Wind Resource Assessment in Dragash - Kosovo

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EXUTIVE SUMMARY

Dragash municipality is a region located in southern Kosovo with rugged mountains and river valleys. Due to complex surface driven local effects and interactions of mesoscale phenomenon (e.g. sea breezes, upslope/downslope winds, monsoon circulations, and low level jets etc.), undertaking a mesoscale modeling approach is very important. Thus, in this study a detailed high resolution wind modeling, analyses and mapping is conducted in order to identify the best local feasible wind power sites that can potentially be identified with the highest capacity factor of the generation of utility scale wind energy project required in that area. The mesoscale modeling tool employed in the analysis is the Weather Research and Forecast model (WRF), developed by the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research (NCAR). ERA-interim (ECMWF reanalysis – European Center for Medium-Range Weather Forecast reanalysis data at a spatial resolution of about 0.75° x 0.75°, T255 Gaussian grid. We used this data set because it is higher resolution than the NCEP data set, which is 2.5 degree grid spacing.

Our findings show that the Dragash area has wind resource regions that are located on higher elevation areas. The valleys showed low and variable wind speeds, while high and medium elevations in the north, east and south have significant wind potential. The central Dragash showed very variable wind speeds and wind power densities.

In terms of seasonal variability, the WRF model predicted wind speeds accurately for the summer representative month of August and winter representative month of December, 1999. The two sites analyzed have good wind potential; however, there are other feasible areas that can generate more wind power in that region. This will depend on many factors including but not limited to proximity to grid connection, access to area, and land use and cover, among others. While the work performed was a good representative of the year, more simulations and observations are required to draw a complete confidence level of wind profiles over the country.
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1 BACKGROUND

Environmentally friendly and low cost wind energy could make significant contribution to Kosovo's electricity needs. Grid infrastructure not being well developed in the Dragash area of Kosovo, wind energy can be an economically feasible source of energy in that region. Many developing countries and countries in economic transition don’t have good wind data useful for wind energy planning. In most cases, the sole source available is often meteorology stations and wind measurements at airports (World Bank, 2010), which are inaccurate for deploying utility scale wind energy projects. In fact, the World Bank (2010) report argued that one might be better-off not to rely on any ground-based wind measurement at all, and instead examine how the local landscape characteristics combined with global meteorology data would suggest where to look for windy sites. This study is exactly following the best practices that need to be considered before deploying expensive wind energy projects.

To date, with the exception of some basic studies, there are no detailed and reliable data and wind map of Kosovo potentially useful for utilization of commercial wind energy projects (USAID, 2012; Sahiti, 2012). However, recently, the country has taken a comprehensive approach to modernizing its energy sector (Taylor et. al., 2012) and this could be considered as one step forward to achieve its energy security using its renewable energy potential. In 2010, the most comprehensive wind measurement was conducted, which used eight ground-based meteorological sites (Fig. 1 and Annex 1) and collected one-year (August 2009 – July 2010) wind speed and direction measurement at existing towers in Kosovo cities (NEK, 2010). In their study, NEK Technologies (Zürich) (2010) concluded that Kosovo has moderate wind resources with very few areas characterized by wind speeds exceeding 6 m s⁻¹, a minimum wind speed needed for commercial utilization of wind energy (Sahiti, 2012). As Sahiti (2012) indicated Mercados’s (2012) preliminary top-down assessment study shows that Kosovo has a wind generation potential of more than 1000 MW installed capacity with a capacity factor of 25%. However, although these studies are very important, none of these studies provide a definitive argument of the potential of Kosovo’s wind energy that should consider long term wind resources.
assessment. Thus, the identification of geographical distribution of wind speed using mesoscale modeling for Dragash region is vital for wind energy project development (Lebassi-Habtezion and Van Buskirk, 2012).

Thus, the objective of this analysis, which focused on the southern part of the country of the Dragash region, emanates from the fundamental reality that the Government of Kosovo and the United Nation Development Program (UNDP)’s recognition of the importance of modeling based wind resource assessment and wind atlas development so that policy makers can take an informed decisions in developing wind energy projects. In developing the wind atlas, this study applied mesoscale wind modeling to downscale coarse resolution reanalysis data, in order to resolve local scale effects (e.g., topography, down slope/upslope winds etc.).

Though the focus of this study is for two sites located in Dragash administrative region of Kosovo, the authors have prepared mesoscale wind speed analysis that covers the southern part of the country at 1km grid spacing by downscaling the ERA-interim (ECMWF reanalysis – European Center for Medium-Range Weather Forecast reanalysis data. The wind power density of the region is calculated at two key heights of 50 and 100m.

2 STUDY LOCATION

The Dragash area is a very complex topographic region with very steep hills and river valleys. Restelica river valley, Brod river valley, the mountain east of Brezan, Plava river and its tributaries in the north, the Sharr Mountain area in Dragash, the Lepenc river basin in southern part of the municipality towards the border with Macedonia, are some of the key topographic features of the area (Fig. 1). The client chose two sites for in-depth wind resource assessment and energy analysis. The geographic coordinates of this study area indicated inside the box (Fig. 1-left) for Site #1 (lat=42.1428°N, long=20.6997°E) and Site #2 (lat=41.9473°N, long=20.6651°E) are plotted in Figure 1-right. As shown in Figure 1-right, Site #1 is located close to the border between Dragash and Prizren territories at 1,196 m above sea level (ASL) and Site #2 is located near Restelica at about 1,540 m ASL. The nearest settlements for Site #1 are Brrut and Zgatar, other clores
settlement is Kuk (at 42.0998°N, 20.7137°E), whereas Site #2 is close to Restelice (at 41.9424°N, 20.6662°E).

