Wind Farm Noise Maps in a Country Side Area

CLAUDIO GUARNACCIA, JOSEPH QUARTIERI, CARMINE TEPEDINO
Department of Industrial Engineering
University of Salerno
Via Giovanni Paolo II 132, Fisciano (SA)
ITALY
cguarnaccia@unisa.it , quartieri@unisa.it , ctepedino@unisa.it

Abstract: - The need for alternative and sustainable energy sources is of high importance nowadays, due to the growth in energy demand and, subsequently, the rise of pollution issues. One of the most relevant source of sustainable energy is the wind. Even if wind turbines represent a clean power source, the acoustical and visual impacts have to be taken into account. The installation of wind turbine, in fact, can lead to annoyance related to the noise emissions, even in rural areas.
In this paper, the monitoring of noise emissions by a wind farm is performed with the aid of a predictive software. Different noise emission scenarios are sketched, related to the wind condition. The introduction of directivity in the source represents a novelty that can improve the prediction of noise maps, with respect to the pointlike source approximation.

Key-Words: - Wind turbines, Noise level, Predictive software, Directivity, Noise map

1 Introduction

One of the most important problems of this century is the energy crisis characterized by the lack of petrol and by the global warning. To cope this problem alternative solutions have been sought, such as green and renewable energies. In this complex scenario of the sustainable development, the wind turbine power source is an important component.

Wind power has been used for different purposes through the ages, but only recently the wind turbines are developed specifically to generate electricity. According to the Global Wind Energy Council report of 2009, approximately at the end of 2008 there were 120.800 MW of wind energy capacity installed around the world [1]. The new global total for wind power production at the end of 2015 was 432,419 GW [2].

During 2015 in the EU 12.800 MW of wind power were installed, that represent an increase of 6.3 % on 2014 installation.

In this scenario, the raise of environmental problems due to the installation of wind farms is an implication to be considered. The most relevant effects are the landscape visual disturbance and the noise annoyance. The latter is usually referred to few sensitive receivers, since the turbines are generally installed in country side and/or in the higher part of hills or mountains close to villages. For this reasons, very often a careful noise investigation prior the installation is not performed, leaving the problems to possible legal procedures started by the inhabitants of the area.

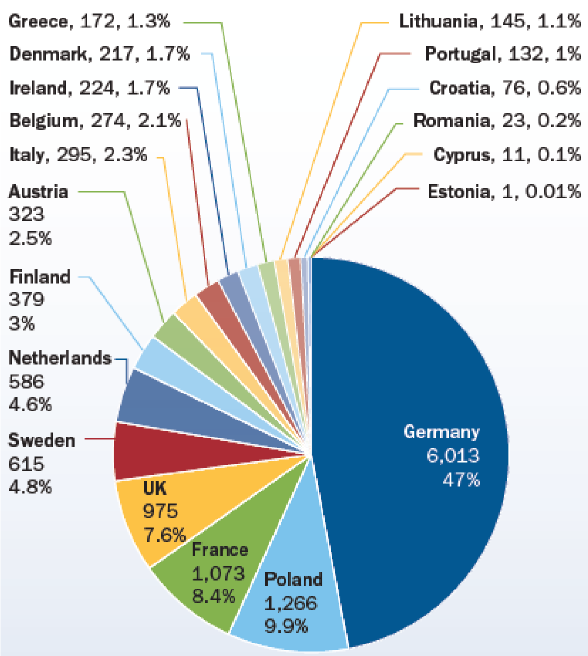

Fig. 1: EU member state market share for new wind energy capacity installed during 2015 (MW).

Several studies in literature regard wind turbine noise problem. The main aim is to help producers and policy makers in the site choice, giving them tools to predict the noise that could be produced by different positions and configurations of wind farm. For instance, Persson Waye and Öhrström [3] proposed an experimental study in order to support the hypothesis that different sound properties can be related not only to the operating condition of the wind farm, but also to the perception and annoyance for wind turbine noise. A relevant result of this experiment, which consisted in recording and compare the noise produced by five wind turbines in terms of reported perception and annoyance, was that the different turbines gave different annoyance perception, although the equivalent A-weighted SPL were the same. These subjective sound characteristic can be very relevant for perception and annoyance, especially at low background noise levels. More subsequent studies enforced this result and suggested that the presence of sound characteristics subjectively described as lapping, swishing, and whistling are responsible for the differences in perception and annoyance between the sounds [4]. In [5-7], some of the authors implemented a simple analytical model, able to give the propagation of the acoustic intensity level as a function of the horizontal distance from the tower, resulting in a Lorentzian function, with a maximum level in correspondence of the tower (minimum distance source-receiver) and an inflection point.

