THE AVAILABILITY OF WIND ENERGY IN THE AFRICAN CONTINENT

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Abstract

Wind is a form of renewable energy, which is always in a non-steady state due to the wide temporal and spatial variations of wind velocity depending on atmospheric pressures. Data concerning wind speed in different regions in Africa have been compiled, evaluated and presented in this article. In order to estimate the actual available wind power, wind observations over several decades from dense station networks or high resolution wind modeling would be required. Both are not available in Africa. Therefore, for this study the potential wind power energy has been estimated instead. It is based on re-analysis data provided by the European Centre of Medium-Range Weather Forecast (ECMWF). This paper presents the background and ideas of the development of the concept as well as the main results, and experience gained during ongoing projects. In Africa, various designs of wind machines for different engineering applications have been developed and some designs are presently manufactured commercially. Results suggest that wind power would be more profitably used for local and small-scale applications especially for remote rural areas. It is concluded that Africa is blessed with abundant wind energy which needs to be exploited perfectly.

1. Introduction

While in the past wind energy was considered to be a renewable energy source primarily for developed countries, this is slowly changing. Since 2004, wind energy production has risen steadily worldwide and the actively installed global capacity increased from 40000 MW at the end of 2003 to 94000 MW at the end of 2007 [1] – [15].

According to the Global Wind Energy Council [16], more wind power capacity was newly installed in developing countries and emerging economies than in the traditional wind markets of the Organization for Economic Co-operation and Development (OECD) in 2010.

Also in Africa, the potential of wind energy has started to be recognized and in Egypt, Morocco and Tunisia wind farms have already been installed. Currently, by far the largest share in wind energy production in Africa is held by Egypt where 97% of all wind power installations are located with total capacities of 550 MW [16]. In Morocco wind energy capacity of around 290 MW exists and in Tunisia the annual wind production amounts to about 120 MW. While wind farms currently exist predominantly in Northern Africa mostly along the Mediterranean coast, wind farm projects are now also under discussion for other areas. Currently planned are the establishment of wind production farms for Nigeria with capacities of about 10 MW, in Ethiopia for about 120 MW, and for Kenya with capacity of 300 MW [17]. A research in the old Sudan before separation of the south region showed wind power density in the Southern region to be ranging from 285 – 380 W/ m^2. Wind power generation is seen as a key investment opportunity by the government of South Sudan. This potential is not exploited. Wind has a disadvantage of being uneconomical and unreliable especially when there is no wind. It could also be used for rural electrifications [18] and [19].

2. Estimate of Mean Winds Across Africa

Wind energy production depends primarily on wind speed and how the winds are changing during the day, a season, a year or even over decades. In order to estimate the actual available wind power, wind observations over several decades from dense station networks or high resolution wind modeling would be required. Both are not available for Africa for this study, and therefore the potential wind power energy has been estimated instead. It is based on re-analysis data provided by the European Centre of Medium-Range Weather Forecast (ECMWF). Re-analysis data incorporate observations and numerical weather prediction output to provide a continually updated best estimate of the state of the Earth atmosphere. It has the advantage that it is available for every grid point distributed equally across entire Africa. The data set has been validated with observations as reported by a study from the German Weather Service [20] and it appears that the data are sufficiently suitable to provide a reasonable estimate of potential wind power on continental scale. This study is based on the mean winds at 100 m above ground for a period from 1979 to 2010. 6 hourly re-analysis model output data on grid cells with roughly a size of 75x75 km^2 have been used. Fig. 1 illustrates that mean winds above 5 m/s are largely found north of the Equator, at the Horn of Africa and in the South of the Continent. In Central Africa there are extended areas with average winds of less than 3.5 m/s**.**

