The potential and economic viability of wind farms in Ghana

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ABSTRACT

The current load shedding in Ghana has led to decreasing productivity leading to economic and social crisis due to Ghana's dependency on hydroelectric power as its main source of power. Incorporating renewable energy sources to the grid installed capacity will ease the burden on Ghanaians. In this study, the potentiality and economic feasibility of wind farm project were evaluated in 11 locations in Ghana. The study employed wind-speed data using meteonorm 7 software in a Typical Meteorological Year 2 format and analyzed with RETScreen Clean Energy Project Analysis modeling software. 10 MW of VESTAS V90 Wind turbine model with a rated power of 2,000 kW was proposed, which, when developed and harnessed, will drastically boost productivity of businesses, industries, and the transport sector in Ghana whilst making significant contribution to the export earnings of the country.

Article History

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Keywords

Capacity factor; Ghana; renewable energy; wind energy; wind speed

Introduction

There is a growing need for clean energy technologies throughout the world due to a global decline in fossil fuel reserves, which results in greenhouse gas emissions leading to global warming. Solar energy is one of the cleanest alternative sources of renewable energy regardless of its initial capital and land use.

Africa is rich in energy resources but poor in its supply. The Sub-Saharan Africa accounts for 13% of the world’s population, but only 4% of its population have access to energy. However, there is a rapid growth of economy and energy by 45% since 2000 (International Energy Agency 2014). Wind potential for Sub-Saharan Africa is estimated at about 1,300 GW, which will produce more than the current level of total African electricity consumption (Mandelli et al. 2014).

Ghana’s dependency on hydroelectric power supply dates back to the 1960s but is currently supported by thermal power. In 2012, the total grid electricity generated in Ghana was 12,164 GWh (8,071 GWh (66%) of hydropower and 4,093 GWh (34%) of thermal power) as against 11,200 GWh in 2011. Ghana’s Renewable Energy Development Programme aims to assess the availability of renewable energy resources; to examine the technical feasibility and cost-effectiveness of promising renewable energy technologies; to ensure the efficient production and use of the country’s renewable energy resources; and to develop the relevant information base that will facilitate the establishment of a planning framework for the rational development and use of the country’s renewable energy resources (Gboney 2009).

In 2002, “Solar and Wind Resource Assessment” (SWERA) Ghana project assessed the wind energy resources in Ghana and concluded that Ghana has wind resource potential (Energy Commission 2012). However, extensive scientific research is limited within the scope of assessing wind farm potentials in Ghana. Currently, Adaramola et al. (2014) have assessed the wind power generation along the coast of Ghana with six selected stations but unfortunately the rest of the regions in the country were excluded from their study.

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Against this backdrop, the study assesses the potentiality and economic feasibility of wind farm project in Ghana from 11 stations, namely Cape coast, Takoradi, Axim, Elmina, Tema, Oshiyie, Warebeba, Aplaku, Adafoah, Anloga, and Mankoadze. This study will bring to bear the wind energy resource potentials, their economic feasibilities in Ghana, and how it can be harnessed and incorporated into the existing energy portfolio to help ease the recent energy crisis.

**Materials and methods**

Wind speed data for the 11 locations in Ghana were generated in a Typical Meteorological Year 2 (TMY2) data format using Meteonorm 7 software and were further analyzed with RETScreen Clean Energy Project Analysis modeling software. Ghana uses Greenwich Meridian Time without daylight savings (GMT +0), therefore a Typical Meteorological Year 2 (TMY2) data set is suitable because it uses local standard clock time. As a result of atmospheric losses due to varying meteorological conditions, a better option for wind speed data was to use Typical Meteorological Year (TMY) data set because of its accuracy (Nrel.gov). However, due to the absence of a TMY, a synthetic TMY2 developed by NREL was employed in this study. Mathematical details are not given in this report for brevity since they are available in existing literature.

