Research Article
RET Screen Assessment of Utility Scale Wind Power Generation Based on Historical Wind Speed Data-the Case of Mankoadze in the Central Region of Ghana

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Abstract: With cost being a vital factor for determining how feasible any power project will be, this study demonstrates that a 50 MW grid-connected wind power plant at Mankoadze in the Central Region of Ghana will be technically and financially viable and competitive at a certain minimum feed-in-tariff together with some incentives. In this study, we analyzed monthly mean wind speed data for Mankoadze at 12 m above ground level (a.g.l.) with RET Screen Wind Energy Project Model. The monthly mean wind speeds at 12 m a.g.l. were extrapolated to 80 m a.g.l. and used to determine the annual energy production of a 50 MW wind farm. The total initial cost of the 50 MW wind power project was estimated and the minimum feed-in-tariff at which the project will be financially viable over a duration of 20 years was ascertained from Net Present Value (NPV) calculations. This minimum feed-in-tariff was again determined for different scenarios of grants and incentives and some recommendations were made.

Keywords: Feed-in-tariff, net present value, wind energy, wind resource assessment

INTRODUCTION

The worldwide demand for energy keeps increasing and this is particularly true in most rapidly developing economies (Akpinar and Akpinar, 2009; Mirza *et al.*, 2007). Clean energy will continue to be the focus of the future as there has been evidence of extreme weather events associated with climate change as a result of conventional energy use (IPCC, 2012). In view of the problems surrounding the supplies of conventional fossil fuels and their volatile prices, wind energy is an indigenous power source which is permanently available in every country in the world (Akpinar and Akpinar, 2005). There are no fuel costs and no supply dependence on imported fuels from politically unstable fuel exporting regions. Wind energy is an abundant, clean, environmentally friendly and inexhaustible energy source (Hanitsch and Shata, 2008). Globally, the wind power industry is in an era of substantial growth as a result of advances in technology and is set to expand as the world looks for cleaner and more sustainable ways to generate electricity (Kollu *et al.*, 2012). From a total cumulative capacity of 14 GW by the end of 1999, the global installed wind power capacity increased to almost 160 GW by the end of 2009 (Wiser *et al.*, 2011). In 2011, wind power accounted for 28% of electricity production in Denmark (Megavind, 2012). In the same year, wind power accounted for 15.7% of electricity production in Spain and 7.8% in Germany (GWEC, 2011).The idea that wind power will play a substantial role in the global energy future has begun to take hold as major potential for growth is seen in Latin America, Asia and especially Africa in the medium to long term (GWEC, 2012).

Ghana as a country has a combination of hydro and thermal power generating sources and has been affected by years of periodic power crisis as shown in Fig. 1 due to increasing energy demand and extensive reliance on the hydroelectric power. The first power crisis occurred in 1984 and was caused by drought whose impacts were felt throughout the West African sub-region (Brew-Hammond and Kemausuor, 2007). The second and third power crises occurred in 1998 and 2002 and were also attributed to low rainfall in the Volta basin (Brew-Hammond and Kemausuor, 2007). The fourth which occurred in 2006 was due more to the shortage of generation capacity in the country than to low levels of water in the Volta Lake Reservoir (Brew-Hammond and Kemausuor, 2007). In 2012, Ghana suffered another power crisis as a result of difficulties in the supply of gas from the West African Gas Pipeline to fuel some of the thermal power plants and this led to a national load shedding exercise with far reaching implications. To forestall the effect of unreliable rainfall and erratic gas supply on the country's power

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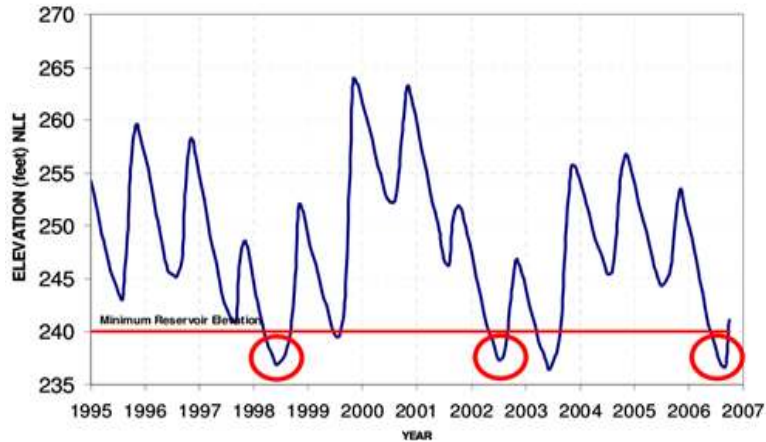
Fig. 1: Water levels in the Volta lake reservoir (crisis years circled): (Brew-Hammond and Kemausuor, 2007)

