OF WIND TURBINES ON RADAR SYSTEMS AND MITIGATION MEASURES: THE CASE OF NGONG WIND FARM IN KENYA

B. Ndirangu[1], F. X. Ochieng[2], J. N. Kamau[3] and C. Mburu[4]
[1, 2,4]Institute of Energy and Environmental Technology, Jomo Kenyatta University of Agriculture and Technology Nairobi, Kenya
[3]Department of Physics, Jomo Kenyatta University of Agriculture and Technology Nairobi, Kenya
E-mail: ndirangubn@gmail.com

Abstract
Air traffic control radar system that monitors traffic in Nairobi, Kenya and its environs is susceptible to display clutter and false targets due to Doppler Effect caused by rotating wind turbine blades along the aviation pathways. This study aims to address the influence of wind turbines on aviation radar system along Ngong Hills. The import of the study lies in the potential increase of wind parks along the aviation pathways of Ngong and their influence on radar systems. The methodology adopted in determination of this influence of these wind parks was by executing ArcGIS Viewshed analysis tool. The input data used was a 60 meter digital elevation model of Kenya obtained from World Resources Institute. This data was re-sampled to 6 meters DEM in order to obtain the precision of higher resolution near the wind turbines. Line of sight analysis was carried out using the LoS tool in ArcGIS to determine the visibility of objects over the surface. The results indicate that all turbines are visible to the radar but not detected due to the distance between the radar and turbines. A map indicating wind power density and radar coverage was also generated showing optimal wind farm setup sites. Based on this, operator guidance for radar system setup, optimal site for setting up turbines and observed displayed effects on radar screens were identified and recommended. Also it's now easy to determine visibility of all wind turbines around Ngong Hills to the JKIA radar.

Key words: wind parks, radar, clobber effect, line of sight, EMI, radar screens, turbines, Ngong, Kenya

1.0 Introduction

According to the preliminary data gathered by World Wind Energy Conference, wind energy has emerged as the leading renewable energy generation method, producing a power yield equivalent to 239 GW by 2011 which is enough to cover 3 % of the world's electricity demand with emerging markets taking lead (Stefan and Jean-Daniel*,* 2012). While this growth is expected to be sustained with commendable reduction in carbon emission, there is need to address the negative impacts associated with the turbines. Some of these impacts include effects on aircraft radar systems, aesthetics, noise, impact birds, bats and other wildlife among others.

According to MoE, Kenya's electricity peak demand will increase from the current 1330MW to 15,026 MW by 2030 in line with the Vision 2030. To meet the increased electricity demand due to the enhanced economic activities various generation sources have been considered, targeting 5,110 MW from geothermal, 1,039 MW from hydro, 2,036 MW from wind, 3,615 MW from thermal, 2,000 MW from imports, 2,420 MW from coal and 3,000 MW from other sources.

Wind farms can cause a number of problems on air traffic radar displays such as clutter, reduced sensitivity and overloading of processing functions (Krug *et al,* 2009). This can have an impact on the safety of the services provided to aircrafts. As the number of turbines and airports continue to grow in the realization of Kenya vision 2030, a major constraint on the deployment of wind energy in Kenya will be the restriction on erecting turbines due to the potentially hazardous effects they may have on aviation and related defense interests.

The Kenya Civil Aviation Authority (KCAA) has no clear guideline on how the effects of the wind turbines on the radar systems should be addressed (KCAA, 2010); probably because of the low penetration of wind energy in the country. But this is bound to change since countries are trying to reduce their carbon emission through adoption of green energy. Various studies have been carried out to determine minimum safe distance between a wind farm and radar system without success. It is however possible to determine the minimum distance where interference from wind turbines would not occur. By using Pythagoras theorem, this distance can be determined as shown in Figure 1.

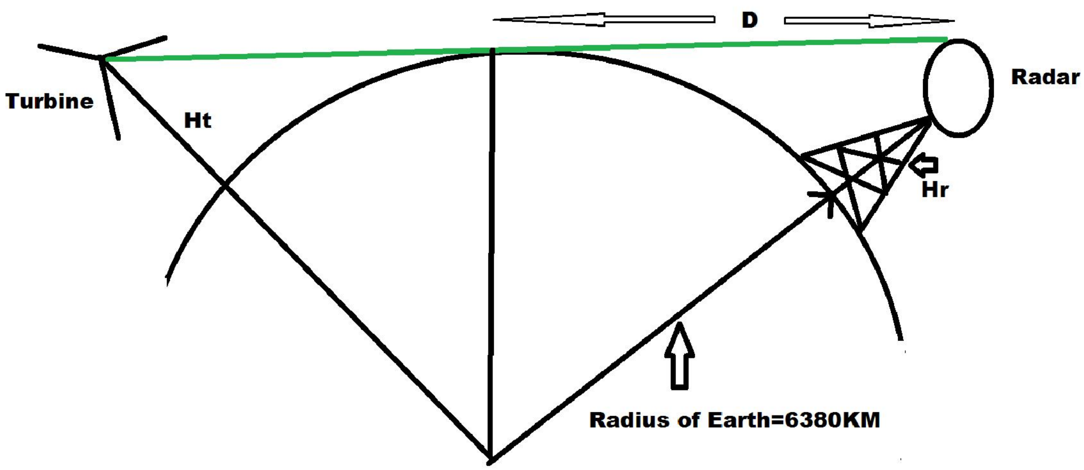

Figure 1: Geometry between wind farm and radar with LoS

$$D = \sqrt{[(R + Hr)^2 - R^2]} \approx \sqrt{2RHr} \text{ since } Hr \ll R$$

Where D is the distance from radar to local horizon of smooth round earth, R is the mean radius of the earth and Hr is the height of object above mean sea level. Since the refractivity of the atmosphere causes bending of waves, effective earth radius rather than true earth radius is used in the calculations. The effective earth radius is 4/3 the earth radius hence

