«3D Geovisualisation of Noise and Visual impact of a proposed wind farm development using a GIS based visual-acoustic 3D simulation»

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Abstract. Visual presentation has been identified as an effective means of communicating landscape related information. Thus the use of three-dimensional representations, instead of 2D cartographic approach, as a tool of communication for environmental impacts has been increased the last years. 3D geovisualisation approaches are used from policy makers and scientists to communicate with the public for the description and exploration of spatial data in different scales. Using digital landscape visualisations are increasing the transparency and the decoding of spatial information by extending the validity of the environmental representations in a more efficient way. This research is discussing the differences between the 2D cartographic representation and 3D visualisation relating to the potential visual and sound impacts of proposed wind farms development on the island of Lemnos. This paper documents an approach of using 3D representations for visibility and noise prediction levels for wind parks as they are derived from a GIS based spatial simulation, for increasing the public understanding of potential aesthetic and noise impacts of the proposed developments.

1. Introduction

Wind energy market developments appear to be a complicated matter all over Europe. Planning, decision and implementation process often fails on the local level where social acceptance is the key issue for successful wind parks development (Appleton & Lovett, 2003; Devine-Wright, 2005; Wolsink, 2007). The location siting process of the wind park considers to be a very crucial factor on influencing the public acceptability. There are two factors that unrest both the local community and government; the first and most understandable from the public sector, is the impact of the new infrastructure in the aesthetic quality of the landscape and the second and less understandable is the noise annoyance factor. Both the above mentioned factors are correlated with the landscape morphology (De Kluijver & Stoter, 2003; Stoter et al., 2008). They are also studied and calculated for every wind park planning and sitting process. The results of these processes are visualized using, as common way of communication with the public, the two-dimensional maps.

Digital visual representation of spatial phenomena has been identified as an effective mean of communicating landscape related information with the public due to the new advances in computer visualisation techniques. Newly, policy makers and scientists are increasingly using of three-dimensional (3D) representations of environmental impacts as a tool of communication with the local government and local communities (Berry et al., 2010; Appleton & Lovett, 2005; Orland et al., 2001; Orland, 1995). 3D geovisualisations are emphasizing the transparency and the decoding of spatial information by extending the validity of the environmental representations in a more efficient way (Appleton & Lovett, 2002). The lack of the visualisation tools used to improve the communication between policy makers and the local communities for wind farm facility development lead us to develop a new 3D geovisualisation approach of visual and noise impact for future wind park development.

This specific research is concerned with discussing the methodology of 3Dvisualisation of digital spatial information relating to the potential visual and noise impacts of proposed wind farms development on the island of Lemnos. This paper documents an approach of constructing 3Dgeovisualisations using spatial analysis results deriving specific spatial visual and noise models. The visibility analysis of spatial models takes into consideration the land morphology combined with the real size of the wind turbines (IEA 1994, Stoter et al. 2008). The final results are two different maps; a binary map which shows whether or not a wind turbine is visible from every point of the island and a quantitative map showing the number of the wind turbines which are visible from each point in the study area. The developed noise spreading model is based on the International Energy Agency: Wind Turbine Noise Model and assumes that the noise spreads over the source either hemi-spherically or spherically. The noise model results in a map that shows for each point the cumulative noise caused by the wind turbines in the study area.

The overreaching aim in this research is to investigate techniques for improving visual communication, dissemination and public participation in the wind energy planning process. Thus the visual and sound spatial simulation results derived from GIS tools are used for the creation of 3D geovisualisations with the noise emissions embedded. Two objectives were identified; the first objective was to improve visualisation of continuous spatial phenomena on the landscape by applying a 3D approach. Based on the specific study area an approach is presented to generate 3D visual impact visualisations and 3D noise maps as basis for noise impact representation in the landscape. The second objective was to examine the potential of 3D visualisation approaches with the noise emissions embedded in comparison with the common used noise maps, for increasing public participation and improving the effectiveness of continuous spatial phenomena representation related to environmental impacts in the landscape. The final results of this research are a) 3D animations and b) real time navigation in a virtual landscape where the user is able to trigger specific “spatial noise tags” in order to achieve the real noise emissions.