Fig. 2: Location of Mankoadze on Ghana map. Slightly modified map from (CIA, 2012)

generation system, there is the need to vigorously consider other generation sources, preferably renewable energy sources, to cater for current and future power demand. This can only be done after thorough analyses are performed to determine the power potential that could be provided by the various renewable energy sources in the country.

Wind speed measurements made in the past especially along the coast of Ghana show good wind regimes capable of generating power. Akuffo *et al.* (2003), a consultancy work between Kwame Nkrumah University of Science and Technology (KNUST) and the Ghana Energy Commission, presents monthly average wind speed data for several coastal sites east and west of the meridian including Adafoah, Lolonya, Pute, Kpone, Asemkow, Warabeba, Mankoadze, Bortianor and Aplaku. Results of these monthly data show that annual mean wind speed for the above mentioned areas reach levels of 6.1 m/sec at 12 m a.g.l. This means even much higher wind speeds at higher levels above the ground due to wind shear. Again, the National Renewable Energy Laboratory (NREL) of the

Untited States (U.S.) Department of Energy has also published a satellite wind map for Ghana at 50 m a.g.l. (NREL, 2013). This wind map was computed from Satellite Ocean Wind Measurement conducted by U.S. satellites between 1988 and 1994. The NREL map for Ghana shows wind speeds between 6.2 and 7.1 m/sec for the coasts of Central, Greater Accra and Volta Regions. This map equally shows much more potential off-shore. Despite the available ground measured wind speed data for Mankoadze, no vigorous analyses of utility power generation and associated costs implications have been made so far. There is still a knowledge gap between possible power generation with typical wind turbines and levels of feed-in-tariff for financial viability. This study uses RETScreen wind energy project model to demonstrate that a 50 MW utility scale power can be generated based on the wind speed data for Mankoadze which had the highest values among all the other sites. This study further shows that the wind power generation can be financially viable and competitive under certain favourable conditions. The scope of this research is limited to annual energy production from a 50 MW wind farm based on the Mankoadze wind speed data and calculation of the minimum feed-in-tariff for financial viability with NPV being the main parameter of interest (Fig. 2).

RESEARCH METHODOLOGY

Overview of methodology: Nineteen months duration wind speed data at 12 m a.g.l. for Mankoadze was extrapolated to 80 m a.g.l. using the power law. This extrapolated data was used together with twenty units of 2.5 MW Nordex N80/2500 wind turbines for grid-connected energy production estimation and financial analyses in the RET Screen wind energy project model. The annual energy production of the 50 MW wind farm and the associated capacity factor were estimated. The total initial cost estimate of the wind project was made and financial analyses were performed to determine viable minimum feed-in-tariffs for variations in a combination of grants and incentives based on NPV calculations. Positive figures for NPV indicated project financial viability whiles negative figures indicated financial non-viability. These estimated minimum feed-in-tariffs were compared with the current bulk supply tariff for utility power generation in Ghana and some recommendations were made. Other further recommendations were made as to how Ghana could gradually utilize and develop its wind energy resources to help address the national growth in energy demand towards a sustainable future.