$$D = \sqrt{(2 * 4/3 * 6380 * Hr)} = 130.44\sqrt{Hr}$$

$$\text{Therefore total distance } D_T = 130.44 \sqrt{(Hr + Ht)} \text{ KMS}$$

1.1 Mitigation Concept for Clutter and Blockage

Most concepts proposed to prevent or reduce clutter are also valid for erroneous wind measurements. Adaptive filters, suggested for removing wind turbine clutter, can also help mitigate erroneous wind measurements. If clutter is removed from the signal, the average wind velocity as well as the spectrum width can easily be estimated. Various concepts for mitigating wind turbine clutter have been suggested in different studies.

Table 1 shows potential impact zones for the weather radar and recommended guidelines as per the world meteorological organization (WMO)

Table 1: Weather radar impact zones

Range	Potential Impact	Guideline
0 – 5 KM	The wind turbine may completely or partially block the radar and can result in significant loss of data that cannot be recovered.	Definite Impact Zone: Wind turbines should not be installed in this zone.
5 – 20 KM	Multiple reflection and multi-path scattering can create false echoes and multiple elevations. Doppler velocity measurements may be compromised by rotating blades.	Moderate Impact Zone. Terrain effects will be a factor. Analysis and consultation is recommended. Re-orientation or re-siting of the turbine may reduce or mitigate the impact

20–45 KM	Generally visible on the lowest elevation scan; ground-like echoes will be observed in reflectivity; Doppler velocities may be compromised by rotating blades.	Intermittent Impact Zone: Notification is recommended.
>45 KM	Generally not observed from in the data but can be visible due to propagation conditions	Intermittent Impact Zone: Notification is recommended.

Placing wind turbines so that they are not in line of sight of radar will ensure no clutter is observed. Under normal conditions radar's measurements will not be affected by objects that are not in the radar line of sight. This method is therefore a certain way of limiting wind turbine clutter. On the other hand reducing the wind turbines' rotor cross sectional area will make the blades invisible to the radar. It has been proposed that stealth materials can be applied to wind turbines as a way of reducing the RCS (David *et. al*, 2013).

Areas contaminated by clutter may be covered by a second nearby radar, a so-called gap-filler (Joan, 2012). This alternative may be a convenient solution for specific cases but could also lead to even bigger problems since an introduction of additional radars introduces new sites which also must be protected. Another method would be by changing the radar scan strategy to pass over areas with wind turbines will limit the amount of clutter received. The drawback is that data will be gathered from higher altitudes which may shorten the effective range of the radar.

1.2 Viewshed Analysis Tool

Viewshed analysis tool determines raster surfaces visibility from one or more observation points. The visibility of each cell center is determined by comparing the altitude angle of the target cell center with the altitude angle to the observation cell center. The local horizon is computed by considering the intervening terrain between the point of observation and the current cell center. If the point lies above the local horizon, it is considered visible. Viewshed analysis tool can be used to determine the visibility of wind turbines from a specific point. Figure 2 shows the input and output of a viewshed analysis.

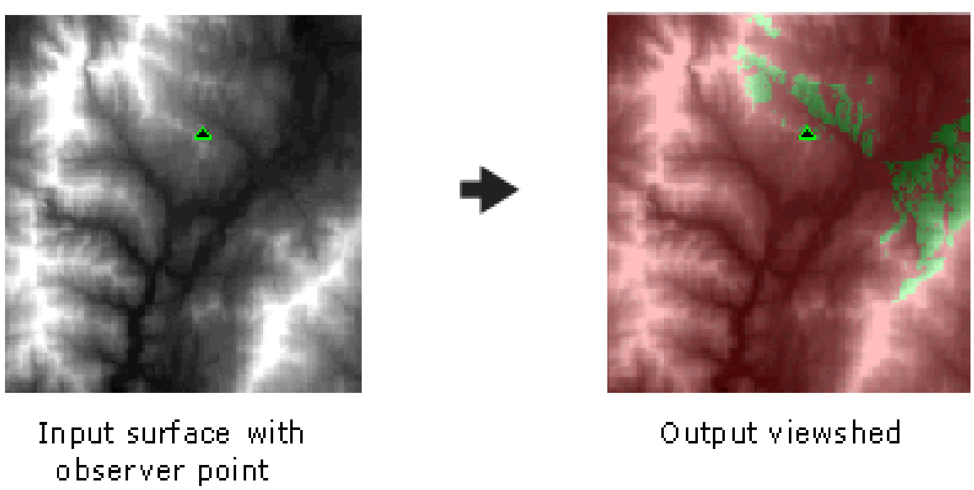

Figure 2: Viewshed analysis – Image courtesy of ArcGIS

This tool has additional features that make it more robust i.e. observation point elevation values, vertical offsets, horizontal and vertical scanning angles, and scanning distances. There are nine items in total: SPOT, OFFSETA, OFFSETB, AZIMUTH1, AZIMUTH2, VERT1, VERT2, RADIUS1, and RADIUS2. SPOT defines the elevation value of observation points which can be increased or decreased by OFFSETA parameter. RADIUS1 and RADIUS2 define the minimum and maximum areas of coverage respectively. OFFSETB controls the elevation of the observed points while AZIMUTH1 and AZIMUTH2 define the start and end sweep angles i.e. between 0 to 360 degrees. VERT1 and VERT2 define the upper and lower scan angles normally between -90 to 90 degrees.