Figure 1: Left, Kosovo Political Map (study area indicated in the box). Right, 90m Resolution Topography of the Study Area i.e. Sites #1 and #2.

3 METHODOLOGY

In the development of the wind atlas in this project, the regional Numerical Weather Prediction (NWP) model used was the Advanced Research dynamics core of the Weather Research and Forecasting (ARW-WRF, hereafter referred to as WRF) model version 3.4.1. The WRF modeling system was developed by the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research (NCAR) with worldwide contributions from hundreds of universities and research organizations. The model (http://www.wrf-model.org) is a state-of-the-art, next-generation NWP system and portable enough for use as operational forecasting and atmospheric research tool. The physics parameterizations are consisted of microphysics, cumulus (convective) parameterizations, planetary boundary layer schemes (PBL), shortwave and long-wave radiation options, as well as land surface models (LSM) (Skamarock et al. 2008).

The WRF model uses a Lambert-conformal map projection centered at 42.0°N latitude, 15.0°E longitude and was configured with three nested domains at 25, 5, and 1 km horizontal resolutions, with grid spacing of 152x157, 316x376 and 341x381, respectively.
The coarse domain encompassed Europe, North Africa and part of the northeastern Atlantic Ocean, with the inner most nested domain covering the state of Kosovo and parts of its neighboring countries (Fig. 2a). The model had 50 sigma levels in the vertical, i.e., randomly divided spacing as a function of a decreasing pressure levels with height that ends at 50mb (~25 km from the surface). The WRF model requires several static and dynamic input variables to run. The static information includes terrain structure, land use and vegetation coverage as well as geographical location data, while the dynamic data required are mainly initial and boundary conditions. For the surface boundary conditions, we used the 30 arc-sec (approximately 1 km resolution) US Geological Survey (USGS) topographic heights ("GTOPO30, 1996) and 30 arc-sec USGS Global Land Cover Characteristics (GLCC; Loveland et al., 1999) land use data, which were developed from 1 km Advanced Very High Resolution Radiometer (AVHRR) satellite images obtained in 1992-1993. The ERA-interim (ECMWF reanalysis – European Center for Medium-Range Weather Forecast reanalysis – at ~78 km horizontal resolution) analysis output that we had used provided “first guess” initial and boundary conditions at 6-hr intervals for both August and December 1999 in the modeling simulations, representing the lowest and highest wind speed records of the year.

Figure 2: (a) WRF model configuration in three nested domains, coarse domain (D01) has 152x157, D02 has 316x376, and D03 has 341x381 horizontal grid points with 25km, 5km, and 1km grid spacing, respectively. (b) Domain-3 topographic heights, with Kosovo inside a sketch box. Coordinates are geographical lat/long.
The performance of the WRF model was evaluated for these months using the monthly meteorological observations archived for 2009/2010 (NEK, 2010, Annex 1) as no wind vector data was available for the simulated year of 1999. The sketched box within Domain-3 (D03) in Figure 2b shows the rough location of the state of Kosovo. Figure 2b also shows color-shaded terrain structure for general overview of its topographic characteristics.

After a set of test-runs of the WRF model with a couple of different physics schemes, the two selected months of 1999 were run by re-initializing the model every week using the ERA-interim large scale “first guess” analysis to acquire an updated synoptic weather, soil and sea surface temperature information and other important parameters described in Bougeault and Lacarrere, (1989), Kain and Frisch (1992), Janjic (1996), Dudhia (1989), and Lozej and Bornstein (1999).

Mesoscale simulations of high resolution climate have very expensive computational resources. This project doesn’t have resource to simulate year long simulation. As a result, we selected climatological representative year using the 30 years (1980-2010) NCEP data set. Figure 3-left, shows the time series of the monthly wind speeds for each year for the period of 1980 to 2010 (gray) and the log-term climatological mean wind speed (black).

![Figure 3: Left: Surface (10m AGL) mean monthly wind speeds (m s⁻¹) from NCEP reanalysis at a grid point closest to Site #1 showing annual trends for the period between 1980-2010 (gray) and climatological trend for the same period (black). Right: 10m Mean monthly wind speed (m s⁻¹) from NCEP reanalysis at the grid point closest to Site #1 for selected years, i.e., Red: 1980-2010 average, Blue: 2009 and Green: 1999.](image)
In general, this plot shows the wintertime high wind speeds season of November to March followed by a decreasing trend during the spring and low wind speeds in the summertime season (April to October). A set of plots is thus produced for the grid point closest to Site # 1 (Fig. 3). Figure 3-right shows the time series of wind speeds for the years closest to the climatological mean (red line). While this plot confirms the annual monthly wind trend over Site #1, it also shows that the best fitting trend to the climatological statistics is the year of 1999 (green line). Although the winds are slightly lower during the climatological high-wind season, the year of 2009 (blue line) in the current decade is also another good fitting trend. This year is also important because of the relative availability of observational data for model performance evaluation.