Wind speed data extrapolation technique: The power law is an expression for predicting wind speeds at higher heights from wind speeds known at lower heights above ground level (Mathew and Philip, 2011). The power law as expressed by Ohunakin *et al.* (2013) is defined mathematically in Eq. (1):

$$\frac{U_h}{U_{ho}} = \left(\frac{h}{ho}\right)^{\alpha} \tag{1}$$

where,

h = The height at which wind speed U_h is to be estimated

h_0 = The height at which wind speed U_{h0} was measured

α = The wind shear exponent (Koçak, 2002) gives a mathematical relationship to estimate the wind shear exponent and is expressed in Eq. (2):

$$\alpha = \frac{(0.37 - 0.088 ln U_{ho})}{\left(1 - 0.088 ln\left(\frac{ho}{10}\right)\right)} \tag{2}$$

The power law has been widely used by several others in various wind power analyses (Jowder, 2009; Albadi *et al.*, 2009; Rehman and Al-Abbadi, 2008; Cancino-Solórzano and Xiberta-Bernat, 2009).

Wind turbine characteristics: Nordex N80/2500 wind turbines were used for the analysis. Each turbine had a rated power of 2.5 MW and 20 units were combined to give the desired capacity of 50 MW. The technical characteristics of each wind turbine and the power curve as defined by Nordex (2009) are respectively given in Table 1 and Fig. 3.

Useful renewable energy production and capacity factor: The collected renewable energy, as expressed by Natural Resources Canada (2004a) is the net energy

Table 1: Technical characteristics of nordex N80/2500 wind turbine

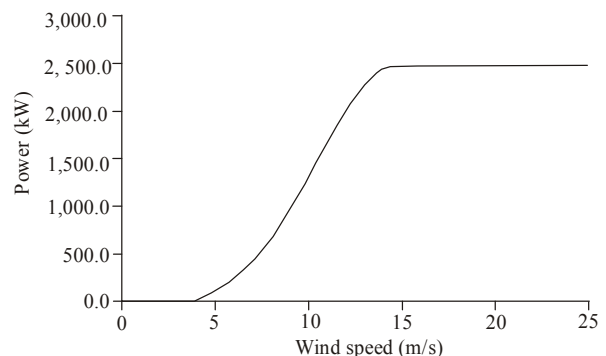| Nordex N80/2500	
Number of rotor blades	3
Hub height	80 m
Rotor diameter	80 m
Swept area	5026 m^2
Cut-in wind speed	Approximately 3 m/sec
Cut-out wind speed	25 m/sec
Rated speed	15 m/sec

(Nordex, 2009)

Fig. 3: Power curve for nordex N80/2500 wind turbine: reconstructed from (Nordex, 2009)

produced by the wind turbines. It is defined mathematically in Eq. (3) (Natural Resources Canada, 2004a):

$$E_c = E_G \times C_L \tag{3}$$

where,
E_C = The renewable energy collected
E_G = The gross energy production
C_L = The losses coefficient

The Losses Coefficient (C_L) is expressed mathematically in Eq. (4) (Natural Resources Canada, 2004a):

$$C_L = (1 - \lambda_a) \times (1 - \lambda_{s\&i}) \times (1 - \lambda_d) \times (1 - \lambda_m) \tag{4}$$

where,
λ_a = Array losses
$\lambda_{s\&i}$ = Airfoil soiling and icing losses
λ_d = Downtime losses
λ_m = Miscellaneous losses

The capacity factor, as defined by Mathew and Philip (2011) as the ratio of the energy actually produced by the wind turbines to the energy that could have been produced if the turbines were to operate at their rated power throughout the time period, is expressed mathematically in Eq. (5):

$$C_F = \left(\frac{E_A}{P_R \times T}\right) \times 100 \tag{5}$$

where,
C_F = The capacity factor
E_A = The actual energy produced by the wind turbines
P_R = The rated power capacity of the wind turbines
T = The duration of operation in hours

Total initial cost estimation: The total initial cost estimate for the wind power project was made partly in line with the experiences of NEK Ghana Limited, a subsidiary of NEK Umweltechnik AG and a company that has some expertise in wind resource assessmentat Prampram in Ghana. The breakdown of the total initial cost estimate is presented in Eq. (6):

$$Total\ initial\ cost = (FS) + (PD) + (E) + (PS) + (BM) \tag{6}$$

where,
FS = Cost related to feasibility studies
PD = Cost related to project development
E = Cost related to engineering
PS = Cost related to the power system
BM = Cost related to the balance of system and miscellaneous