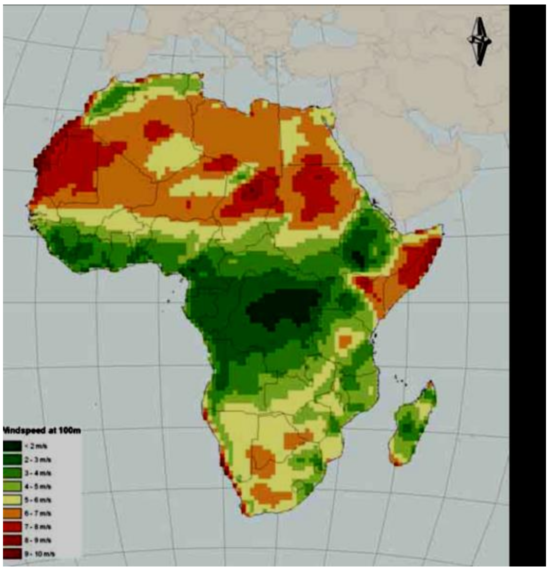

Fig. 1 Geographical distribution of average wind speed over Africa at 100 m height derived from 6-hourly ECMWF re-analysis data for a period from 1979 to 2010

3. Potential Availability of Wind Energy Resources

While the distribution of mean winds is a first good indicator where wind energy production might be profitable, the potential energy production cannot be extrapolated from it without a number of important assumptions with regard to the wind turbines, their size, efficiency, density as well as land use.

For this study we assume modern technology wind turbines with a diameter of rotor blades of 80 m and full working hours in a year (8760 h). Following literature, the maximum wind power that can be converted into energy has been set to 59.3% [21] a coefficient that is likely to be lower in reality. In order to calculate the average wind energy production potential per square kilometer, it is assumed that five wind turbines can be sited per square kilometer [22].

Furthermore, there is a minimum and maximum speed in which wind turbines operate. Following guidance from the “Wind Power program (online)”, these limits have been set to 3.5 m/s for the so called cut-in speed and to 25 m/s for the upper cut-out speed. Full productivity is assumed from a rated output speed of 15 m/s onwards, meaning that higher winds will not yield more energy production than the one at 15 m/s. A cut-in speed of 3.5 m/s is considered the minimum speed for wind turbines to start operating, but for larger commercial wind turbines, a cut-in speed of 5 m/s may be more appropriate. Therefore, here all maps are based on the assumption of a cut-in speed of 3.5 m/s, but are provided for both cut-in speeds for comparison in tabular form.

The potential wind energy has been calculated as:

$$E(v) = {}^{1}\!/_{2}\ \rho A v^3 C_p\ t$$

Where: ρ = air density (kg/m^3), A = the area swept by the rotor blades (m^2), C_p = power coefficient [21], t = hours, v = wind speed at 100m (m/s) if $3.5 < v < 25$. Else, for $v < 3.5$ and for $v >$ 25, the wind energy E = E(0) = 0. For $v > 15$ m/s, the wind energy is set to the one of 15 m/s: E = E(15).

Fig. 2 illustrates the potential wind energy production for Africa excluding areas with water bodies, cities, deep forest and nature reserve areas which are shown in white. Perhaps desert areas should also be excluded but has not been done for this study. There is obviously a high degree of uncertainty associated with the absolute values because of the quality of the underlying input data and assumptions made, and should be seen as indicative values only.

The available data on the currently existing power grid is also drawn in fig. 2. It is quite obvious, that for those regions with the highest values of potential wind energy production, there is little infrastructure with regard to existing power grids. This would mean that many of the countries potentially most benefiting from wind energy would not only have to invest in the wind farms themselves but also into an extension of the grid.

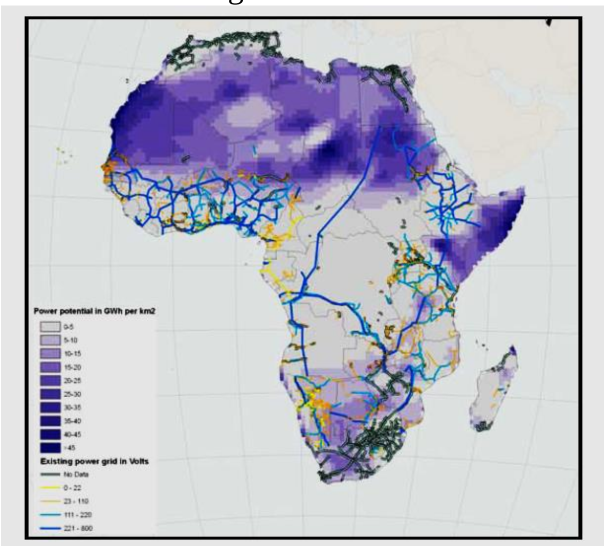

Fig. 2 Potential wind power production in GWh per km^2 excluding regions with water bodies, forest, cities and protected areas and assuming 5 turbines per km^2. Overlaid is the position of available data on existing power grid with capacity in k Volt

4. Different Scenarios of Potential Availability of Wind Energy Resources

It is of interest to calculate the total potential energy that can be produced per country, taking into account the current distribution of the grid and by excluding obvious areas where wind farms cannot be established such as cities, water bodies and forest areas. Assuming that wind farms are only installed within +/- 35 km of range to the power grid, the geographical distribution of national potential wind energy is shown in Fig. 3.