The closest year to the 30-year mean NCEP reanalysis climate was thus selected for the simulation of the two sites for wind energy resource assessment. The year 1999 is closest to the mean, while 2009 was the second best (Fig. 3-right). Also in this figure, it is shown that the winter wind speeds of the year 2009 have some deviations from the mean climate. As a result, we selected the year 1999 for the modeling study. Moreover, by identifying the seasonality of the wind over that site we selected two representative months: one in the winter (December) and other in the summer (August), in which their average will be similar to the annual wind fields of the region. We started our analysis by validating our results against observations. Since, wind data for validation was not available for the year 1999; we used station mean monthly wind speed data of the year 2009 from eight stations in Kosovo (Fig. 1). As shown in Figure 3, notice that the climatology of the year 1999 and 2009 is similar except some small differences during the winter months.

Finally, using the WRF model output for every 15 minutes for domain 3, wind speed and direction values were extracted for Site #1 and Site #2. Statistical analyses of the local distributions of wind speed and wind direction were carried out for each site. We analyzed the 2D distribution of the wind speed at 10, 50, and 100 m levels from which the wind power density of the Dragash region was calculated.
4 RESULTS AND DISCUSSION

4.1 Model Validation

For the fact that the mesoscale wind models are at best simplified descriptions of the real world, they could exhibit quite significant errors and biases. Thus, it is important to validate the results so as to increase the accuracy of mesoscale wind maps. Moreover, even if mesoscale maps were perfect representations of the average wind climate, due to specific location’s characteristics such as hilltops, valleys etc., microscale wind modeling is important for proper accounting. Thus, in this analysis, mesoscale model outputs have been validated using the one-year wind speed measurements of eight wind sites recorded during 2009/2010 period. It should be noted however that, observational data for model validation was not available for this particular year of 1999 for Kosovo, the year the modeling simulation performed. Therefore, since the monthly mean wind speed of 2009 (NEK, 2010) was the next best matching trend to the climatological values and its observational monthly mean wind speeds were available for eight stations in the country (Fig. 1; Annex1), these mean data values were utilized to validate the WRF model performance. According to the observed wind speeds, generally, the months of December to May are high wind speed season and June to November are a low wind speed season. This shows the importance of wind speed seasonal variability in wind energy planning.

Taking into consideration that only two months of the year were reproduced as representatives of the highest and lowest wind records of 1999, the model yearly wind speed station-average (4.88 m s\(^{-1}\)) was well correlated to the observed values (4.49 m s\(^{-1}\)) with overall positive bias (model overestimation) of 0.39 m s\(^{-1}\). While WRF overestimated December monthly mean wind speeds with a bias of 1.11 m s\(^{-1}\), it slightly underestimated August values with a bias of (minus) -0.34 m s\(^{-1}\). Qualitatively, statistical values were also histogram-plotted to show the model’s prediction performance for each of the eight individual stations. Figure 4 show that the model overestimated December predictions on five of the eight stations. While WRF slightly underestimated values on one station (#3), it predicted well on the two stations (#4 and #8). Likewise, whereas WRF model underestimated August predictions on four of the eight stations, as shown in
Figure 5, it slightly overestimated on one station (#5) and accurately predicted on the three stations (1#, 4#, and 8#).

Figure 4: Comparative analysis of Modeled and Observed monthly wind speeds for the month of December 1999 (modeled) and 2009 (observed).

Figure 5: Comparative analysis of Modeled and Observed monthly wind speeds for the month of August 1999 (modeled) and 2009 (observed).

Kapp and Jaisli 2010 have a detailed description of the stations used for evaluations in terms of station geographical locations and altitudes, which is shown in Figure 1 and Annex1 of this report. In general, WRF, configured with the high resolution in space and time, predicted accurately wind speeds over Kosovo for August and December 1999. While the work performed was a good representative of the year, more simulations and observations are required to draw a complete confidence level of wind profiles over the country. The slightly higher biases in December are consistent with the higher winter time winds in 1999 as compared to 2009 (Fig. 3). In the summer the 1999 and 2009
climatology is similar and thus the results are reflected as low biases of August winds in the comparisons.

4.2 Site Wind Speed Statistics

As indicated in the methodology, the wind speed data from the WRF model was output every 15 minutes and wind speed and direction values were extracted for Site #1 and Site #2. Afterwards, the statistical analyses of the local distributions of wind speed and wind direction on each site was carried out with distributions of wind speed with 1 m s\(^{-1}\) step classes and distribution of wind direction in 12 sectors. Later, the wind speed and wind direction distribution curves were constructed. The average air density was evaluated from the respective elevations of the two sites and the average wind power density was estimated for each site for the months of August and December. The turbulence intensity (TI) of the winds, which are irregularities of the winds, can cause power reduction and extra load to turbine. To assess its magnitude, the average value was thus estimated using the standard deviation of the wind speed normalized by the average wind speed at each site. Surface roughness at each site was also calculated from a wind shear computed using a second measurement at 49 m level of the model. The probability density functions, Rayleigh and Weibull distributions, which are good analytic approximation of wind speed distributions, were plotted as well. Finally, the energy yield and the capacity factor, from the model data, and from Rayleigh and Weibull distributions were calculated.