In this paper, after presenting the sources in a wind turbine, the authors describe the implementation of a wind farm in Italy in a noise predictive software. The resulting models will give interesting information about the noise map and propagation in a country side area. In addition, the directivity of the source will be implemented in the software, giving new results and map features.

2 Noise sources in a wind turbine

There are many types of noise that can be generated by wind turbine operation: tonal, broadband, low frequency, and impulsive. They are caused by turbine components, interaction of wind turbine blades with atmospheric turbulence, interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine. In addition, they could be originated when the turbine blade encounters localized flow deficiencies due to the flow around a tower [8]. Thus, the noise can be classified into mechanical noise and aerodynamic noise, according to the source.

The mechanical noise is generated by the mechanical components of the wind turbines during their operation. The sources of this noise are mainly: gearbox, generator, yaw drives, cooling fans, auxiliary equipment. The hub and tower could act as loudspeakers, transmitting the mechanical noise and radiating it. The noise is directly propagated from the component surface or interior, into the air.

The aerodynamic noise is the largest noise produced by the wind turbine operation and is correlated to the rotors speed. It could by classified into two groups: inflow turbulence noise, airfoil self-noise. These noises depends on the atmospheric turbulence and on the interaction between blades and wind.

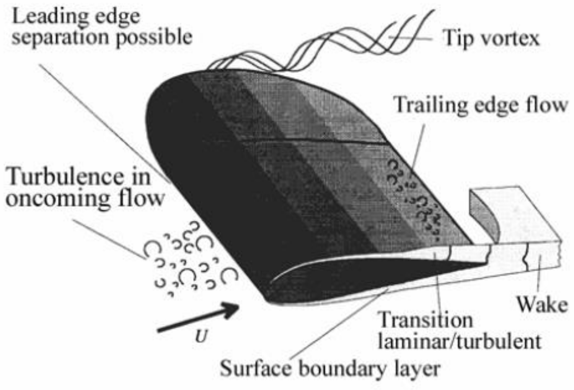

Fig. 2: Schematic of flow around rotor blade [8]

3 Software model

In this section, the authors present the implementation of a preliminary model in the predictive software CadnaA® (produced by DataKustik) framework. This model allows to describe the source “wind turbine” in different operating condition, varying the geometry of the source, its power level and directivity.

The software algorithm is based on “Angle Scanning” and inverse “ray-tracing” principles. The area under study can be divided in many small surfaces in which a receiver is placed at a variable height (in our case is 2 m), obtaining the calculation grid. From each grid element, many rays with a full angle coverage (omni directive) are released and these rays, potentially after many reflections, intercept the noise source. The attenuation of the sound wave is given by the path length of the single ray. In addition, specific receivers can be inserted in the map, with the possibility to export the results in a worksheet.

The first step consists in the software simulation of a single pointlike source, without directivity. This means that the source emits in the full solid angle. The parameters of the simulations are resumed in Tab.1 and the resulting noise map is reported in Fig. 3.

Tab. 1: Simulation and calculation grid parameters

L_W	98,0 dBA
Height of the source	70 m
Evaluation grid height	2 m
Receivers height	4 m
Distance between receivers	10 m

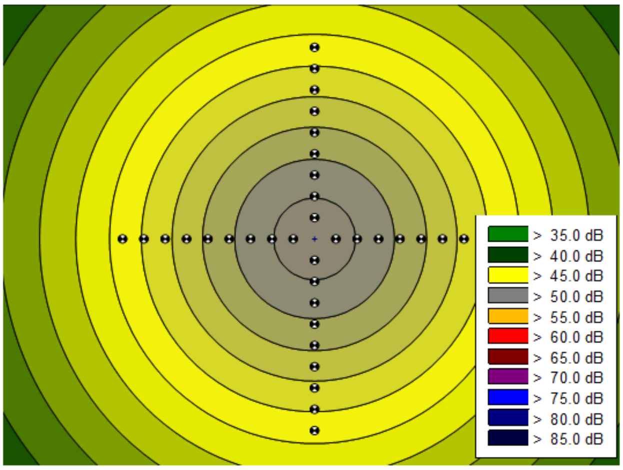

Fig. 3: CadnaA® noise map (values are in dBA) for a pointlike source with L_w=98 dBA, height=70 m. The grid is evaluated at 2 m from the ground and the distance between two receivers (black and white circles) is 10 m.