Net present value: Net present value is an indicator of how much value is added to an investment as a positive NPV figure indicates the economic viability of an investment under specified conditions of discount rate and the economic life time of an investment (Natural Resources Canada, 2004b). NPV as defined by Natural Resources Canada (2005) is expressed mathematically in Eq. (7):

$$NPV = \sum_{t=0}^{N} \frac{C}{(1+d)^t} \tag{7}$$

where,
C = The net cash flow (revenue + savings - expenses) in year t
d = The discount rate
N = The economic life time of the investment

RET screen wind energy project model: The RET Screen wind energy project model is an internationally acknowledged model used to evaluate the energy production and life-cycle costs of wind energy projects ranging in size from large-scale to small-scale wind farms, including single-turbine wind power systems (Georgilakis, 2008). The RETScreen wind energy project model has helped to facilitate several worldwide projects including a $210 million 100 MW wind energy project by the Sustainable Energy Authority of Ireland (Leng *et al.*, 2004). Several others like Himri *et al.* (2012), Rehman and Al-Abbadi (2007) and Rehman (2005) have used RET Screen for various wind energy related analyses. Details on how to use the RET Screen wind energy model can be found at "www. retscreen. net".

RESULTS AND DISCUSSION

Measured wind speed data for Mankoadze: Mankoadze is a village in the Central Region of Ghana and located at Latitude 5.20° N and Longitude 0.41° W (Google, 2013). Figure 2 shows the location of Mankoadze on map. Monthly average wind speed data for Mankoadze for the period of data collection (January 2001 to July 2002) as presented by Akuffo *et al.* (2003) and as graphed in Fig. 4, shows the lowest and highest mean wind speeds of 4.4 m/sec for January and 8.3 m/sec for April respectively at 12 m a.g.l.

Extrapolated wind speed data for Mankoadze: The wind shear exponent, calculated with Eq. (2) based on the annual mean wind speed and found to be 0.213 was used together with the power law (Eq. (1)) to extrapolate the measured wind speed data to 80 m a.g.l. The extrapolated results are presented on a monthly basis in Fig. 5. The extrapolated data has an annual mean wind speed of 9.2 m/sec with April registering the highest average figure of 12.4 m/sec and January recording the lowest value of 6.6 m/sec.
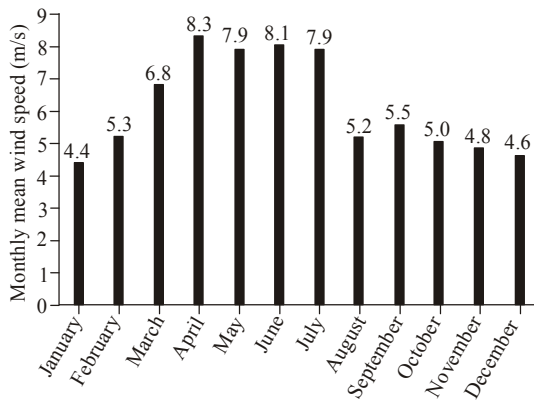
Fig. 4: Monthly mean wind speed variation at Mankoadze (12 m a.g.l.) (Akuffo *et al*., 2003)
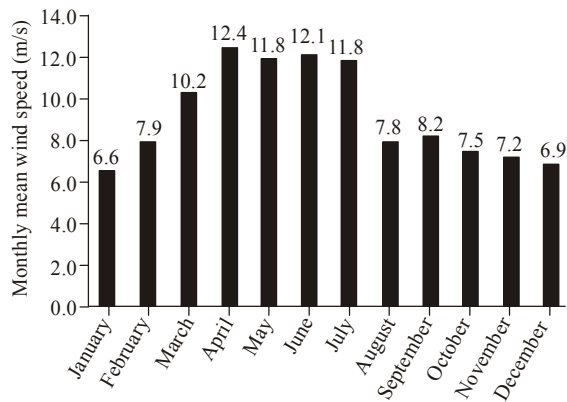

Fig. 5: Extrapolated wind speed data for Mankoadze (80 m a.g.l.)