The Weibull distribution probability density function has 2-scale parameters: the a-scale parameter, which tells the maximum of the distribution and the c-shape parameter. When the c-shape parameter of 2 is assumed and the a-scale shaped factor is calculated, the resulting distribution is called Rayleigh distribution. The Rayleigh distribution applies only in a certain wind regions. The Weibull and Rayleigh parameters were computed and plotted using a software tool called ALWIN (ALWIN, 2013). Once the Weibull and Rayleigh distributions were computed and a turbine is selected from a catalog in ALWIN utility package, the energy yield was calculated by integrating over the power curve of the turbine multiplied by the probability density function for wind speed. Note that the probability density function for wind speed was computed by the Weibull distribution. The capacity factor of the turbine, which is a measure of the efficiency of the turbine, was
also calculated from the ratio of the energy output to the energy input. For this project, the NORDEX N-60/85 was used for both sites. This turbine has a stall control and it has also a hub height of 85 m, a nominal power of 1,371 kW, and cut-in/cut-out speed of 3.5 and 25 m s\(^{-1}\), respectively (Fig. 6).

Figure 6: NORDEX N-60/85 Power Curve used to estimate the statistical distributions for the selected two sites using modeled winds.

### 4.2.1 Wind Speed Statistics of December

**Weibull Wind Speed Distribution Curves:** Figures 7 (top and bottom) show the Weibull and the Rayleigh frequency distribution curves plotted using ALWIN, for December 1999 for both Sites #1 and #2, respectively. The data was every 15 min, at 10 m Above Ground Level (AGL) height and there were 2,977 wind speed and wind direction data points in the calculation. The blue bars are frequency of the wind in each class. For example, 10% of the wind speed lies between 1 and 2 m s\(^{-1}\) for Site #1 and the same percentage between 0 and 1 m s\(^{-1}\) for Site #2. The solid black line is the Weibull distribution at the hub height, which is 85 m and the dashed line is the Rayleigh distribution. Also as shown in Figures 7, the Rayleigh distribution is not a good fit for the model dataset at each site, whereas the Weibull curve shows a very good fitting. Hence, only the Weibull distribution is discussed in the subsequent sections. The average model
wind speed is given by $V_m = 6.67$ and $5.9 \text{ m s}^{-1}$ for Sites #1 and #2, respectively. The average speed from the Weibull distribution is slightly higher and is given by, $V = 7.27$ and $6.22 \text{ m s}^{-1}$ for Sites #1 and #2, respectively.

![Wind Speed Distribution](image1)

![Wind Speed Distribution](image2)

Figure 7: Weibull and Rayleigh frequency distribution curves plotted for Site #1 (top) and Site #2 (bottom), using ALWIN, for the month of December 1999.

The average turbulent intensities for each site were also calculated and are 0.797 and 0.867, which are really high. This is due to the diurnal variability of the wind speed, which resulted in high standard deviation and high turbulence on the site. The average wind power densities for Site #1 and #2 in December are therefore 570 and 366 W m$^{-2}$. 

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respectively. The wind speed distributions show that both sites have good wind distributions with > 250 W m\(^{-2}\) wind power densities. These calculations are at the hub height of the turbine with the extrapolation of the analytic distribution curves. Although these methods are very vital for statistical analysis of observed wind data, mesoscale modeling provides a liberty to use the wind data at several key levels to compute the wind power densities at each key level. However, the site analysis has important wind energy yield and capacity factor calculations at the hub height of a specific turbine.

**Wind Direction Distribution**: Figures 8 and 9 show the wind direction distribution curves plotted using ALWIN, for December 1999 for both Sites #1 and #2, respectively. Similar to the wind speed, the dataset is every 15 min, at 10 m AGL height and there were 2,977 total data points to compute the statistics. The wind directions were classed in 12 sectors, with each sector covering 30 degrees. The wind direction distributions are shown on the left and the distributions of the average and maximum wind speed per sector are shown on the right. For Site #1, more than 50% of the wind was from southwest; so were the maximum and average wind speeds (Fig. 8).

![Wind Speed and Direction Distribution for Site #1](image)

**Figure 8**: Wind speed and direction distribution for Site #1 for December 1999 from WRF model output at 15 min time resolution.

For Site #2, 30% of the winds came from southwest and a significant percentage also came from west, south and southeast. For the average and maximum wind speeds, most
of the wind flow blows from the southwest, and it also partly blows from a span covering from northwest to southeast (Fig. 9).

Figure 9: Wind speed and direction distribution for Site #2 for December 1999 from WRF model output at 15 min time resolution.

The wind direction distribution is vital information from the wind statistics. It provides us the orientation where the average and maximum wind speeds are blowing from. And therefore, the above qualitative pictorial representations of the wind direction distribution are very important information in the construction of local wind farms.