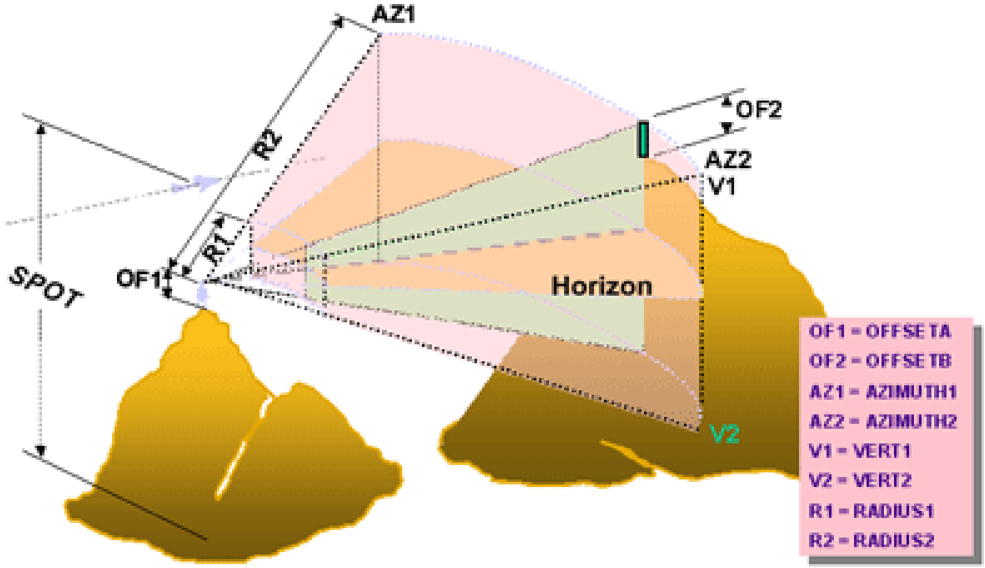

Figure 3: Parameters for controlling viewshed analysis – Image courtesy of ArcGIS

1.3 Line of Sight – LoS Analysis tool

Line of sight analysis tool determines the visibility of cells along a specific path from an observation point to a target point. The output is graphic line where green color shows all visible points and red color as obstructed points from the observer point.

2.0 Data collection

Kenya wind data was obtained from SWERA website database. This database contains a collection of GIS data for various countries. Raw data was drawn from the Kenya national meteorological department where measurements were taken from different stations throughout the country. These measurements were carried out at 10 meters height over long period of time mainly for agro metrology and civil aviation. In this case only five years data and for around ten of thirty four stations in Kenya was used by SWERA to generate wind resource geo-referenced map. The data was processed while taking into consideration of obstacles, surface roughness and topography producing generalized wind climatology at the height of 50 meters by the virtue of interpolation.

Kenya's digital elevation model (DEM) at 90-meter resolution was obtained from World Resources Institute website. The data was gathered through shuttle radar topography missions (SRTM). Areas with regions of no data in the original SRTM data were filled using interpolation methods. Coordinates of the Ngong Wind Park turbines, JKIA aircraft radar and satellite imagery of Nairobi and its environs were obtained from Google map and online resources from ESRI. Ministry of Energy provided the coordinates, type, rating and the number of the proposed wind turbines within the environs of Nairobi. Radar screen images for the weather radar, PSR and the SSR were to be obtained from the KCAA radar station in Embakasi. ArcGIS, the simulation software used was downloaded from ESRI website under the student license category.

3.0 Methodology

3.1 Simulation

Two assumptions were made during the simulation exercise. Firstly, that the terrain between JKIA and Ngong wind farm is without obstacles and secondly the wind farm was is a single turbine due to its size. In order to determine the minimum wind turbine height that can be detected by the radar system, line of sight analysis was performed.

The 90 meter digital elevation model was re-sampled to 6 meter digital elevation model in order to enhance resolution using ArcGIS 10.1 simulation software resample tool. The re-sampled data was further analyzed to enhance topology effects using the hill shade tool. By running the Line of Site (LOS) tool from JKIA to Ngong Wind Farm, visible and blocked cells along the path were plotted. Due to the distance between the two points (34 KMS), the spacing of turbines and the small number of turbines (six), all the wind turbines were treated and analyzed as one point rather than six points. The resultant data obtained was in form of an image and graphical representation of the cross section of the terrain profile between the two points.

Viewshed analysis was performed on the Kenya DEM model on a height above ground (OFFSETA) of 16m (radar antenna height) with 1.5 degrees tilt angle. The viewshed (resultant layer) was added to the DEM and turbine location layers. Using ArcGIS software, wind data was sampled using cubic convolution in order to enhance its sharpness. Wind resource data layer, viewshed layer and the DEM for Kenya layer were overlaid using ArcMap and their transparency varied using image analysis tool. Further the two layers color properties were adjusted in order to enhance contrast.