The RETScreen modeling software by National Resource Canada employed in the study is capable of analyzing and assessing the energy production, energy production cost and savings, greenhouse gas emission reduction, life cycle costs, operation and maintenance cost, and financial feasibility of the wind power system. The selection of the locations is based on the availability of data from Meteonorm 7 software, NASA global solar radiation database, and their accessibility to the national grid. In Table 1, the geographical coordinates of 11 locations in Ghana selected for the study are given.

To estimate the wind energy potential, there is the need to accentuate its challenges, such as array losses, airfoil soiling and/or icing losses, miscellaneous losses, and downtime losses. Other related coefficients such as pressure adjustment, temperature adjustment, and wind shear exponent were also considered. In Table 2, the wind energy losses, its related coefficients, and the technical specifications of the wind turbine used in energy yield estimation are given.

**Results and discussion**

VESTAS V90-2.0 MW wind turbine model was used for wind turbine performance analysis, economic analysis, and emission analysis. This turbine model was selected because of its support for load and power modes, which in turn maximizes energy production under specific wind and site conditions. In addition to this, the turbine can be configured to run de-rated when wind conditions require it. Moreover, under mild wind conditions, the turbine can be uprated thus maximizing annual energy production (Vestas).

In Figure 1 (a), the gross energy production (MWh) of VESTAS V90 Wind turbine model with a rated power of 2,000 kW is given. It is evident that five locations, namely Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba, together produce energy between 5,000 and 6,000 MWh whilst...
The remaining six locations produce below 2,000 MWh. This is because the wind turbine model has a relatively high cut-in speed and high rated wind speeds, which only favors sites with high wind speed regimes such as the five locations in this study, namely; Takoradi, Adafoah, Cape coast, Mankoadze and Warebeba. The potential for wind energy development for the remaining six locations, namely Aplaku, Axim, Anloga, Elmina, Oshiyie, and Tema, is limited. However, there are potentials for low capacity wind turbines for these locations.

In Figure 1(b), the specific yield (kWh/m^2) of the wind turbine in 11 locations in Ghana is given. Specific yield is a more precise measurement for calculating the cost of wind energy (price per kilowatt-hour) since it measures the annual energy output per square meter of area swept by the turbine blades as they rotate (Windenergyfoundation.org). It is evident that five locations, namely

Table 2. Wind energy losses, its related coefficients, and specifications of the wind turbine used in the estimation of energy yield.

| Variable                               | Estimate |
|----------------------------------------|----------|
| Wind shear exponent                    | 0.14     |
| Array losses                           | 7%       |
| Airfoil soiling and/or icing losses    | 3%       |
| Miscellaneous losses                   | 5%       |
| Downtime losses                        | 10%      |
| Availability                           | 94%      |
| Temperature adjustment coefficient     | 0.96     |

| Parameter                           | Unit |
|-------------------------------------|------|
| Cut-in wind speed                   | m/s  |
| Rated wind speed                    | m/s  |
| Cut-out wind speed                  | m/s  |
| Hub height                          | m    |
| Rotor diameter                      | m    |
| Swept area                          | m^2  |

Figure 1. A comparison of (a) gross energy production, (b) specific yield, (c) energy exported to the grid, and (d) capacity factor, for the 11 stations in Ghana.
Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba, together produce an annual energy between 600 and 800 kWh/m$^2$ whilst the remaining six locations produce less than 200 kWh/m$^2$. This is because specific yield (kWh/m$^2$) is directly proportional to the wind speed regime and capacity factor of the wind turbine.

In Figure 1(c), the energy export (MWh) to the grid is given. In the same vein, Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are the locations that have the highest energy between 4,000 and 5,000 MWh, which can be exported to grid system, whilst the remaining six locations produce less than 2,000 MWh of energy, which can be exported to the grid.

In Figure 1(d), the capacity factors of the wind turbine for the 11 stations in Ghana are given. Capacity factor of wind power is vital information for stakeholders, both public and private, during decision-making toward the investment of this renewable energy potential. In view of this, only five locations, namely Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba, obey the 21% by European Union (Boccard 2009) and 22.5% by GRUBB (1993). These locations have a capacity factor of 23.9%, 27.3%, 27.2%, 27.3%, and 27.3%, respectively. The capacity factor of the remaining locations is below 10%, which is not a good sign of economic investment.