The overall goal of this contribution is the creation of 3D visual and acoustic impact representations of wind farms in comparison with the 2D cartographic approach in order to enhance public communication as far as Visual and Noise Impact assessment concern.

2. Methodology

Visual presentation has been identified as an effective means of communicating landscape related information, particularly due to the increasing GIS software and hardware visualisation capabilities (Dockerty et al., 2006). Effective spatial information and communication between policy makers and the public, during the planning process of a wind farm development is one of the most important elements of the environmental decision making process (Devine-Wright, 2005; Berry et al., 2011). In terms of wind farm planning process and as far as wind farm environmental assessment concerns, this can be divided into two different but related impacts, namely the visual and noise impacts. The potential visual and noise impacts of proposed wind farms are accessed before the development of the facility as a part of the environmental impact assessment. In this process the social acceptance is a key issue for successful wind energy market development. For this planning process policy makers and public stake holders state that there is a lack of planning instruments to improve or support social acceptance (Madeleine et al., 2012).

2D viewshed mapping techniques and cumulative noise maps traditionally used to inform the public for the potential visual and noise impacts. Current tools and techniques available for determining visibility and simulating data for noise levels fail to adequately integrate visual and acoustic factors for facility planning in terms of public participation (Appleton & Lovett, 2003). Additionally 2D noise maps can cause lack of understanding of the noise impact from the public (Kluijver de Henk & Stoter 2003). Thus, participatory wind power planning needs adequate new instruments to enhance public participation in a more efficient way in terms of communicating with the spatial information.

In contrary 3D visualisations provide an effective way of representing large amounts of spatial related information to a wide audience, especially those with no experience of GIS or mapping (MacEachren et al., 1994; Appleton & Lovett, 2002). Also GIS based 3D visualisations have proved to facilitate the communication between various stakeholders, policy makers and the public in the context of participatory wind power development (Lange & Hehl-Lange, 2005).

This paper illustrates the results of a 3D landscape visualisation based on GIS-based visual and noise spatial analysis results in comparison with the common used in the wind facility planning process, viewshed and cumulative noise maps.

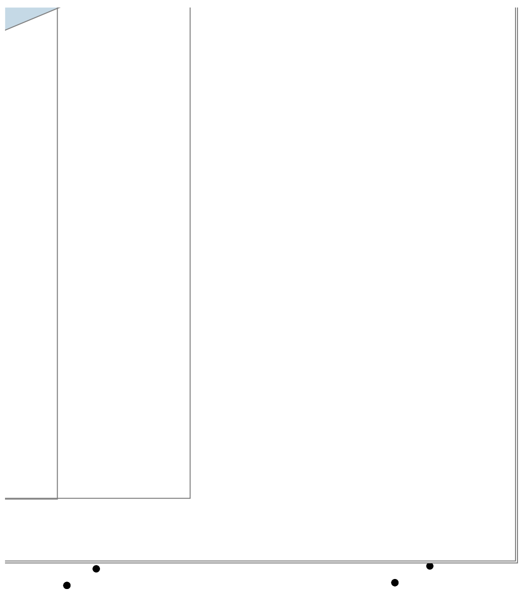

Figure 1. Overview of the workflow

The workflow presented in *Figure 1* is divided into 2 phases. In the first phase, all the appropriate geodata for the study area was collected and the visual-acoustic spatial information was created with the use of spatial analysis tools. Additionally in the first phase all the cartographic representations in the form of viewshed and noise cumulative maps were implemented. In the second phase the visualisation specifications were set according the visualisation needs and the datasets, when needed, are modified for optimum results. The most important data modification was the classification of each spatial feature by visual attributes. In particular for the data collection the level of detail required by the scale of visualisation was taken into consideration. Thus the amount of generalization performed during rendering was kept in low levels having in mind that the aim of the project was not the creation of the most realistic landscape visualisation possible but to create the better audience oriented visualisation. In this phase all the 3D visualisations are created in the form of a) 3D animations and b) real time navigation visualisation. Finally the comparison between 2D and 3D approach is realized.

