Plant CO_2 emission factors mainly because of their different specific fuel consumption rates. Though Iberafrica and Gulf Power Plants used the same type of fuel as Thika Power Plant, the latter was noted to be more efficient because it had a combined cycle comprising a steam unit which generated power using heat recovered from the exhaust fumes. Also, despite Embakasi GT using relatively clean fuel than the other Power Plants its emission factor was higher because of its relatively high specific fuel consumption rate.

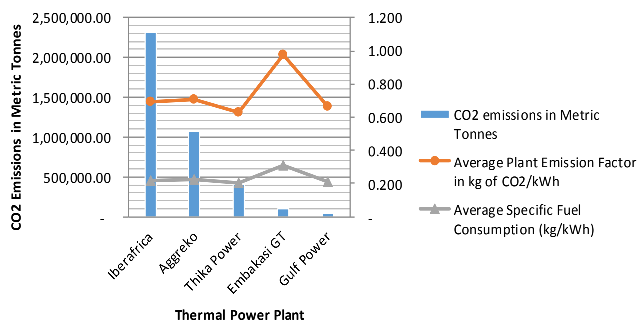

Figure 3. Comparison of Plant CO_2 Emission Factors and Average Specific Fuel Consumption rates

An annual trend on CO_2 emissions shown on Figure 4 indicated that the thermal Plants combined emission Factor was highest in 2011/2012 at 0.715kg of kg of CO_2/kWh because of generation coming from Embakasi GT which had the highest Plant Emission Factor. The decline in 2013/2014 was as a result of combined effect of generation from Thika Power which had a lower Plant Emission Factor and discontinuation of generation from Aggreko. The lowest combined Emission Factor was observed in 2014/2015 resulting from discontinuation of generation from Aggreko and reduced generation from Embakasi GT.

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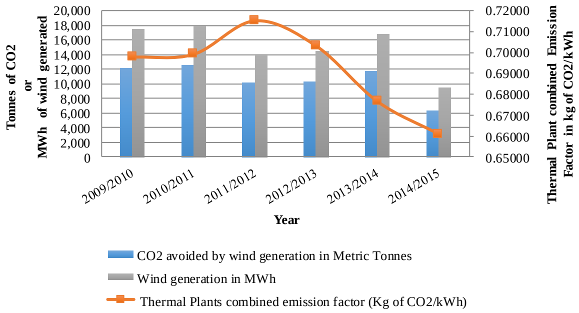

Figure 4. Annual variation of avoided CO_2 emissions, Wind generation and Thermal Plant Combined emission factor.

3.3 Avoided CO_2 emissions

Figure 5 shows the CO_2 emissions were on a downward trend from 2009/2010 to 2012/2013 owing to increased hydro energy on improved hydrology. The spike in 2013/2014 was due to low hydro power on poor hydrology whereas the sharp decline in 2014/2015 was due to increased geothermal energy from enhanced geothermal capacity. Also, the CO_2 avoided owing to wind power generation was observed to be below 2.5% of the combined emissions on all the years in the study period. This was as a result of low penetration of wind power into the Nairobi region compared to penetration of thermal power. A total of 63,196MT of CO_2 was avoided from September 2009 to August 2015 which translates to 10,533MT of CO_2 annual average.

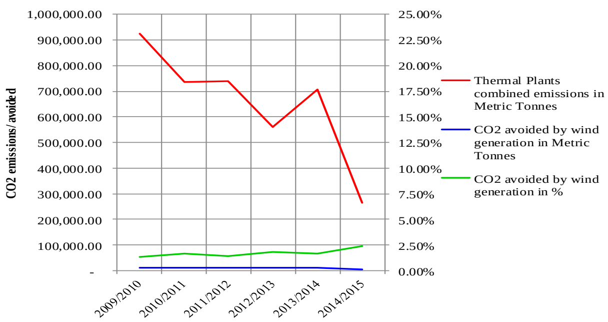

Figure 5. Annual variation of CO_2 emissions and CO_2 avoided by wind generation

4. Conclusion

The study found that on average 0.702 Metric Tonnes of CO_2 was avoided for every MWh of wind power generated. This translate to annual average of 10,533MT of CO_2 and a total of 63,196MT of CO_2 being avoided from September 2009 to August 2015.

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