**Energy Yield Curves**: Figures 10 (top and bottom) show the energy yield estimated from the turbine at both sites at the hub height of the NORDEX N-60/85 turbine model for December 1999. For Site #1, the Weibull curve fits well again and the average power production is calculated to be 391.6 kW with total energy production of 291.4 MWh. Similarly, for Site #2 the average power from the Weibull distribution is 315.6 kW and the total energy production is 234.8 MWh. The capacity factors of Site #1 and #2 are 28.6 and 23.0%, respectively. These are relatively good considering the maximum wind power generation not exceeding 59%. Also note that the maximum average-power and total-energy productions are higher in Rayleigh than Weibull distribution estimation. However, only results from the Weibull distribution are analyzed, since its curve fits better with the measurements than the Rayleigh curve.
Figure 10: Different options of estimating average power and total energy productions using measurements, Rayleigh and Weibull distribution curves for Site #1 (top) and Site #2 (bottom) for December 1999 from WRF model at 15 min output.
4.2.2 Wind Speed Statistics of August

**Weibull Wind Speed Distribution Curves**: Similarly, Figures 11, 12-&-13, and 14 show the wind speed, wind direction and energy distribution curves, respectively, analyzed for August 1999 for both Sites #1 and #2. Similar to the methods used for December, the Weibull and the Rayleigh frequency distribution curves were plotted using ALWIN from the 15 min model dataset, at 10 m AGL height with 2,977 data points in the calculation.

![Wind Speed Distribution Curves](image)

Figure 11: Wind speed probability distribution for Site #1 (top) and Site #2 (bottom) for the month of August.
While the average model wind speed is given by $V_m = 3.06$ and $2.86 \text{ m s}^{-1}$ for Sites #1 and #2, the average wind speed from the Weibull distribution is slightly higher and is given by, $V=3.42$ and $3.2 \text{ m s}^{-1}$ for both Sites #1 and #2, respectively (Figs. 11, top and bottom). The average turbulent intensities for each site were also calculated and are 0.651 and 0.607, which are considered high. The average wind power densities for Sites #1 and #2 in August are therefore 34 and 22 W m$^{-2}$, respectively.

**Wind Direction Distribution**: Figures 12 and 13 show the wind direction distribution curves plotted for both sites using ALWIN, for August 1999. For Site #1, around 24% of the wind was from southwest, while 18.5% from east and 11% from north (Fig. 12-Left).

![Wind Direction Statistics](image)

Figure 12: Wind direction statistics for Site #1 for August 1999 from WRF model output at 15 min time resolution.

The maximum and average wind speeds were blowing from almost every direction (Fig. 12-Right). In a similar analysis, for Site #2, 23% of the wind was directed from the northwest, while significant amount were coming from the southeast (~21%), the west
(~15%) and from the southwest (~13%). Again as in Site #1, the maximum and average wind speeds in Site #2 were blowing from all directions (Fig. 13-Right).

Figure 13: Wind direction statistics for Site #2 for August 1999 from WRF model output at 15 min time resolution.

Energy Yield Curves: Figures 14 (top and bottom) show the energy yield estimated from the turbines at both sites at the hub height of the NORDEX N-60/85 turbine model for August 1999. For Site #1, the average power production from Weibull distribution is calculated to be 90.6 kW, with the total energy production of 67.4 MWh. Similarly, for Site #2 the average power from the Weibull distribution is 52.3 kW and the total energy production is 38.9 MWh. The capacity factors of Sites #1 and #2 are 6.6 and 3.8 %, respectively. This shows that these results are very low and that the turbines at both sites engage most of the time only at 4-7% capacity during the low-wind speed month of August. Therefore, it can be easily shown that the energy yield difference between December and August is significantly large. This is due to the seasonal variation of wind speed, where the summer wind speeds are low due to smaller temperature gradients driving a small pressure differences that result in low wind speeds. Summer weather
conditions are dominated by surface effects causing differential heating (e.g., sea breezes). However, in the Dragash area, in the absence of coastal effects, the topographic driven local katabatic and anabatic winds are the main local effects, which do not generate stronger flows in summer. During winter, the intensification of a thermal gradient across the polar front causes mid- and high-latitude high wind speeds.

Figure 14: Different options of estimating average power and total energy productions using measurements, Rayleigh and Weibull distribution curves for Site #1 (top) and Site #2 (bottom) for August 1999 from WRF model at 15 min output.
In summary our site analysis of the wind speed statistics based on the 10m model wind speed and direction data showed a high wind potential in December and a low wind potential in August. The December month is a representative for the winter months. We anticipate similar wind distributions for the five months of November, December, January, February and March. October and April would be transition months between the wind seasons and the month of August would be representative for the five months of May, June, July, August and September.

The vertical profile of the wind speeds is necessary to identify the 2D view of the wind distribution along the hills. It will also show the effects from boundary layer phenomenon (e.g. Low Level Jets) in changing the wind distributions near the surface. The horizontal distribution of the wind speed and the horizontal distribution of the wind power density are also critical information for this study. We would not be sure which site has the best resources until we analyze the horizontal distribution of the winds at different levels covering the Dragash area. All these analyses are therefore discussed in the subsequent sections.