2.1. Study Area

The proposed wind farm development is siting to the Limnos island, located to the North-East Aegean sea, consist of 124 wind turbines placed into three different areas within the island. As a study area three wind farms in the South East part of Limnos called Lagades, Fournos and Myloi are selected. This area covers a total of 36 square Kilometers and is represented in *Figure 2* into the boxed area.

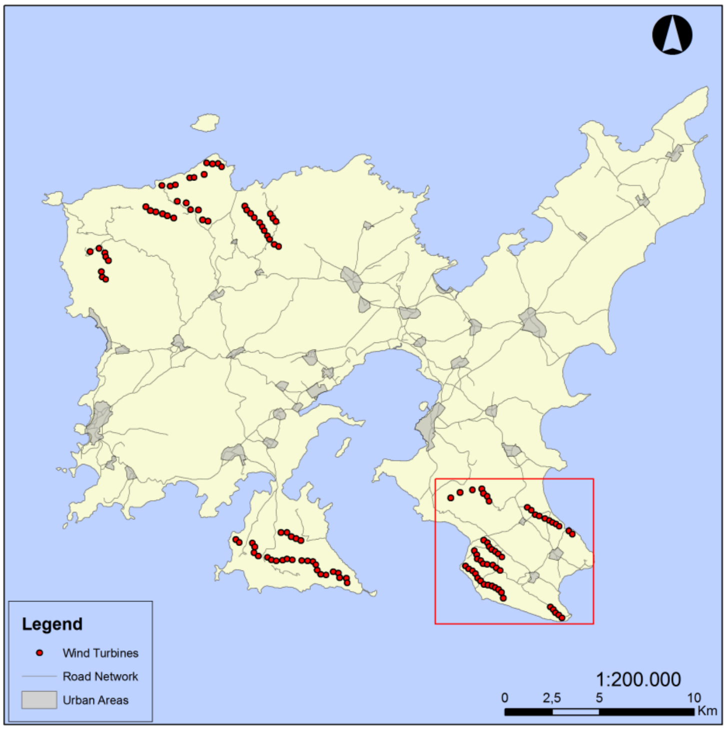

Figure 2. The study area consists of three wind parks with a total of 52 wind turbines covering 36 square Kilometers. The wind turbines development is encircling three villages with the total population of 650 citizens.

2.2. 2D Visualisation of Wind Farms Visibility and Noise Analysis

A common problem in siting wind farms is the visual impact to the neighborhood but also to areas in a distance from them. This impact must be minimized in order to avoid Not In My Back

Yard (NIMBY) syndrome from local people (Devine-Wright, 2005). The visibility analysis is a spatial process that identifies the locations which can be seen from observer points. In visibility analysis the real terrain surface is taken into consideration by utilizing a Digital Elevation Model (DEM) with 30 m cell size and several other parameters were specified (such as the observer and wind turbines height, the horizontal/vertical viewing angles) in order to simulate the real conditions. The following figure depicts the main parameters that are utilized in visibility analysis.