4.0 Results and Data Analysis

Figure 4 shows the location of four wind farms marked with red pins and the viewshed marked in light blue color shades. Figure 5 shows viewshed analysis on the terrain around Ngong Wind Park zoomed to a radius of 5 kilometers while Figure 6 shows cross sectional LoS analysis from JKIA radar station to Ngong Wind Farm. Section of LoS marked with green show visible areas (cells) and sections marked in red show blocked areas. The same is further represented in 3D as shown in Figure 7

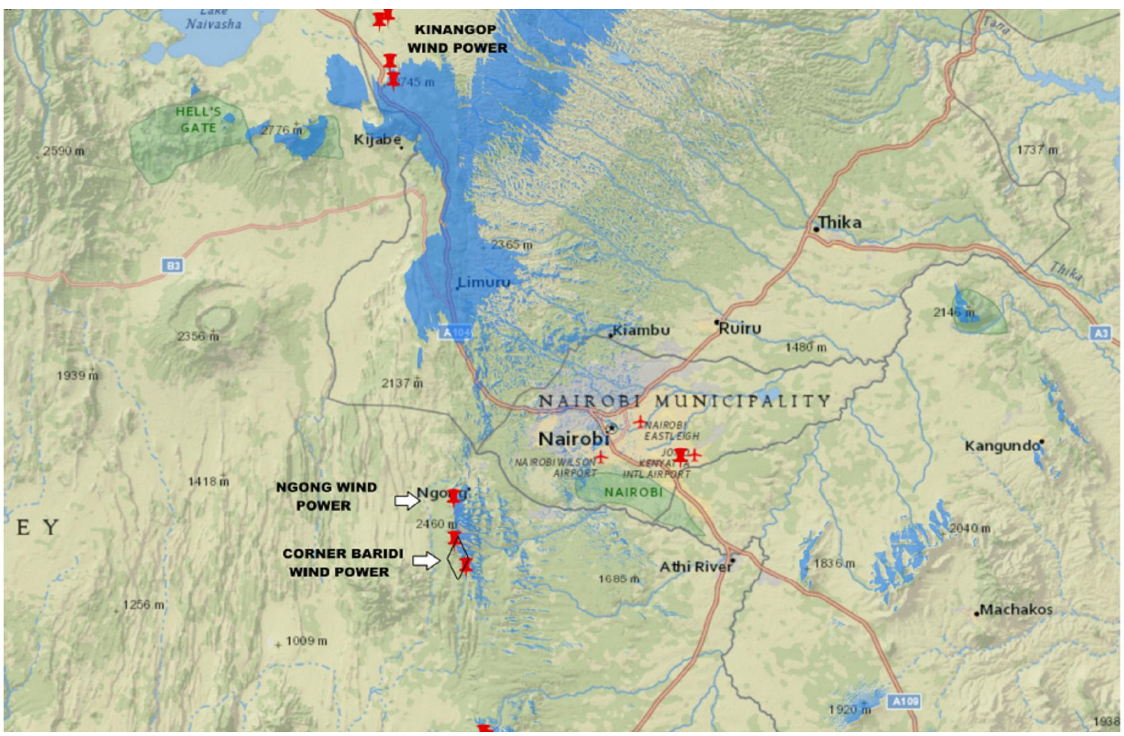

Figure 4: Viewshed analysis along Ngong, Kipeto and Kinangop Wind Farms

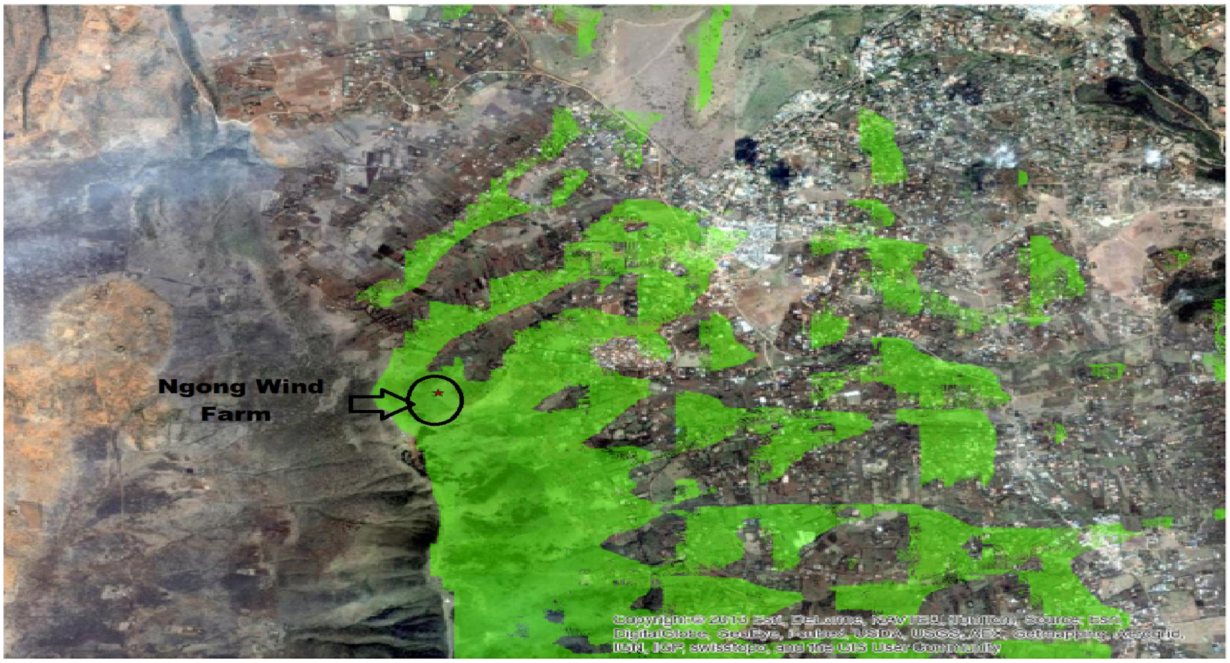

Figure 5: Viewshed analysis on Ngong wind farm

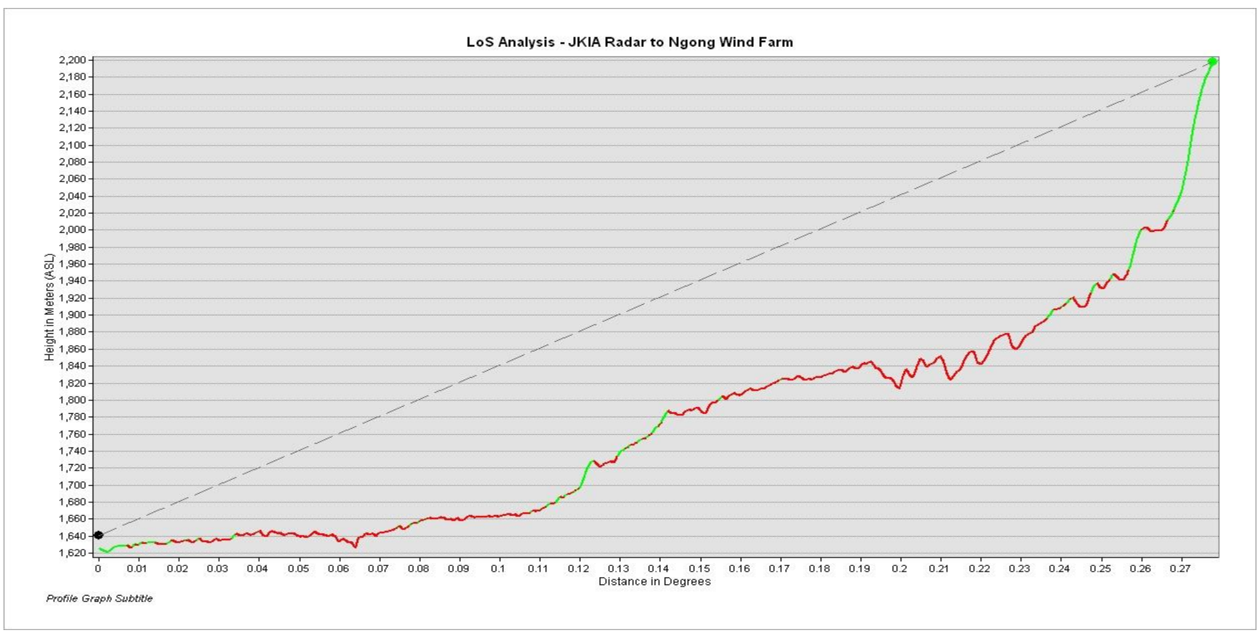

Figure 6: Cross sectional Line of Sight analysis from JKIA Radar to Ngong Wind farm