4.3 Vertical Profiles of Wind Speed

The December vertical profiles of zonal cross-sections of Sites #1 and #2, respectively, were plotted in Figures 15 (top and bottom). These plots were produced to show the wind speed distribution in the vertical plane. Vertical profile analysis can show important boundary layer dynamics and interactions with the surface fields. The topographic structures of the nearby hills and valleys/passes are displayed as white or blank spaces in Figures 15, with 2D color-coded zonal wind speed cross-sections that stretched for more than 50 km across the east-west sides of each site. There were low level jets (LLJs) centered at about 4 km and the crests of the hills ranged from 1.5 to 2.5 km. The hills close to the LLJ had momentum transfer due to mixing during the day, while the valleys far away from the jets had relatively low wind speeds. The Site #1 (around 20.7°E) vertical profile shows the highest wind speeds by the foot-hills (left of 20.7°E at the box edge), during December, where there was wintertime cold air advection from the west (Fig. 15-top). The Site #2 profile shows the maximum wind speeds over the top-hills at the border of Macedonia, where the deep valley in the east created down slope winds that
tipped the LLJ toward the hill. The east side, along the border of Albania has also showed similar high winds (Fig. 15-bottom). The wind shear is also high, which creates high turbulences as we had identified earlier from our site statistical data analysis.

Figure 15: Vertical profile of monthly mean wind speed for Site #1 (top) and Site #2 (bottom) for December 1999.
4.4 2D Modeled Wind Speed and Wind Power Density Distribution

The wind speeds and directions, especially over complex terrain structures, are significantly affected by surface features within 1-km above the surface. Above the boundary layer the winds area called geostrophic, where the surface effects are minimal and the changes in the wind speed and direction are due to large scale temperature and pressure changes. Since the Dragash area is not a coastal zone, the main dynamic forcing for the spatial variability of the wind are the surface characteristic of the region, which includes the topography and surface roughness.

The 10m model wind distributions were plotted for the months of December and August. These plots utilized the modeled monthly average wind speeds from the model domain at 1-km horizontal grid spacing (Fig. 16 and 17). As a surrogate for the annual average wind speed distribution, the average of the two months was also plotted (Fig. 18). The results of the analysis show that during the high wind speed season of December, north and southeastern parts of Dragash, bordering Macedonia, and north and southwestern parts of Dragash, bordering Albania, have high wind speed potentials (Fig. 16).

Figure 16: 10m modeled monthly (December 1999) average wind speeds around the selected two test-sites from the WRF model 1-km horizontal grid spacing domain.
This is consistent with the results of the two vertical profile plots where the top of the hills experienced higher wind speeds due to their proximity to the LLJ. The valleys generally showed lower wind speeds across all Dragash. The average wind speeds for the month of December in these locations could range from 8 m s\(^{-1}\) to 10 m s\(^{-1}\) at a height of 10 m ASL. During the same month, the central parts of Dragash (between 20.6\(^\circ\)N and 20.7\(^\circ\)N longitudes) experienced higher variability where the wind speeds range from 4.5 m s\(^{-1}\) to 7 m s\(^{-1}\). In the central region there are two relatively higher wind speed zones. One is on the west side of Zhur along the 42.1\(^\circ\)N latitude-line and the other in the south above the 41.9\(^\circ\)N latitude-line, south of Restelice. These showed consistent high annual wind speeds ranging 6 – 7.5 m s\(^{-1}\) in the north and 7 – 8.5 m s\(^{-1}\) in the south. Hence, there could be an alternative site on these regions if the top of the major hills are not accessible for wind power development.

On the other hand, during the low wind speed months such as in August, the wind speeds are very low and could generally range from 2 m s\(^{-1}\) to 5 m s\(^{-1}\) (Fig. 17).

![Figure 17: 10m modeled monthly (August 1999) average wind speeds around the selected two test-sites from the WRF model 1-km horizontal grid spacing domain.](image-url)
Please note that as the vertical height increases, the wind speed increases as well. This implies that even during the low wind speed season, the utility scale wind turbines could show some performance if a two motor (one for high, another for low wind speeds) design is used.

Moreover, the modeled annual monthly average wind speeds of the 1-km horizontal grid spacing domain was also estimated as shown in Figure 18. The patterns of the distribution are similar to that of December and August with higher wind speed on the hills and lower wind speeds over the valleys and low elevation hills. The wind speed near the two sites is in the mid range at about 4.5 – 6 m s\(^{-1}\). However based on this wind speed mapping and if locations are accessible, better sites are available that can have higher wind speeds and big wind resources. For example, the hill west of Site #1 showed consistently higher wind speeds than the site itself and the region south of Restlice showed similar high wind speed distributions consistently, as well.

Figure 18: 10m modeled monthly (Annual 1999) average wind speeds around the selected two test-sites from the WRF model 1-km horizontal grid spacing domain.

In summary during the month of December, the 10m wind speed distributions of the area showed high winds over the high and mid elevation hills, while the low elevations and
valleys showed relatively low wind speeds. During the high wind season the highest wind speeds were observed over the mountains in the northern and southern border with Albania, the mountains behind Kuk and the mountains on the southeast border with Macedonia. During August the wind distribution is low all over the region with 3.5 – 4 m s$^{-1}$ speed on the top of the highest elevation hills. We also analyzed the 50m and 100m wind distributions that showed higher wind speeds with similar pattern, as expected.