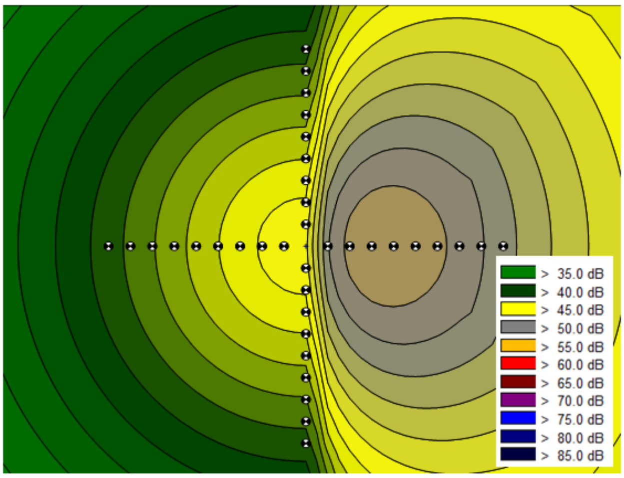

Fig. 4: CadnaA® noise map (values are in dBA) for a pointlike source with L_w=98 dBA, height=70 m with high directivity. The grid is evaluated at 2 m from the ground and the distance between two receivers (black and white circles) is 10 m.

In order to obtain a more accurate noise map, the directivity of the source, due to the wind speed and direction, can be taken into account. Such a purpose is pursed giving, as an input in the source parameters, the directivity vector. Thus, a new simulation with the same parameters resumed in Tab. 1, was performed, assuming that the favourite direction of noise was west. The noise map obtained is shown in Fig. 4, in which is clearly shown the shift of the maximum point in the wind direction, with respect to the previous map. This result leads to the conclusion that, in addiction to orography and other features of the source and of the area, also the directivity is important to obtain accurate noise maps of the wind farm.

4 Simulations of the noise produced in a wind farm

In this section, a wind farm will be implemented in the predictive software CadnaA®. The software allows to simulate the entire area under study, implementing the real orography and features of the terrain, the wind turbines (as the pointlike sources described in the previous section), together with any other relevant element, such as roads, buildings, foliage, etc.. After implementing the model, a noise map is produced, giving immediate information about the noise impact in the area, according to the different conditions considered in each simulation.

4.1 Description of the wind farm

The wind farm under study is located in Taverne Vecchie, in the town of Postiglione, province of Salerno (Italy). The map of the area, taken from Google maps © and then implemented in the software CadnaA, is shown in Fig. 5.

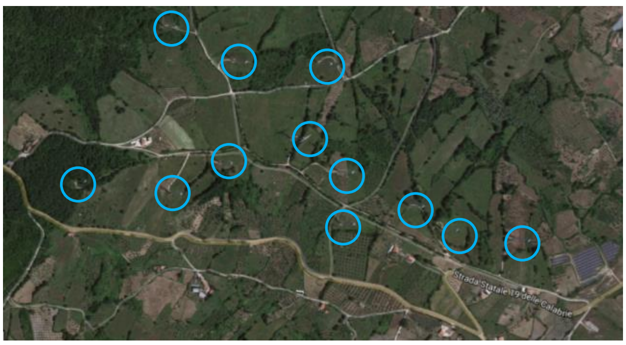

Fig. 5: Map of the area of Taverne Vecchie, Postiglione (Salerno, Italy) (Courtesy of Google Maps©). The turbines are highlighted by the light blue circles.

The wind farm is composed by 12 turbines Vestas V52. The height of the hub is 65 m from ground level.

The turbines are placed quite close to the town of Postiglione, that is a small village of about 2500 inhabitants. The area is rural and composed of small hills. Few roads, with quite low traffic flows, surround the wind farm. The noise produced by these roads can be negligible in the noise map drawing.

4.2 Description of the simulation parameters

As already stated in previous sections, each wind turbine is implemented into the software as a pointlike source. The value of the acoustic power assigned to each turbine is related to the wind speed in each hour. The acoustic source power as a function of the wind speed is reported in Fig. 6 [9].