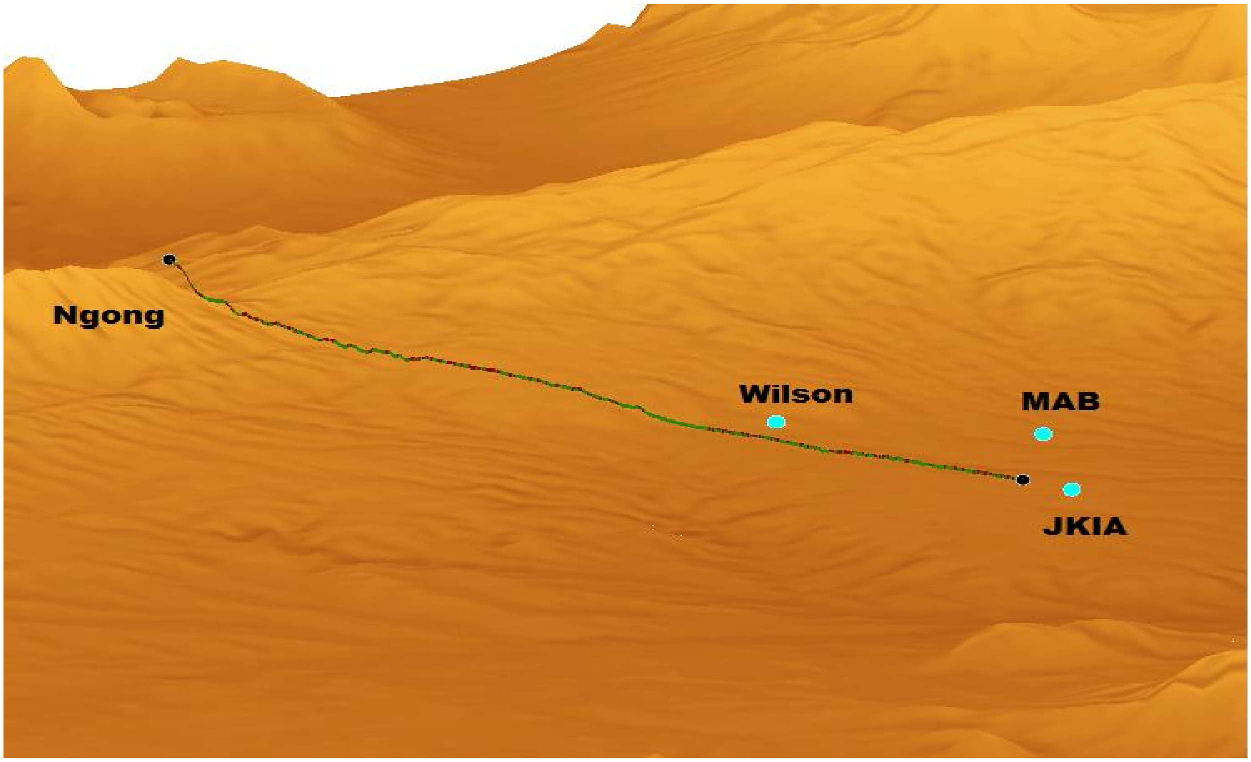

Figure 7: LoS in 3D from JKIA Radar to Ngong Wind farm

Figure 8 shows wind radar map where the viewshed analysis is represented by black shading and wind profile represented by the other colors. The key to the right indicates different annual wind speeds with shades of brown being highest at 10m/s and shades of purple being the lowest at 2m/s. In this figure we only have shades of yellow with a maximum wind speed of 7m/s along Ngong hills peaks. Areas with no viewshed and are marked in yellow indicates the best areas of setting up a wind farm.