At this juncture, it is necessary to consider the five outstanding locations, namely Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba. The land cover for wind turbine installation is of vital importance due to its correlation with specific yield (kWh/m$^2$). According to Tom Gray’s rule of thumb, 60 acres per megawatt (242,811 m$^2$/MW) is advisable for a wind farm on land (Aweo.org). Therefore, for the five locations, 600 acres (2.43 km$^2$) of land is required for VESTAS V90-2.0 MW.

**Financial analysis**

Economic analysis for wind turbine project is as crucial as capacity factor for decision-making bodies in both public and private sector investment. The RETScreen Clean Energy Project Analysis modeling software is capable of performing financial analysis based on financial parameters such as project lifetime, inflation rate, debt interest rate, energy cost, greenhouse gas emission credit, energy cost escalation rate, etc.

In order to calculate the cost of electricity, the following assumptions are made. In Table 3, the summary of financial input parameters for cost analysis are given. Unless otherwise stated, input parameters are sourced from RETScreen Clean Energy Project Analysis modeling software.

Cost analysis was categorized into three sections; before, during, and after the wind power project. Before the wind power project was undertaken, the following were taken into consideration: a feasibility study that included site investigation, resource assessment, environmental assessment, preliminary design, detailed cost estimate, greenhouse gases baseline study, report preparation, project management, and travel and accommodation; development, which included contract negotiation, permits and approval, site survey and land rights, greenhouse gases validation and registration, project financing, legal and accounting, project management, and travel and accommodation. During the wind power project implementation, the following were considered: engineering, which included site and building design, mechanical design, electrical design, civil design, tenders and contracting, construction supervision; power system: wind turbine, and transmission lines; balance of system and miscellaneous, which included specific project costs, wind turbine foundation, wind turbine erection, spare parts, transportation, training and commissioning, and contingencies.

After completion of the wind power project, the following were considered in the cost analysis: operation and maintenance cost, which included land lease and resource rental, property taxes, insurance premium, parts and labor, contingencies; and periodic costs, which included parts and labor. From our analysis, it is evident that 10 MW of wind power project investment in the five locations in Ghana requires not less than US$33,000,000.

In Figure 2 (a), the net present value for wind power project in the five selected locations in Ghana is given. The net present value for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are: $1,657,369, $2,351,310, $2,325,761, $2,343,736, and $2,343,630, respectively. A positive net
The present value shows that the wind power projects in Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are profitable and as such worth investing.

In Figure 2(b), the simple payback period and benefit–cost ratio for wind power project in the five selected locations in Ghana are given. The simple payback for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are 5.6, 4.9, 4.9, 4.9, and 4.9 years, respectively. The benefit–cost ratio for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are 2.36, 2.94, 2.91, 2.93, and 2.93. A benefit–cost ratio for the project in all the five location shows a positive value greater than 1, which gives a signal that the benefits of the wind power project outweighs its cost. A shorter simple payback period means a desirable investment (Himri, Stambouli, and Draoui 2009). Takoradi has the longest simple payback time of about 6 years yet, since the benefit–cost ratio is twice more than the initial investment and the project lifetime is 20 years; however, it is still worth investing in.