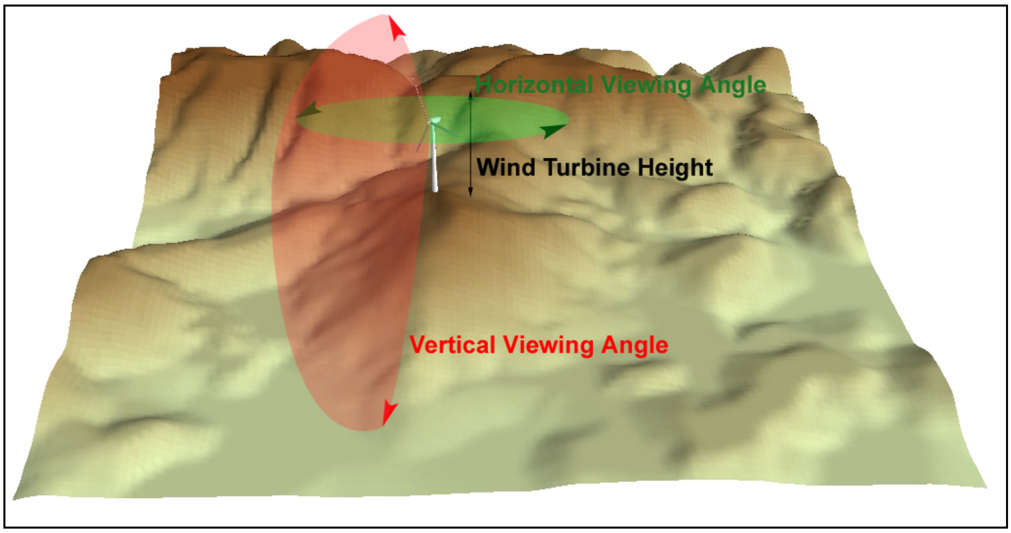

Figure 3. The three parameters considered in visibility analysis a) wind turbine height b) Horizontal and c) Vertical viewing angle

The following maps show the results from visibility analysis of the wind turbines in the island of Lemnos, using an observer height (wind turbines) of 110 m, location height of 1,80 m (in order to reveal if at this location a wind turbine can be seen from locals), horizontal viewing angle from 0° to 360° and vertical angles from -90° to +90°. The first map is binary and shows in green color the areas that could see a wind turbine and in red color the non-visible areas. The second map is a quantitative one that shows additional information of how many wind turbines could be seen from each location.

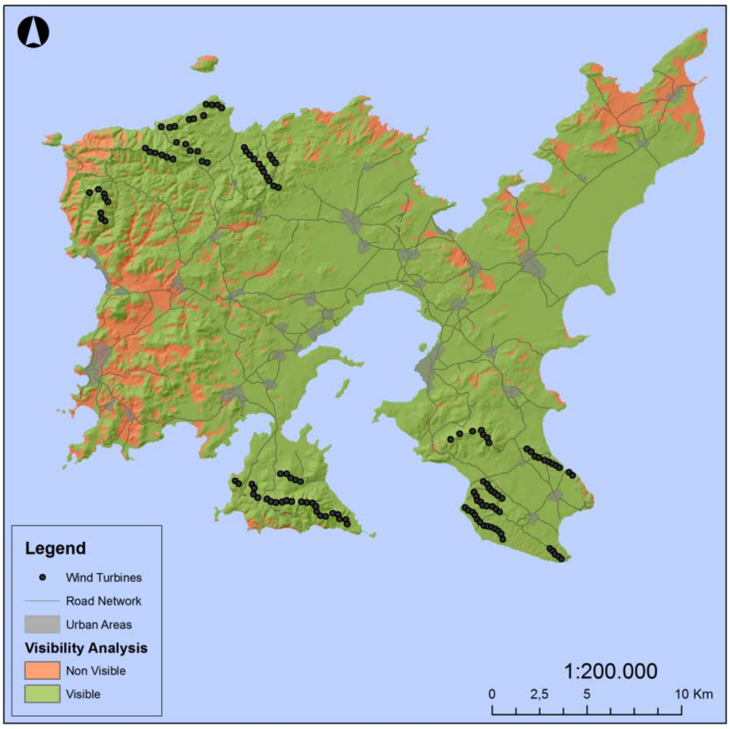

Figure 4. 2D representation of qualitative results. With the red are the areas that the wind farms are not visible.