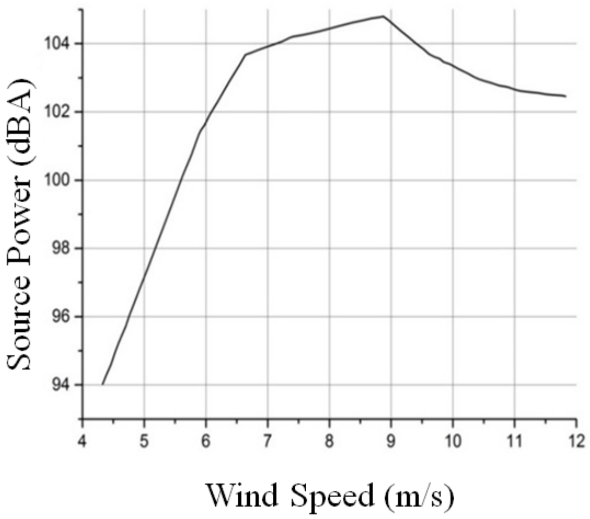

Fig. 6: Source power level as a function of the wind speed of a turbine Vestas V52, with height of the hub 65m [9].

The calculation is performed on a grid having 2x2 m^2 elements. In each grid element, a virtual receiver, with height of 4 m, is placed and used to draw the map of the levels in the entire area. Of course, all the items in the map have been inserted with their relative height with respect to the terrain. The orography was implemented considering the height points given by the map of the area.

Fig. 7 reports the 3D view of the wind farm. This figure shows the presence of turbines in the hill landscape and their relative heights. It is easy to notice how the orography of the terrain modifies the distance between sources and receivers, as will be highlighted by noise maps.

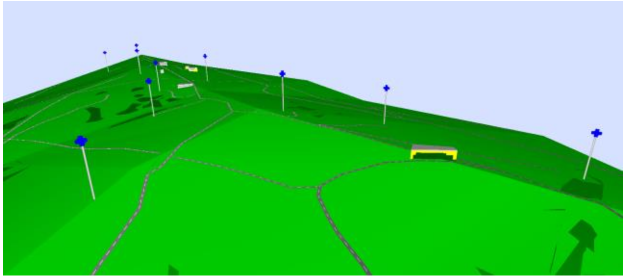

Fig. 7: 3D view of the wind farm area of Taverne Vecchie, implemented on CadnaA®. The blue crosses are the pointlike sources simulating the wind turbines.

4.3 Simulations of the noise map without source directivity

The first simulations have been run neglecting the source directivity, i.e. assuming an isotropic emission of the wind turbines.

In order to highlight the variation during a typical winter time day, hourly average wind velocities have been set, extracting information from online weather databases. Each wind speed corresponds to a source power level, as reported in Tab. 2.

Once the power levels have been fixed, noise maps can be calculated for each different wind speed (i.e. for each different source power level). Results are reported in Figg. 8-15.

Tab. 2: Simulation parameters

Hours	Wind Velocity [m/s]	Lw [dBA]	Hours	Wind Velocity [m/s]	Lw [dBA]
01 AM	5.3	98.3	01 PM	9.2	104.3
02 AM	6.1	102	02 PM	8.9	104.6
03 AM	6.4	102.8	03 PM	8.3	104.6
04 AM	7.2	104	04 PM	7.5	104.2
05 AM	7.5	104.2	05 PM	6.4	102.8
06 AM	8.1	104.4	06 PM	6.4	102.8
07 AM	8.6	104.7	07 PM	5.6	100.1
08 AM	9.2	104.3	08 PM	5	97.4
09 AM	9.4	104	09 PM	5.3	98.3
10 AM	9.4	104	10 PM	5	97.4
11 AM	9.4	104	11 PM	5.3	98.3
12 AM	9.4	104	12 PM	5.3	98.3

Looking at the resulting noise maps, it is evident that there is a strong influence of the orography of the terrain, that changes the distances between sources and receivers, according to the slope of the hill. In addition, it can be noticed that when the wind speed is basically constant, the noise map does not change.

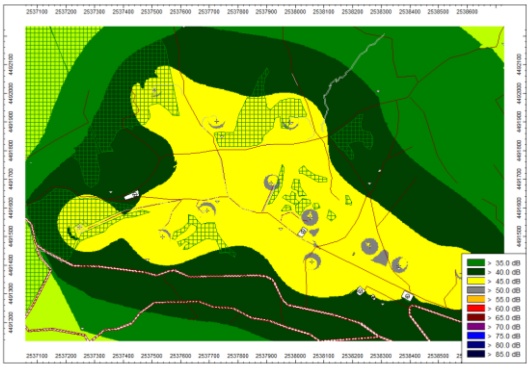

Fig.8: Noise map of the wind farm area. Source Power Level: 98.3 dBA. Hours: 01 AM, 9PM, 11PM, 12PM.