### Table 3. Summary of financial input parameters for cost analysis (RETScreen).

| Item                                      | Value        |
|-------------------------------------------|--------------|
| Installed capital cost                    | US$1,200/kW  |
| Feasibility study                         | US$35,300    |
| Development                               | US$63/kW (Nrel.gov) |
| Engineering                               | US$24/kW (Nrel.gov) |
| Balance of plant                          | US$418/kW (Nrel.gov) |
| Annual operating expenses                 | 10 $/kW/year |
| Miscellaneous/contingency fund            | US$418/kW (Nrel.gov) |
| Avoided cost of energy                    | 0.0950 $/kWh |
| Renewable energy production credit        | 0.025 $/kWh  |
| Renewable energy production credit duration | 10 years    |
| Renewable energy credit escalation rate   | 2.5%         |
| GHG emission reduction credit             | 5 $/t CO₂    |
| GHG reduction credit                      | 21 years     |
| GHG credit escalation rate                | 0%           |
| Energy cost escalation rate               | 5%           |
| Inflation rate                            | 10.4% ((BoG))|
| Interest rate                             | 15% (BoG)    |
| Nominal discount rate                     | 8% (Nrel.gov) |
| Real discount rate                        | 5.7% (Nrel.gov) |
| Project lifetime                          | 20 years (Nrel.gov) |

Figure 2. A comparison of (a) net present value, (b) simple payback, (c) net annual GHG emission reduction, and (d) energy production cost, for five stations in Ghana.
In Figure 2(c), the net annual greenhouse gas emission reduction for the wind power project in all the five locations in Ghana is given. Net annual greenhouse gas emission reduction for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are 1,667, 1,902, 1,893, 1,899, and 1,899 tCO$_2$/year, respectively. Africa’s role in global greenhouse-gas emissions may be relatively limited, but its involvement in the issue is pronounced (International Energy Agency 2014). In particular, temperatures across the continent are projected to rise faster than the global average (James and Washington 2013). In this era of quest for clean energy technologies, a wind power project that is efficient in reducing greenhouse gas emission is the most effective and worth investing in. According to IPCC (2011), wind energy offers significant potential for near- and long-term GHG emissions reduction given the commercial maturity and the cost of the wind energy project.

In Figure 2(d), the energy production cost for wind power project in the five locations is given. The energy production cost for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are $92.78/MWh, $81.30/MWh, $81.67/MWh, $81.41/MWh, and $81.41/MWh, respectively. In 2012, the cost of energy production in Sub-Saharan Africa including Ghana was $115/MWh without losses and other power supply related cost, which can add further $50–$80/MWh to consumers (International Energy Agency 2014). This is to say that this wind power project is good for investment.

Conclusions

In this study, the potentiality and economic feasibility of wind farm project were evaluated in 11 locations in Ghana. Because wind power projects are capital intensive, only five locations with capacity factor greater than 22% were selected for performance evaluation and financial analysis. The study employed wind-speed data from 1991 to 2010 using the meteonorm 7 software into a Typical Meteorological Year 2 (TMY2) format and analyzed with RETScreen Clean Energy Project Analysis modeling software designed by Natural Resources Canada. A summary of findings from the study are as follows:

- The gross energy production (MWh) of VESTAS V90 The wind turbine model with a rated power of 2,000 kW, cut-in wind speed of 4 m/s, cut-out wind speed of 25 m/s, and hub height 105 m produces energy between 5,000 and 6,000 MWh for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba. In the same vein, 4,000–5,000 MWh of energy can be exported to grid system.
- The potential for wind energy development for the remaining six locations, namely Aplaku, Axim, Anloga, Elmina, Oshiyie, and Tema, is limited. However, there are wind energy potentials for low capacity wind turbines that can be utilized for these locations.
- To utilize the 10 MW of wind energy proposed in this study, 600 acres (2.43 km$^2$) of land is required for VESTAS V90-2.0 MW.
- The energy production costs for Takoradi, Adafoah, Cape coast, Mankoadze, and Warebeba are $92.78/MWh, $81.3/MWh, $81.67/MWh, $81.41/MWh, and $81.41/MWh, which are lower compared to the energy production cost in Sub-Saharan Africa including Ghana at $115/MWh without losses and other power supply related costs, which can add further $50–$80/MWh to consumers.

From the study, 10 MW of wind energy was proposed yet, more can be exploited if there are more public and private sector investments and the projects are undertaken without financial constraints. Developing and harnessing this renewable energy potential will drastically boost productivity of businesses, industries, and the transport sector while making significant contribution to the export earnings of the country.

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