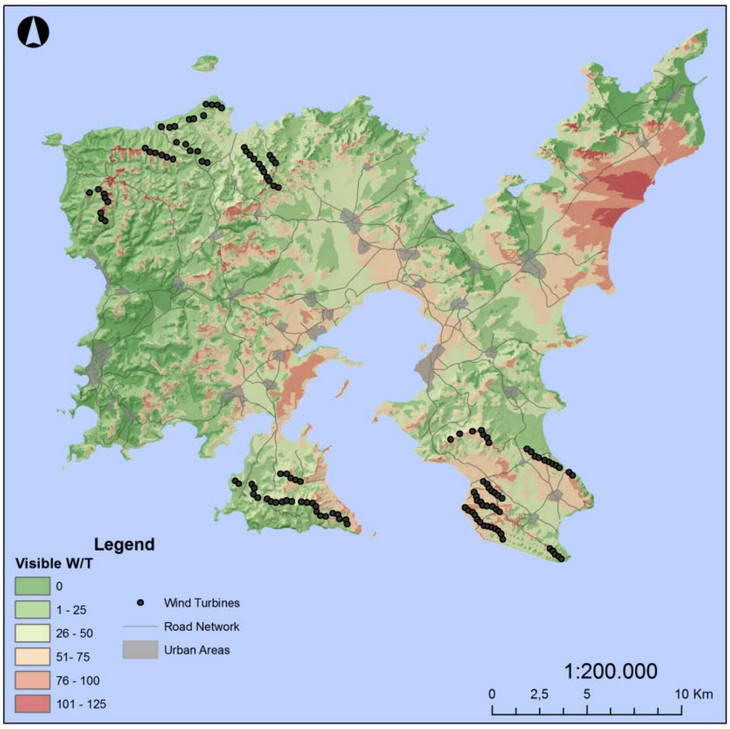

Figure 5. 2D representation of visibility analysis quantitative results. This map illustrates the additional information of how many wind turbines (W/T) could be seen from each location.

Another problem in wind farms' siting process is the noise caused by the wind turbines. In order to estimate the noise, a simple model based on the assumption of hemispherical sound propagation over a reflective surface, including air absorption was utilized (International Energy

Agency 1994). The equation 1 was used for the estimation of noise at a location in an horizontal distance D from a wind turbine, while the equation 2 was used to estimate the Euclidean distance between the locations (Figure 6). The equation 3 was utilized to estimate the accumulated noise at each location caused by the total number of wind turbines.

$$\mathbf{L_{P(j)}} = \mathbf{L_W} - 10\mathbf{Log}_{10}(2\pi\mathbf{R}^2) - \alpha\mathbf{R} \quad (1)$$

$$\mathbf{R} = \sqrt{\mathbf{D}^2 + ((\mathbf{H_W} + \mathbf{h_W}) - (\mathbf{H} + \mathbf{h}))^2} \quad (2)$$

$$\mathbf{L_P} = 10\mathbf{Log}_{10}\left(\sum_{j=1}^{n} 10^{\mathbf{L_{P(j)}}/10}\right) \quad (3)$$

Where:

$L_{p(j)}$: Sound power level at a location caused by wind turbine j

L_w: Sound power level of wind turbine (110dB)

a: Sound absorption cause by atmospheric conditions (0.005 dB/m)

R: Euclidean distance between location and wind turbine

D: Horizontal distance between location and wind turbine

H_w: Altitude of the wind turbine above sea level

h_w: Height of the wind turbine above ground (69 m)

H: Altitude of the location above sea level

h: Height of the location above ground (1,80 m)

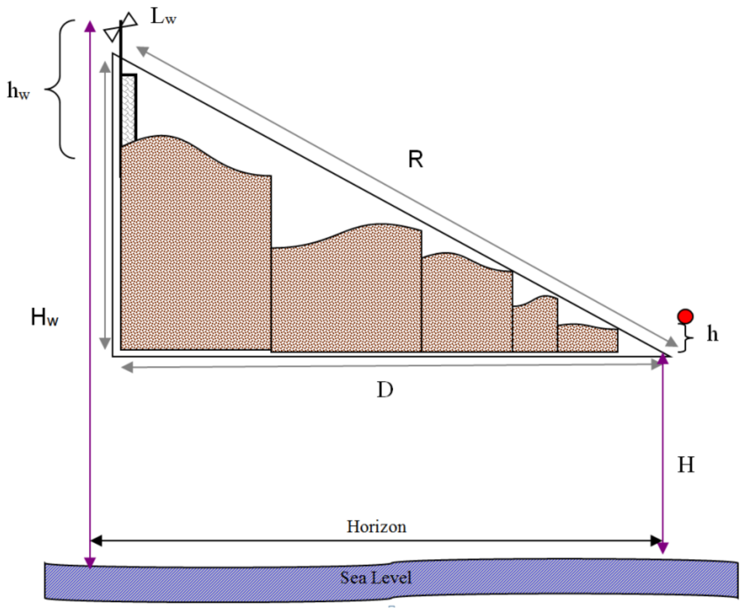

Figure 6. This figure illustrates the visibility analysis variables used and their relation with the landscape morphology.