4.5 Wind Power Density Distribution

We used the 50m and 100m wind speed distributions to estimate the wind power densities across the Dragash region. These vertical heights are key levels as most of the wind turbine hub heights are planted around those level values. The wind power density is the energy yield proportional to the swept area air density and the velocity cubed. It is given by the following equation:

$$P = \frac{1}{2} \bar{\rho} A v^3$$  \hspace{1cm} (1)

Where, $\bar{\rho}$ is the average density,
$P$ is the Power,
$A$ is the area, and
$v$ is the wind speed.

The wind power density linearly depends on the density of air and for site wind data analysis, the standard density value is used, where rho ($\bar{\rho}$) is 1.22 kg m$^{-3}$. This standard value corresponds to the density of dry air at a temperature of 15°C and a pressure of 1013.25 hPa. In areas of complex terrain however, the special and temporal variations of density could be significant and thus the wind power density calculations could be biased. To reduce such uncertainties, the special distribution of the density was calculated at 50m and 100m model levels, based on the temperature, pressure and mixing ratio (moisture effect) meteorological parameters, using the ideal gas law. The following equation is used to calculate the moist air density. Dry area density are used in the standard calculations, however we included the moisture effects to account the density variations due to moisture, which can affect the wind power density calculations.
\[ \rho = \frac{P}{\bar{R}} \left( \frac{1+w}{1+1.6078w} \right) \]  

(2)

Where, \( \rho \) is the average density, 
\( P \) is the Power,  
\( T \) is the Temperature,  
\( w \) is the mixing ratio,  
\( \bar{R} \) is the universal gas constant.

The temperature, pressure and mixing ratio were first extracted from the WRF model 1-km horizontal grid length domain at the two levels specified above and the density was calculated using equation 2. Finally, the wind power density was estimated using equation 1.

The density variation for the months of December (left) and August (right) at the levels of 50 m (top) and 100 m (bottom) are shown in Figure 19. The spatial variation shows that the northern part of Dragash has higher density than the southern and eastern part of the region.

Figure 19: The 2D density variation for the months of December (Left) and August (Right) at the levels of 50 m (Top) and 100 m (Bottom), respectively.
This is due to the high elevation areas in the south and lower altitudes (valleys) in the north. It can also be noticed from the plots that the seasonal density variability is not significant, as the variation is very small between the high wind speeds month of December and low wind speeds month of August.

Using equation 2 and the above density values, the 2D annual average wind power densities for the 100m and 50m vertical heights were calculated and are shown in Figures 20 and 21, respectively. Over intermediate terrain elevations, wind power densities at 100m (Fig. 20) above the surface vary over the course of the year between 10 – 200 W m\(^{-2}\) in summer (August figure not shown, as it is in the lower blue regions, as expected), and 100 – 1,600 W m\(^{-2}\) in winter. The lowest wind power densities are at some sheltered location like the river valleys, ranging from 50 – 200 W m\(^{-2}\) in August to 100 – 2,700 W m\(^{-2}\) in December.

![Map diagram](image)

Figure 20: December average wind power densities for the 100m vertical heights.

The highest wind power densities are at the high and medium elevation hills and range from 800 – 2,700 W m\(^{-2}\). Site #1, for example, has around 1,300 W m\(^{-2}\) which is consistent with our wind power density estimation when we did the statistical analysis.
(570 W m\(^{-2}\), at 10m height). Likewise, notice that Site #2 is located around the 900 W m\(^{-2}\) contour compared to its surface estimated value of 366 W m\(^{-2}\). It is interesting to see Site #1 is near an island of high wind speed region. As mentioned in the previous section, it would be in a good resource region if it would be slightly moved to the west. The regions east and south of Zaplluxhe, southeast of Manastirice, south of Zhur, west-southwest-northwest of Kuk, the region between Brod and Restelice, as well as the south corners at the border of Albania and Macedonia are high wind power density areas in the Dragash region.

Figure 21: December average wind power densities for the 50m vertical heights.

Similarly, the 50m (Fig. 21) wind power densities showed similar patterns and lower values as expected. The seasonal range of wind speeds over intermediate terrain elevations is between 10 – 200 W m\(^{-2}\) in August and 400 – 1,600 W m\(^{-2}\) in December. Due to the rise in terrain, wind speed generally increases towards the border of the country. The lowest wind power densities are again identified at some sheltered locations like the river valleys, ranging from 50 – 100 W m\(^{-2}\) in August to 100 – 400 W m\(^{-2}\) in December. The highest wind power densities are at the high and medium elevation hills.
and range from 400 – 1,600 W m². Accordingly, Site #1 is around 700 W m² contour line, which is consistent with our wind power density estimation when its statistical analysis at the surface was performed (570 W m² at 10m). Notice also that Site #2 is around 400 W m² contours, while its surface value was estimated at 366W m². It is again interesting to see Site #1 is near an island of high wind speed region. As mentioned in the previous section, it would be in a good resource region if it would be slightly moved to the west. As these key levels are close to the hub heights of most turbines, it is important that they are estimated as accurately as possible. Therefore, our results showed consistency between the site surface analysis and the wind power density calculations at key levels of 50m and 100m. These levels are very important for identifying the best wind sites.