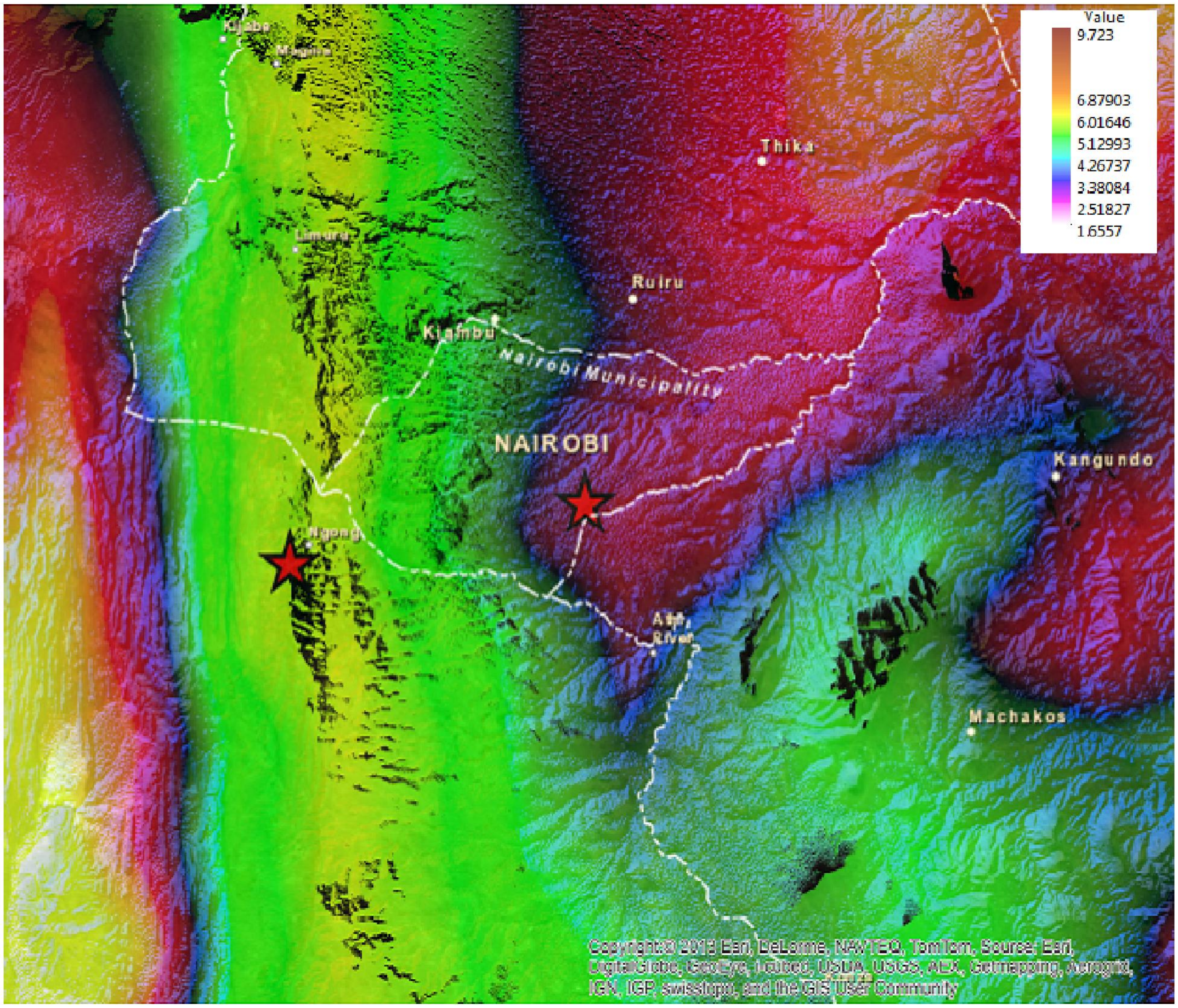

Figure 8: Wind-Radar map

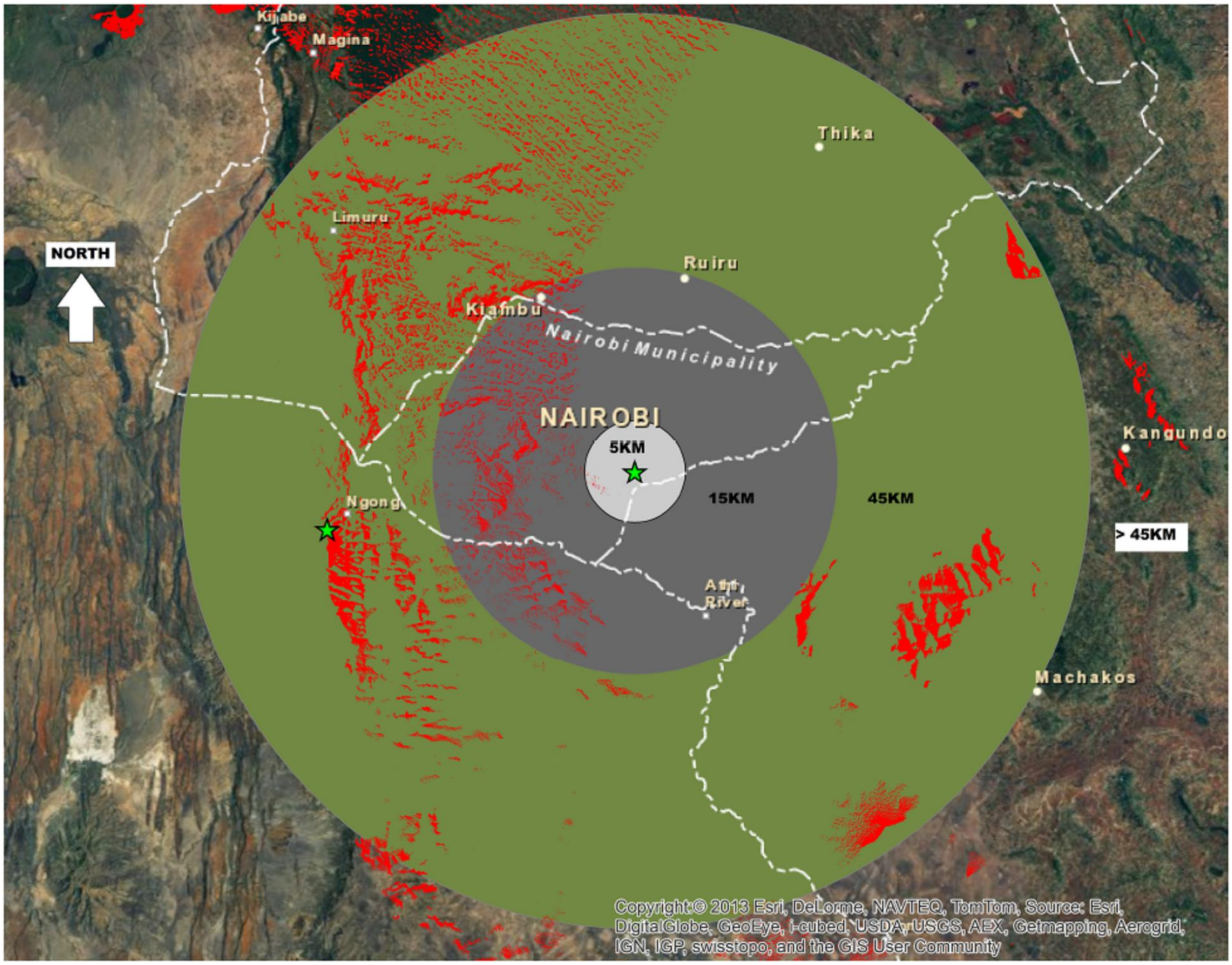

Figure 9: Weather radar impact zones

Figure 9 shows zones from the weather radar station where different measures should be taken if a proposed wind farm falls within a specific region. No wind farm should be set up within the 5KM zone. Between 5 – 20 KM zone, comprehensive analysis should be carried to ascertain non-interference of the wind farm while over 20 KM zone, KCAA should only be informed.

5.0 Discussions and Conclusions

It should be noted that in this preliminary analysis there were a number of factors that were not considered i.e. buildings and other obstacles along the sight line for both the LoS and viewshed analysis. However the effect of the curvature of the earth was included. In this analysis, the resulting views show that the whole of Ngong Wind Farm is visible to the radar. Also using Pythagoras theorem and taking a turbine and radar height of 75 and 10 meters respectively, the longest distance on ground that the JKIA radar can cover is approximately 50 kilometers. The assumption being that the earth is a smooth surface between JKIA and Ngong. However this is not the case as Ngong area is on a higher altitude than JKIA by 563 meter.

The large difference in altitude between the two points guarantees total visibility of the wind farm hence there is zero meter minimum turbine height. The minimum turbine height can only be achieved by tilting the radar beam angle. This will cause the radar beam to cover less area leading to omission of crucial data as less area will be covered.

On the radar operational parameters, the PSR have a range accuracy of approximately 50 meters and an azimuth accuracy of 0.16 degrees. The 6 turbines can only be visible as one turbine since the wind farm azimuth is a mere 0.004 degrees. The azimuth accuracy of the radar deteriorates with an increase in the distance from the radar to the target. The turbines rotor tip speeds operate at an average speed of 65 m/s which is higher than the minimum Doppler speed for the radar which is 15 m/s. The Doppler radar treats all echoes from speeds of 15 m/s and below as unwanted clutter and hence not plotted. This shows that the wind farm will be detected as a single turbine.