Clearly, the absence of power grids limits the potential wind energy in some regions, like for example at the Horn of Africa.

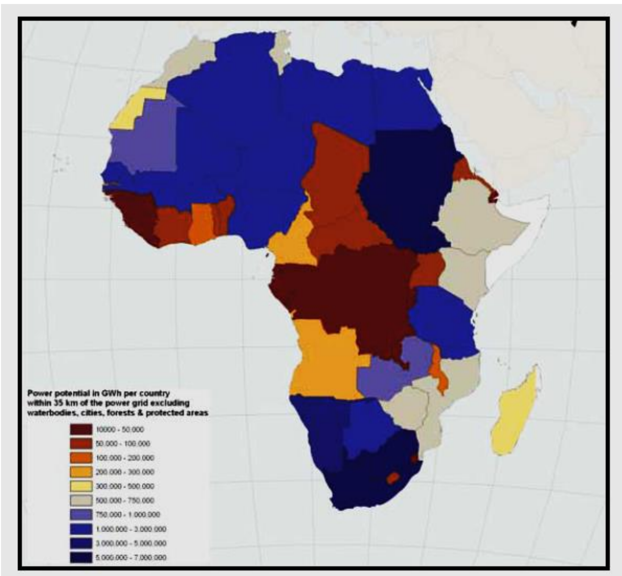

Fig. 3 Potential National annual wind energy production in GWh/year excluding areas with water bodies, cities, forest, nature reserves and pixels further than +/- 35 km from the current power grid and assuming 5 turbines per km^2

Potential wind energy power for different scenarios for entire Africa is given in Table 1 below.

Table 1 Values of total potential wind energy in TWh (i.e. Terawatts hour)over entire Africa taking into account different scenarios of areas to be excluded and distance to the power grid and assuming a cut-in value of 3.5 m/s and 5 m/s and 5 turbines per km^2

		Distance from current power grid				
I: Reference		+/- 35 km*		+/- 50 km	+/- 100 km	unlimited
Cut-in speed in m/s		3.5	5**	3.5	3.5	3.5
I	Total potential wind energy without restrictions on landuse	52432	35992	67325	103656	293731
II. Total potential wind energy excluding areas with						
II a	- water bodies and cities	51542	32024	66289	102233	291982
II b	- water bodies, cities, forests	45739	29278	59024	92070	278517
II c	- water bodies, cities, forests, and nature reserves	41012	26418	52332	80201	251937

Note: * only values on the grid are considered; ** cut-in speed for larger commercial turbines.

Thus, under the assumption that on every square kilometer within +/- 35 km in range of the existing power grid, 5 turbines are installed and excluding areas with water bodies, cities, forest and nature reserves, the total potential wind production energy amounts to a capacity of 40000 TW per year when considering a cut-in value of 3.5 m/s. Using a higher cut-off value of 5 m/s instead of 3.5 m/s reduces the overall potential wind energy by 35%. For comparison, the currently actual available wind energy power in Africa is estimated at about 9 TW [16], and the projections for the next decades are 166 TW for 2020 and 587 TW to 2030.

5. Conclusions and Future Projections

For this first study a number of rather coarse assumptions needed to be made with regard to the wind field, parameters for converting wind into wind energy, land use and distribution of the power grid. Therefore the results of this study are to be interpreted rather qualitatively than quantitatively.

In order to have a more detailed and quantified study, research would be needed into a more accurate representation of the wind fields taking also into account local effects such as orographically induced winds or land-sea wind circulations. More detail on technical specification of wind farms would be required.

Finally, with more reliable information on cost for constructing wind mills, expansion of the power grid, and value of energy, a cost-benefit study could be performed.

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