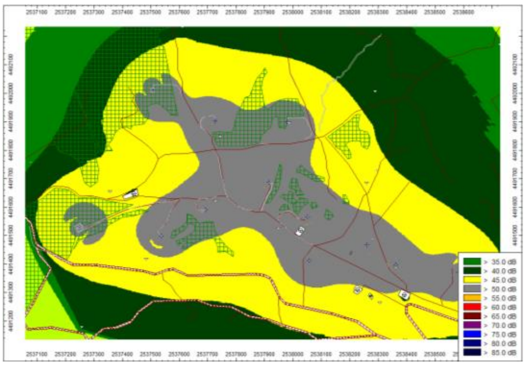

Fig.9: Noise map of the wind farm area. Source Power Level: 102.2 dBA. Hours: 02 AM.

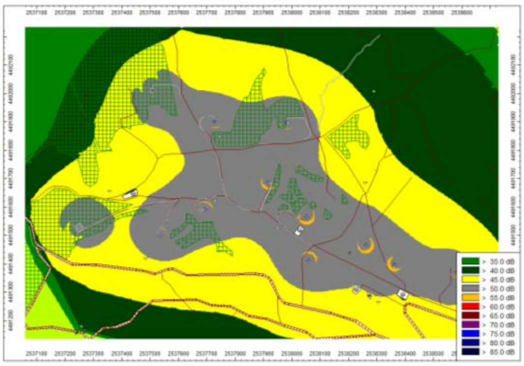

Fig.10: Noise map of the wind farm. Source Power Level: 102.9 dBA. Hours: 03 AM, 5 PM, 6 PM.

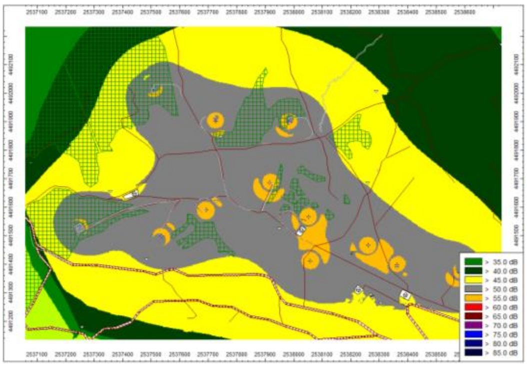

Fig.11: Noise map of the wind farm area. Source Power Level: 104.2 dBA. Hours: 05 AM, 01 PM, 04 PM.

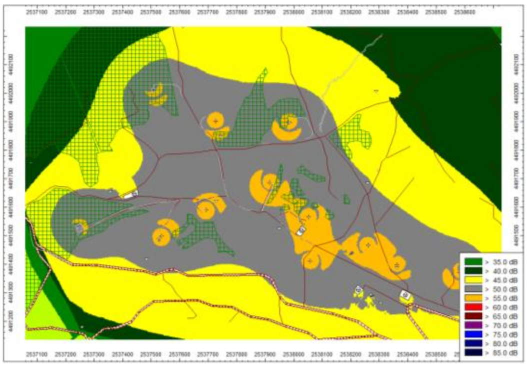

Fig.12: Noise map of the wind farm area. Source Power Level: 104.7 dBA. Hours: 07 AM, 02 PM.

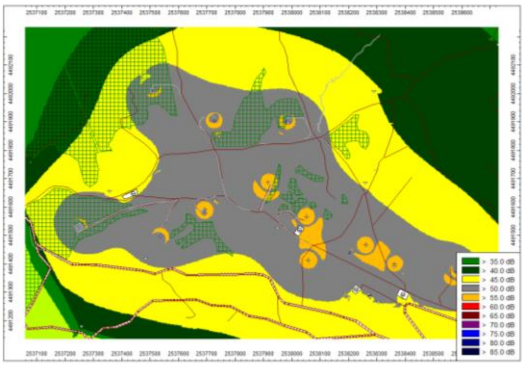

Fig.13: Noise map of the wind farm area. Source Power Level: 104 dBA. Hours: 04 AM, 09 AM, 10 AM, 11 AM, 12 AM.