From the JKIA radar screen shots (not provided due to security reasons) it's evident that the Ngong Wind farm does not cause clutter even though the turbines are visible to the radar from the simulation results. The predominant wind direction around Ngong Hills is North West thus the nacelle and the spinning rotor blades point to the same direction. This is achieved through the yawing mechanism. JKIA radar station is to the east of Ngong wind farm hence the radar will pick signatures mostly from the trailing edge of the rotor blade. The trailing edge has minimal echo resulting to minimal or no clutter on the radar display. This together with the wind farm visibility as one turbine explains why the farm does not cause clutter on radar displays.

Signal attenuation due to the large distance separating the two points and the size of the turbines can also make the turbines invisible to the radar. The Vestas V52 turbines are only 75 meters tall and are less likely to be detected by the main lobe of the antenna beam. Along Ngong area, the minimum flight level allowed is 9000 feet hence the antenna main lobe beam has more focus on higher attitudes. This means that very low and high altitudes are covered by the side lobes which are weaker. If an echo is picked by the side lode, the radar MTI treats it as false target and is discarded.

The Wind-Radar map generated will be used to determine the best location for setting up a wind farm in an optimal location. The map overlays the viewshed showing radar coverage and the wind profile. Locations with high wind speeds that are visible to the radar are not ideal for setting up a wind farm. On the other hand locations with high speeds that are not visible to the radar are ideal for setting up a wind farm. The analysis of setting up a wind farm using a wind radar map should be carried out using ArcGIS or any other GIS software as this will ensure high resolution and color contrast of the maps leading to more accurate results. The weather radar impact zone map generated will give KCAA a guideline on zones which are likely to interfere with the radar system depending on their proximity.

In conclusion, the objectives of this study have been fully achieved. Further analysis should be carried out using more advanced simulation software which will put into consideration structures along the line of sight between the wind farm and radar station. This will result into more accurate results thus allowing for application of correct mitigation measures. The final benefit will be the growth of wind farms in Kenya while having minimal or no effects on the aviation radar systems.

References

Bech, J., (2012). Doppler Radar Observations - Weather Radar, Wind Profiler.

Chris, N. (2008). Radar Impact Modeling for the Proposed Ray Wind Farm.

Civil Aviation Authority (2011). CAA Policy and Guidelines on Wind Turbines.

David De La Vega, James, C. G., Lars, N. (2013). Mitigation Techniques to Reduce the Impact of Wind Turbines on Radar Services. Bilbao.

Eliud, W. *et al.* (2012). EIA Study of Proposed 100 MW Wind Energy Facility, Kajiado Kenya. Kurrent Technologies.

Fraye, A., Christoph, N. and Alexander, M. (2009). Annual Report 2008 - The Compatibility of Wind Turbines and Radar.

Frye, A., Neumann, C. and Muller, A. (2009). The Compatibility of Wind Turbines with Radars. EADS Defence and Security.

Hart Aviation (2009). Wind Energy and Aviation Interests- Study for sustainability Victoria.

http://en.openei.org/wiki/SWERA/Data

http://www.wmo.int/pages/about/index_en.html Ionospheric Radar, and Other Advanced Applications. Intech.

Jago, P. and Tylor, N. (2002). *Wind Turbines and Aviation Interests – European Experience and Practice.*

Jarvis, A., H. I. Reuter, A. Nelson, Guevara, E. (2008). Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org).

KCAA, (2010). Manual of Aerodrome Standards. Chapter6, Visual Aids for Denoting Obstacles.

KenGen (2009). Tender Documents for Ngong II wind Power Project.

KenGen (2012). *Ngong Power Station.* Extracted on March 2012 from http://www.kengen.co.ke/index.php?page=business&subpage=wind&id=1

Kenya Country Report; Solar and Wind Energy Resource Assessment, Daniel Theuri May 2008.

Knill, A. (CAA), (2002). Potential Effects of Wind Turbines on Navigational Systems. London.

Krug, F. and Lewke, B. (2009). Electromagnetic Interference on Large Wind Turbines. Brande Denmark.

Laith, R. (2008). Wind Turbines and Radar Interaction, London.

Manwell, J. F. and McGowan, J. G. (2009). Wind Energy Explained - Theory design and application (2nd edition). West Sussex.

Michael, B. (2008). *Wind Farms & Radar.* Virginia.

Selex Manual, Theoretical Calculation of ATCR-33S DPC System Performance, Annex 4.16 – 2 Selex Operations Manual (2009). SIR-S Performance Description, Annex 4 -15.2

Sengupta, D. L. and Senior, T. B. A. (1994). Electromagnetic Interference from Wind Turbines, Wind Turbine Technology, ASME Press New York, 1994.

Simbo, A. O. (2006). Wind Farms and Their Effect on Radio Navigation Aids. Toulouse France, June 2006
Spaven Consulting (2001). Wind turbines and radar: Operational experience and mitigation measures. Edinburgh.

Stefan, G. and Jean-Daniel P. (2012). 12th World Wind Energy Conference & WWEC2013 Trade Fair. Bonn.

UNFCC CDM-Executive Board (2011).Lake Turkana 310MW Wind Project.

Vestas Wind Systems A/S (2007). *V52 – 850 kW* - The turbine that goes anywhere*.* Randers Denmark.

Wind Energy and Aviation. (2012). *Interim guidelines*, Extracted on April 2012 from http://www.bwea.com/aviation/avwkgp.html