5 CONCLUSION

In this study we have documented the wind resource assessment of the Dragash region of Kosovo. Using the WRF mesoscale model, we simulated two representative months (August and December) for 1999. The year was selected based on the climatological wind data analysis from the NCEP reanalysis. Our modeling configuration utilized three nested domains, with the highest grid resolution of 1-km covering the Dragash region. This resolution was enough to resolve the necessary topographic structures, such as wide river valleys and mountain ranges. We ran the model for one month by continuous re-initialization of every seven days and 24-hr spin up period to ensure model accuracy not to drift from the observed reanalysis fields. In domain three, we saved the data every 15 minutes that is necessary for detailed statistical analysis on selected locations. The client selected two sites for detailed statistics and energy yield calculations. Site #1 is on the North, whereas Site #2 is on the south location of the central Dragash region.

The model results were validated against observations from eight stations around Kosovo. For the validation analysis, we used mean monthly observed data averaged from 10 min time resolution dataset recorded during 2009. The use of 2009 for validation was justified by the climatological proximity of that year to the simulated year of 1999. Our validation results showed very good match with observations. Following model evaluation, we used the 15 min modeled wind results at 10m height to carry out the statistical analysis of the
probability density distributions of the wind speed and the wind direction in twelve sectors, and the energy yield and capacity factor for both sites.

In summary our site analysis of the wind speed statistics based on the 10m model wind speed and direction output showed a high wind potential in December and a low wind potential in August. The December month is a representative for the winter months. We anticipate similar wind distributions for the five months of November, December, January, February and March. While October and April would be transition months, the month of August would be representative for the five months of May, June, July, August, and September.

We also analyzed the vertical profile of the wind distribution during the high wind season of December. The vertical cross-sections are sliced over the respective sites. The hills close to the low level jet centered at 4km have higher wind resources since they get momentum transfer from the jet by eddy mixing. The valleys have relatively low wind speeds. While the Site #1 (around 20.7°E) vertical profile shows the highest wind speeds by the foot-hills (left of 20.7°E at the box edge) due to December wintertime cold air advection from the west (Fig. 14), the Site #2 profile shows the maximum wind speeds over the top-hills at the border of Macedonia, where the deep valley in the east created down slope winds that tipped the jet toward the hill. The east side, along the border of Albania has also shown similar high winds. The wind shear is also high, which creates high turbulences as we have identified from our site statistical data analysis.

We also analyzed the 2D distribution of the 10m wind speed output. During December, the 10m wind speed distributions of the Dragash area showed high winds over the high and mid elevation hills, while the low elevations and valleys showed relatively low wind speeds. During the high wind season, the highest wind speeds were observed over the mountains in the northern and southern border with Albania, the mountains behind Kur and the mountains on the southeast border with Macedonia that ranged 6 – 8.5 m s⁻¹. During August the wind distribution is low all over the region with 3.5 – 4 m s⁻¹ speed on the top of the highest elevation hills. We also analyzed the 50m and 100m wind distributions which showed higher wind speeds with similar pattern as expected.
Finally, we calculated the wind power densities of the whole region at the model levels of 50m and 100m. We chose these levels because those are key levels for most turbine hub heights. In the wind power density analysis we included the temporal and spatial moist air density variations around that region. In our density calculations the temporal and spatial variations were significant and used to calculate the wind power density at those key heights. The wind power densities of the two heights showed similar patterns as the distribution of wind speeds where the high and medium elevations showed the high wind power densities, with a maximum of 2,700 W m\(^{-2}\). The low elevations, on the other hand, showed low wind power densities of up to 400 W m\(^{-2}\). The August distributions are generally low ranging from 10 – 200 W m\(^{-2}\).

While the central Dragash relatively has low wind power density, two locations that showed consistent high wind resource in the central Dragash are the hills west of Site #1 and the region south of Restlice. Kosovo in general and the Dragash municipality in particular need renewable energy resources to meet their economic development goals and to catch up in the renewable energy technologies with the rest of the European countries. This study showed that the Dragash area has significant wind power potential to augment its current power generation. The economic value of wind energy is significant. Even though, the highest wind resources area are located in the high elevations where the access is limited, other sites in the areas with lower elevations mentioned above could also have good alternative wind resources for smaller scale stand alone wind farms.

This study answered outstanding wind resource assessment questions about the Dragash municipality wind resources. Due to lack of observational data, microscale wind modeling would be challenging to accurately reproduce for any location in the area. Extensive ground stations measurement campaigns are thus necessary to acquire temporally high resolution meteorological data at key locations in the region. Microscale and long-term mesoscale modeling simulations, environmental and socioeconomic impacts as well as economic feasibility studies are some of the relevant studies that could be carried out in the future to exploit the wind energy resources in Kosovo.
Acknowledgement: We thank the client for selecting us to conduct this challenging task. We would be very happy to cooperate in any climate and energy related consulting project in the future.
REFERENCES

ALWIN Software, 2013. [Available Online at: www.ammonit.de/download/alwin_e.exe]


1. ANNEXES

Annex 1: Observed Wind Speed of eight locations (Source: NEK, 2010).

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