The above mentioned noise model was developed in a GIS environment, and the following map show the total sound power level (noise) at each location.

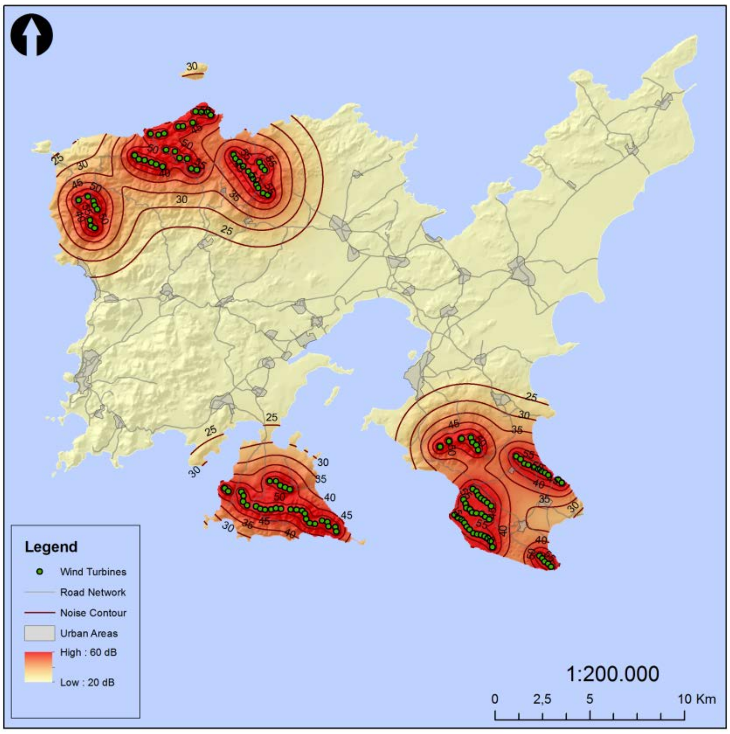

Figure 6. A cumulative noise map representing the "Noise Prediction" results all wind farms proposed locations.

3. 3D Visualisation Development

For the creation of the 3D digital landscape of the study area, 3D Nature's (www.3dnature.com) visualisation software Visual Nature Studio 3 (VNS3) was used. VNS is one of the most sophisticated Land Visualisation software currently available that combines both the 3D and GIS software capabilities. It incorporates ready and images for representing landscape related features, both natural and man-made. In this research external image processing tools and 3D software were used as well, to model the wind turbines and some of the tree species. Spatial related information produced from GIS software in the form of ESRI;s shapefiles and grids and was imported to the VNS software. Objects of landscape elements such as vegetation and 3D models of wind turbines were added according to the corresponding coordinates of their actual locations. During the visualisation stage the most important data modification was the classification of each spatial feature by visual attributes. Thus the need for suitable data must be considered when collecting or collating data appropriate for 3D geovisualisations. As the aim of this study was to create a model of visual and noise impact in wide geographic area (approximately 36 square Km) the level of detail was kept relatively simple. For example the trees included in to all visualisations by using "billboard" based on photographic images and the geometry of all buildings consist the villages was very simple using primitive geometric shapes.

3.1. 3D visualisation of visual impact

A number of preset fixed and animated cameras were used to produce animation and still images from three different heights and numerous positions in the landscape close to the villages (Skandali, Fisini and St Sophia) of the study area. The heights selected for the visualisations were

2m, 10m and 500m above ground. The following *Figures 6, 7 and 8* showing the results of the 3D visualisation approach.

Figure 7. 3D representation of wind parks from the road with the direction from St Sofia to Kaminia village. The view has an orientation facing the North and the height from the ground is approximately 2 meters.

Figure 8. 3D representation of visual impact in the area of the Fisini and Skandali villages. The orientation is North East and the height from the ground is 10 meters.