Wind farm energy production and capacity factor: The annual energy production of the 50 MW wind farm at 80 m a.g.l. as computed in RET Screen is 121.7 GWh. This energy is generated at a capacity factor of 27.8%. The computations were made with wind farm availability, array, airfoil and miscellaneous losses of 98, 10, 5 and 3%, respectively. These assumptions are typical values for standard wind farms across the world (Natural Resources Canada, 2004b).

Significance of the extrapolated wind speed data and the energy production: Stankovic *et al*. (2009) reports that wind turbines are economical with annual average wind speed of 5.5 m/sec or more at hub height. The annual mean wind speed computed in this study of 9.2 m/sec at 80 m a.g.l. is far more than this economical minimum wind speed. This indicates positive economic prospects for wind energy utilization at the data location. Goransson and Johnsson (2009) reports that despite high availability of modern wind turbines, the capacity factor rarely reaches beyond 30% for onshore wind power. Again, GWEC (2012) reports that average capacity factors globally today are about 28%, but
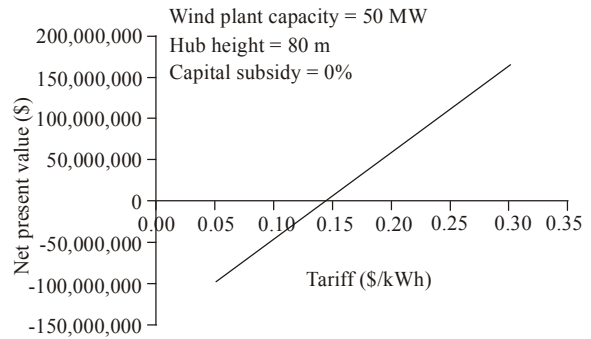

Fig. 6: Effect of 0% grant/capital subsidy on NPV for Mankoadze

varies widely from region to region. In addition, French wind farms produced power with an average capacity factor of 24% in 2008 (GWEC, 2008). These facts attest that the capacity factor figure of 27.8% estimated in this study falls in line with typical wind farm capacity factors around the world.

Financial analyses: The initial costs related to the wind energy project include that for preparing a feasibility study, performing the project development functions, completing the necessary engineering, purchasing and installing the wind energy equipment, construction of the balance of plant and costs for any other miscellaneous items. Most of the cost estimates used in this analysis were guided by the experiences of NEK Ghana Limited, a subsidiary of NEK Umweltechnik AG, a company that has some expertise in wind resource assessment in Ghana. The total initial cost estimate for the 50 MW wind power project is $116,762,250. The revenue for this grid connected wind power project was assumed to come from a fixed feed-in-tariff throughout a project life of 20 years. Different feed-in-tariffs (a range of $ 0.05 to 0.30/kWh) were used for the computations to determine their effect on NPV at a discount rate of 10% and for different levels of grants/capital subsidies. The results of the effect of feed-in-tariff on NPV for different capital subsidies of 0, 40 and 80% are shown in Fig. 6 to 8, respectively. Figure 6 shows that without capital subsidy, the wind power project will be financially viable at a minimum feed-in-tariff of $ 0.15/kWh. Figure 7 shows that at 40% capital subsidy, the wind power project will be financially viable at a minimum feed-in-tariff of $ 0.10/kWh. Figure 8 shows that at 80% capital subsidy, the wind project will be financially viable at a minimum feed-in-tariff of $ 0.06/kWh.

Significance of the financial analyses: The current highest bulk supply tariff as published by the Public Utilities Regulatory Commission of Ghana is GH¢0.16/kWh (PURC, 2011). At the current currency exchange rate of $1 = GH¢1.99 (Bank of Ghana, 2013),
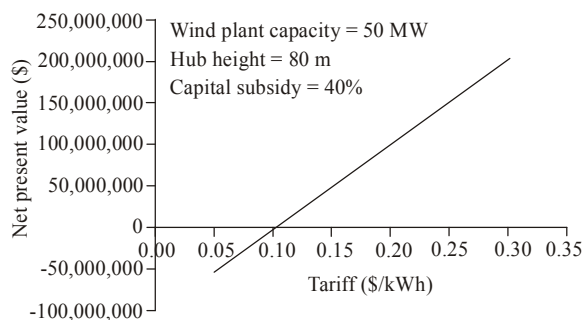
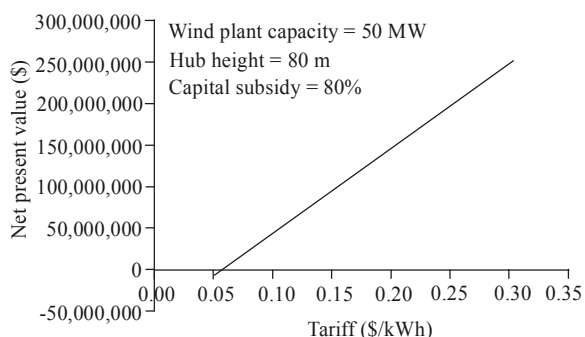Fig. 7: Effect of 40% grant/capital subsidy on NPV for Mankoadze