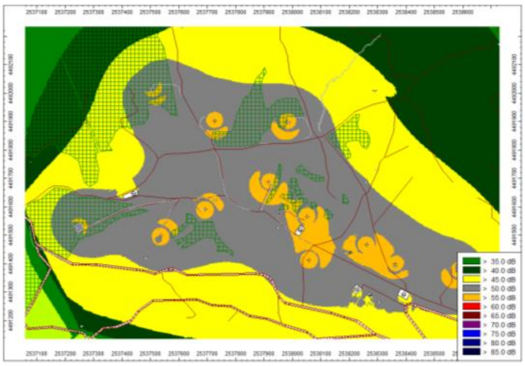

Fig.14: Noise map of the wind farm area. Source Power Level: 104.6 dBA. Hours: 3 PM.

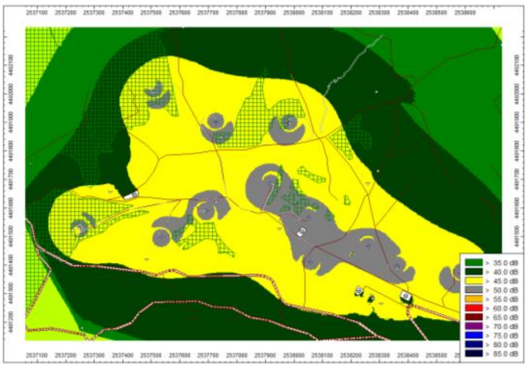

Fig.15: Noise map of the wind farm area. Source Power Level: 100.1 dBA. Hours: 7 PM.

In order to perform a comparison with the noise maps produced in presence of directivity (see next subsection), new simulations have been executed, considering a different wind speeds set, in a day of the week in which variation in the wind direction were recorder. The parameters used in the new simulations are resumed in Tab. 3. In this case, the wind direction has not been used.

Resulting noise maps are reported in Figg. 16-19, and, in Fig. 20, the 3D view of the area is showed.

It is interesting to notice that, of course, the higher levels are obtained close to the turbines and for higher wind speeds. In addition, outside the wind farm area, the noise rapidly decreases.

Tab.3: New simulation parameters

Hours	Wind velocity [m/s]	Direction	L_{WA} [dBA]
01am-02am	5.28	W	98.3
03am-05am	5	WSW	97.4
06am-08am	4.7	W	96
09am-11am	5	W	97.4
12pm-2pm	5.28	WNW	98.3
3pm-5pm	3.6	WNW	93.4

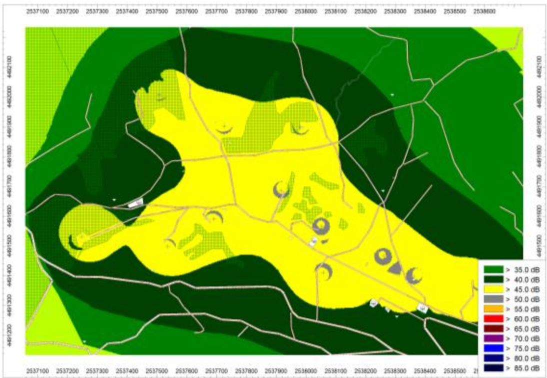

Fig.16: Noise map of the wind farm area. Source Power Level: 98.3 dBA.

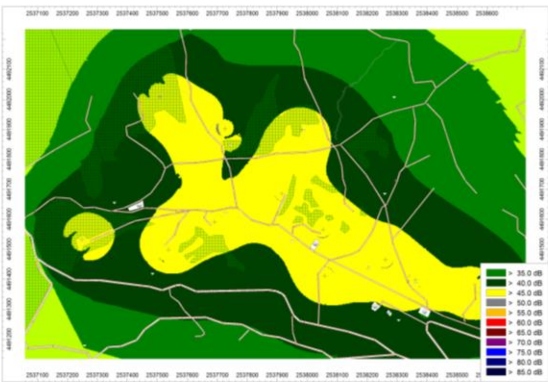

Fig.17: Noise map of the wind farm area. Source Power Level: 97.4 dBA.

Fig.18: Noise map of the wind farm area. Source Power Level: 96 dBA.