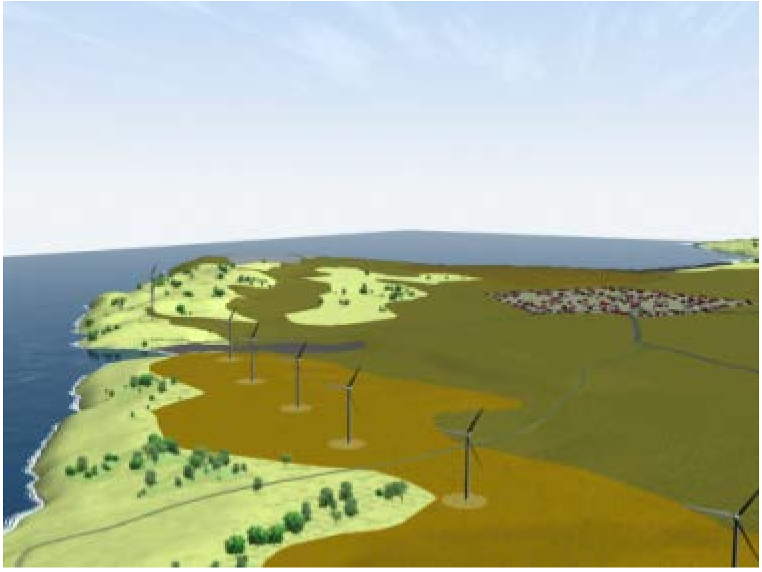

Figure 9. 3D representation of the Rachi wind park development close to the St Sozon village. The height from the ground is 500 meters.

3D visualisation of the proposed wind farm development provides an effective way of presenting the visual impact to non-experts as provides increased levels of realism that help people to imagine the future landscape. Additionally the level of realism is expecting to maximize the understanding of the wind park development visual impact from the local government and the local community.

3.2. 3D visualisation of noise models

Many continuous spatial phenomena with an environmental impact such us noise have a 3D component. Most of noise spatial calculation methods, models or software computes noise using 3D dimensional data, although the most common output of these is 2D maps. Additionally 2D mapping approach has been widely used to study the impact of these phenomena and as a mean of communication for landscape related information with a non-expert audience. In this research is illustrated how noise impact visualisations can be extended towards 3D by the combination of a continuous surface (representing landscape) from which 3D contours of the noise emissions can be generated with 3D object based data. Noise impact visualisations were created for the study areas (Skandali and Fisini villages) and the noise contours are illustrated in *Figures 10 and 11*.

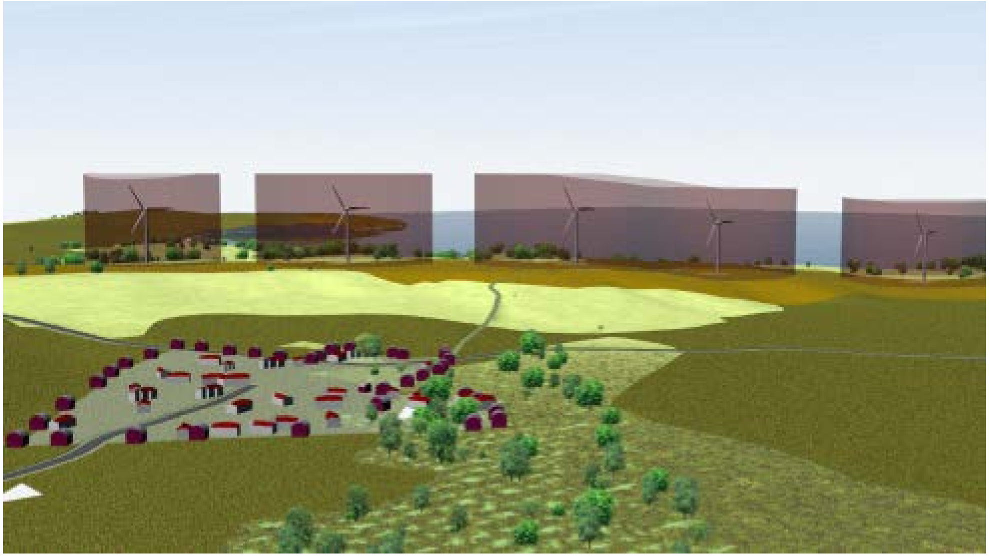

Figure 10. 3D representation of the Rachi wind park development close to the St Sofia village. With the red color the 55 dB noise contours are representing.