Fig. 8: Effect of 80% grant/capital subsidy on NPV for Mankoadze

GH¢0.16/kWh translates to $ 0.08/kWh. This PURC highest bulk supply tariff of $ 0.08/kWh is lower than the feed-in-tariff estimates made in this study, except for the analysis made for the 80% capital subsidy. From the context of this analysis, it is evident that for this wind project to be financially feasible in the Ghanaian framework, there should either be a minimum of 80% capital subsidy, a separate negotiations for feed-in-tariff charges, or exploration of other sources of revenue. The wind farm could be blended with agricultural purposes or used as a tourism site to create additional revenue. The wind project could again be considered partly for carbon credits in order to derive financial benefits from the greenhouse gas emission savings throughout the project life.

CONCLUSION AND RECOMMENDATIONS

In the mist of efforts made by some individual countries to explore clean energy sources for ultimate benefit, wind energy still remains widely untapped in Ghana despite the promising potential. Historical ground wind speed measurements show potential for wind power generation in Ghana, especially along the coastal areas, based on moderate annual mean wind speed figures at low levels. This study, with the aid of RET Screen, further analyzed wind speed data for Mankoadze, a coastal town in the Central Region of

Ghana, estimated wind energy generation of a 50 MW wind farm at 80 m a.g.l. and further reported on the associated financial implications. Analysis of extrapolated wind speed data at 80 m a.g.l. for nineteen months gave an annual mean figure of 9.2 m/sec with April registering the highest average of 12.4 m/sec and January registering the lowest average of 6.6 m/sec. The annual energy production of the 50 MW wind farm at 80 m a.g.l. as computed in RET Screen was 121.7 GWh with an associated capacity factor of 27.8%. The implementation of the said 50 MW wind farm will require substantial capital of over $100 million. With feed-in-tariffs being the only source of revenue and without capital subsidy, it was estimated that this wind power project will be financially viable at a minimum feed-in-tariff of $0.15/kWh. With capital subsidies of 40 and 80%, the wind project will be financially viable at minimum feed-in-tariffs of $ 0.10 and 0.06/kWh, respectively. The current Public Utilities Regulatory Commission of Ghana's highest bulk supply tariff of $ 0.08/kWh is lower than the feed-in-tariff estimates made for the analyses with 0 and 40% capital subsidies. From the context of this analysis, for this wind project to be financially feasible in the Ghanaian situation, there should either be about 80% capital subsidy, separate negotiations for feed-in-tariffs, or exploration of other sources of revenue. The land for the wind farm could be blended with agricultural purposes or used as a tourist site to create additional revenue. The analyses made in this study is based on extrapolated wind speed at 80 m a.g.l. which may not necessarily be the same as actual measured wind speed at that same height. It is recommended that wind speed measurements be made at Mankoadze at 80 m a.g.l. and compared with the analyses in this study.

ABBREVIATIONS

$	:	United States Dollars
a.g.l.	:	Above Ground Level
CIA	:	Central Intelligence Agency
GW	:	Gigawatts
GWEC	:	Global Wind Energy Council
IPCC	:	Intergovernmental Panel on Climate Change
KNUST	:	Kwame Nkrumah University of Science and Technology
kWh	:	Kilowatt hours
m	:	Meters
MW	:	Megawatts
NPV	:	Net Present Value
NREL	:	National Renewable Energy Laboratory
PURC	:	Public Utilities Regulatory Commission

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