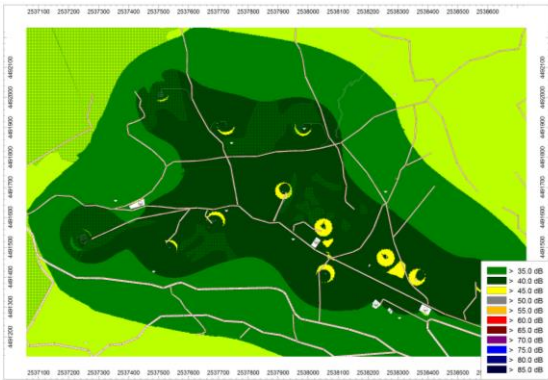

Fig.19: Noise map of the wind farm area. Source Power Level: 93.4 dBA.

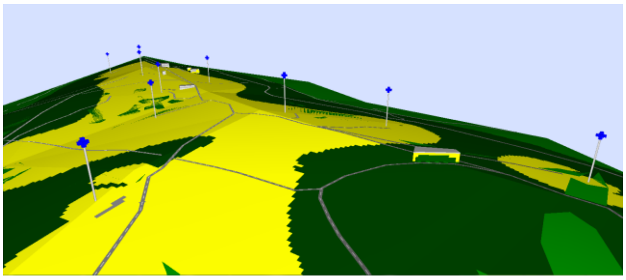

Fig. 20: 3D noise map of the wind farm area obtained in CadnaA®. The Source Power level is 97.4 dBA.

4.4 Simulation with the directivity of the sources

In this subsection, simulations with the directivity of the noise source are presented, assuming that this feature of the turbine depends on the wind direction.

Let us recall that turbines have an internal engine able to orient the nacelle in order to maximize the rotor speed and, consequently the energy production. This means that the turbine rotates according to the wind direction.

The parameters of the simulations with directivity are the same of Tab.3.

In order to obtain a realistic noise map, wind speed data of a typical day of the winter months were used. The choice was a day with a moderate variation of the wind direction, in order to see how noise maps change. It is important to underline that, usually large changes in the wind direction correspond to high values of the wind speed. In this cases the turbines do not operate, in order to prevent mechanical damages.

Resulting noise maps are reported in Figg. 21-26, and, in Fig. 27, the 3D view of the area is showed.

It is evident that the directivity change very much the noise map simulations, influencing the higher values zones position. Again, wind speed is the most influent parameter in noise production.

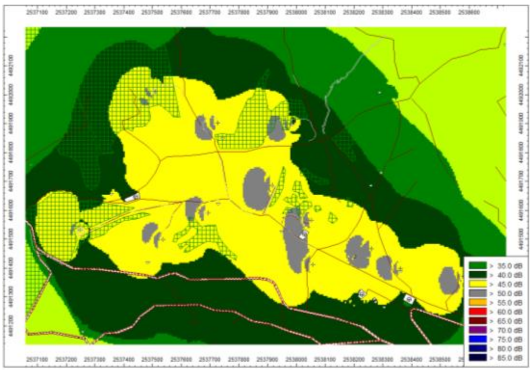

Fig. 21: Noise map of the wind farm area. Source Power Level: 98.3 dBA, with a preferred direction: West.

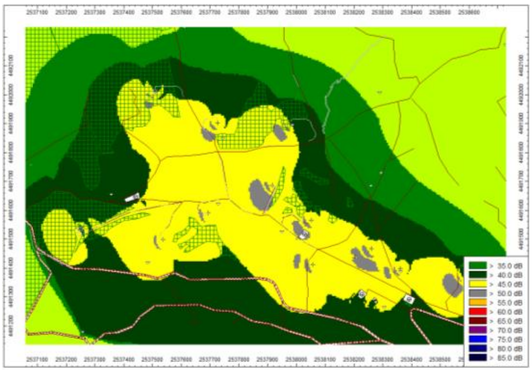

Fig. 22: Noise map of the wind farm area. Source Power Level: 97.4 dBA, with a preferred direction: WSW.

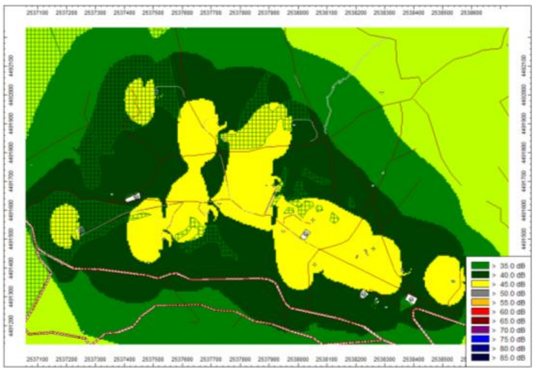

Fig. 23: Noise map of the wind farm area. Source Power Level: 96 dBA, with a preferred direction: W.