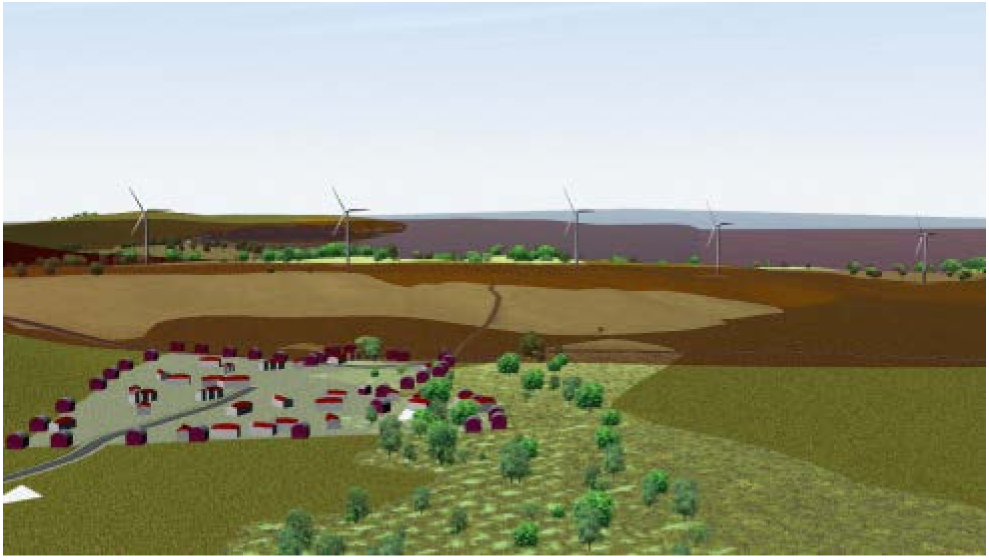

Figure 11. 3D representation of the Rachi wind park development close to the St Sofia village. With the red color the 45 dB noise contour is representing. It is clear viewed that the 45dB noise barrier is present to the first houses of the village.

The developed 3D landscape visualisation is combined with wind turbines noise emissions. A synthetic noise of actual wind turbine sound was used as base data for noise implementation and was modified according to predicted sound levels. These audio files were integrated into the visualization model at prespecified locations of the virtual environment. Thus the user is able to go to any location in the visualization in order to explore both the visual and acoustic impact.

4. Conclusions

Public involvement is a critical element for a successful environmental impact assessment process. The effective public participation and the understanding of environmental visual and noise impact information are essential. Thus is critical to present spatial information in such a way that increasing the understanding of potential aesthetic and noise impacts of the proposed developments.

In this paper is presented a 3D visualisation approach to enhance the public communication output in wind farm planning process in the island of Limnos, Greece. This approach shows how landscape related environmental impacts and continuous spatial phenomena can be visualised in a more effective way. Traditional two dimensional approaches by means of tables and 2D noise and viewshed analyses maps are insufficient to communicate with the public and non-experts. The users may have difficulties in understanding the scale of the development, the real size of the wind turbines, the visual impact in the landscape and the predicted noise level results solely based on a 2D layout.

The proposed approach represents the above using 3D geovisualisations implementations. Thus scientists are possible to achieve a better and more comprehensive communication with the public sector and the local communities in order to support local acceptance of future developments. 3Dgeovisualisations are emphasizing the transparency and the decoding of spatial information by extending the validity of the environmental representations in a more efficient way. These visualisations can help local government and the local community to understand the spatial distribution of future wind farms development and their effects on the landscape. Consequently the use of 3D cartographic visualisation is possible to achieve the necessary degree of interaction realism and decoding of the spatial information from non-experts ensuring and improving public participation in the planning process.

We believe that such representations enhance current cartographic visualisation without substitute them, contributing decisively to the optical propagation of the spatial information. The combination of appropriate 2D & 3D visualisations can illustrate the complexity of the spatial information in a different and more understandable way.

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