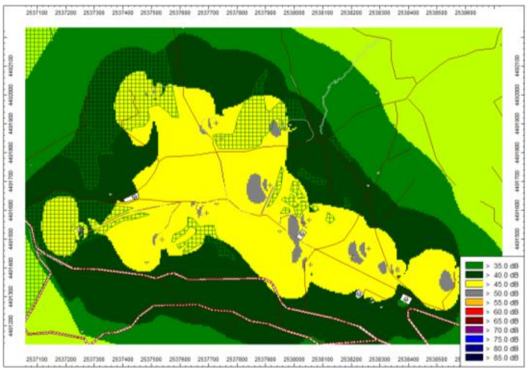

Fig. 24: Noise map of the wind farm area. Source Power Level: 97.4 dBA, with a preferred direction: West.

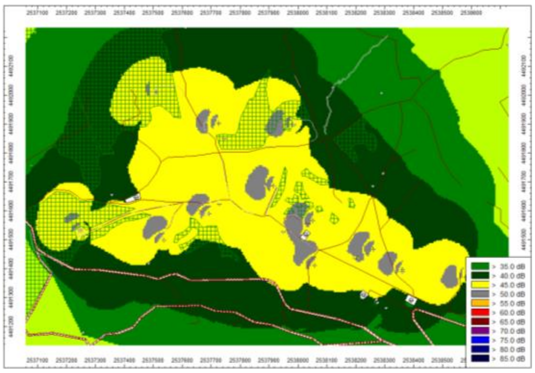

Fig. 25: Noise map of the wind farm area. Source Power Level: 98.3dBA, with a preferred direction: WNW.

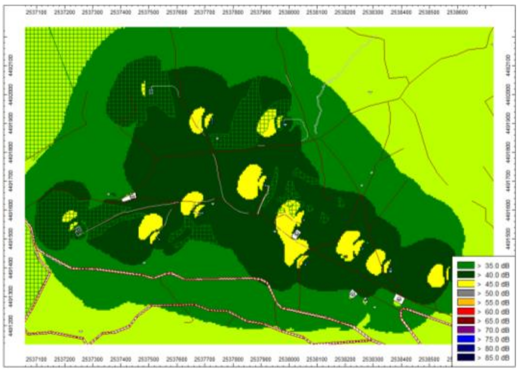

Fig. 26: Noise map of the wind farm area. Source Power Level: 93.4 dBA, with a preferred direction: WNW.

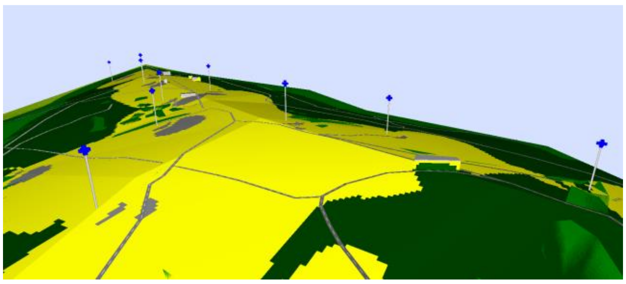

Fig. 27: 3D noise map of the wind farm area obtained in CadnaA®. The source power is 97.4 dBA with directivity.

5 Conclusions

In this paper the authors faced the problem of the noise produced by wind turbines by means of predictive software approach. The modelling of a wind farm in the framework of the software allowed to run various simulations, with different wind speed and direction.

Results showed that the operation of wind farm produces a noise map that is clearly influenced by the position of the turbine with respect to the hill slope. In fact, even though wind speed is the most influent parameter in noise production, basically because it fixes the source power level, the orography of the terrain represents an important feature in the noise propagation, since it affects the distance between sources and receivers.

In addition, the introduction of directivity of the source, related to the wind direction and, consequently, to the sound propagation, led to strong variations in the noise map. In particular the shape of the sound field is modified, introducing a shift in the same direction of the wind.

The procedure described in this paper can be useful to understand how the noise propagates in the area of the wind farm and furnishes a tool to help policy maker in wind turbine placement choice or wind farm design.

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