Applying New Computer-Aided Tools for Wind Farm Planning and Environmental Impact Analysis

Morten Lybech Thøgersen[*] (mt@emd.dk), Per Nielsen[*], & Mads. V. Sørensen[*]
Per Toppenberg[**] & Erik Søe Christiansen[***],

[*] Energi- og Miljødata (EMD), Niels Jernesvej 10, DK-9220 Aalborg, tel. (+45) 96354444, fax (+45) 96354446
[**] Nordjyllands Amt (County of Northern Jutland), Niels Bohrs Vej 30, DK-9220 Aalborg
[***] Nibe Kommune (Municipality of Nibe), Strandgade 1, DK-9240 Nibe

Abstract: The demand for an environmental impact analysis (environmental assessment study) in any major Danish wind farm project has initiated the development for a set of computer-aided tools for wind turbine planning purposes. This paper gives an introduction to the newly developed computer-aided tools integrated in the wind farm design and planning tool WindPRO. The new module WindPLAN includes three interrelated spatial planning models: a weighted visibility calculation model, a conflict check calculation and a wind resource weighted planning module. The application of the models is exemplified through a case study covering the municipality of Nibe – situated in the Northern Jutland, Denmark. The different analysis are heavily dependent on detailed GIS-data – showing objects such as local housing, leisure areas, preservation areas etc. Finally, a brief presentation of other valuable computer-aided tools integrated in the WindPRO/WindPLAN module is given, such as rendering of terrain profiles, user defined map composing and saved pollution calculation.

Keywords: Spatial planning, environmental impact analysis, GIS, environmental impact assessment, software

1. Introduction

When seeking new sites for wind farm development or preparing to redevelop existing wind farm areas, legislative requirements often demand detailed environmental impact assessments to be performed. Most of these analyses may be performed re-using data, such as roughness areas and height contours, already prepared for traditional wind energy analysis. However, the new analysis will benefit from the detailed land use data (in vector format) often available through geographic information systems (GIS), which is easily loaded into the working environment of WindPRO, see Figure 1.

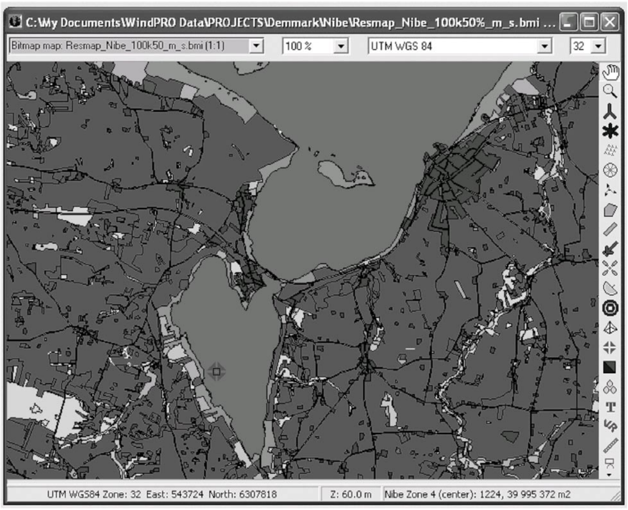

Figure 1: Part of the GIS data used for the Nibe case.

2. Case Study: the municipality of Nibe

The municipality of Nibe is situated in the Northern Jutland, Denmark. It covers an area of about 18,000 hectares, and the northern part has a large coastline along the inlet of Limfjorden. In Figure 2 the borders of the municipality are shown with a solid line.

According to the database WindSTAT of existing turbines [1], 66 turbines ranging from 99 to 750 kW are in operation in the municipality. These turbines include the wind farm of Nørrekær Enge II, with 42 Nordtank 300 kW turbines. The total rated effect is 37 MW.

3. Input Data

The traditional roughness, orography and turbine data have been supplemented with detailed digital vector map data with area classifications. In the current case study, we have used the free downloadable AIS data [2], where vector data information on roads, cities, preservation areas, lakes, churches etc. is found. The data has been loaded and grouped into different WindPRO layers. Each layer is containing information on distance criteria (see section 4). The same layers are used in the visibility analysis, but with other metadata applied, namely the height object and the population density (see section 3). The GIS data used for the current case study covers an area of 75 x 75 km including a total of some 120,000 individual polygons with metadata classification.

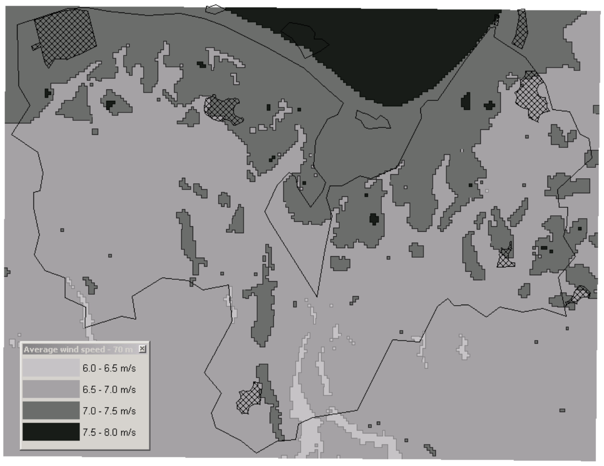

Figure 2: WTG-areas and the wind resource in Nibe.

According to the AIS database [2], five areas within the municipality were registered as available for potential wind farms, see hatched areas in Figure 2 ranging from 25 hectares to 305 hectares in size, covering a total of 590 hectares, i.e. approximately 3% of the total area.

The wind resource is calculated using WindPRO [3] in combination with the WAsP model [4]. These calculations showed that the annual mean wind speed varies from 6.1 to 7.9 m/s, see Figure 2.

3. Weighted Visibility Analysis

The purpose of a weighted visibility analysis is to identify areas within a municipality, where turbines may be erected with the smallest possible visual impact. Thus, the weighted visibility analysis can identify areas where the erected turbines are not visible to the majority of the inhabitants, such as due to forests or hills hiding the turbines.

A weighted visibility analysis has some relationship to the zones of visual influence analysis (ZVI). The ZVI generates a map of the visibility impacts of specific turbines with fixed positions, whereas the weighted visibility analysis calculates a map in a grid, where it is calculated for each grid point how visible a WTG positioned at this grid point would be. The visibility is defined as the accumulated visible impact area of the turbine considered. The visibility analysis has the option of including two types of weights: A distance weight, so points from a specific distance, L_1, is given lower weight linear decreasing to a certain distance, L_2. Also, each area included in the calculation can have an area weight, typically dependent on the population density.

Input to the analysis is height contour lines, digitized areas with object heights (such as forests, cities) and finally areas with weight values applied (e.g. the number of inhabitants per unit area for the different area types). Also one must specify the object height (typically the total height of the WTG) and the height of the observer (approximately the eye-height like 1.5 meters above the ground).

The result from the weighted visibility calculation is shown in Figure 3, where the legend numbers illustrate the number of (weighted) inhabitants being able to see a WTG positioned at a given position. Also neighbour municipality data is included in the calculation. The analysis was – in this case - performed including surrounding areas within a zone of 40 km from the considered calculation point. An object with a height 75 meters was analysed in a grid size of 100-meter.

4. Conflict Check Analysis

The conflict check analysis processes information of required distance demands from the geographic objects to the turbines. These distance demands are found in various laws and possibly also in local requirements. The distance demands are often functions of the turbine properties (such as total height or rotor diameter), the subject heights (such as the height of a forest) or the subject areas (such as the area of a lake).

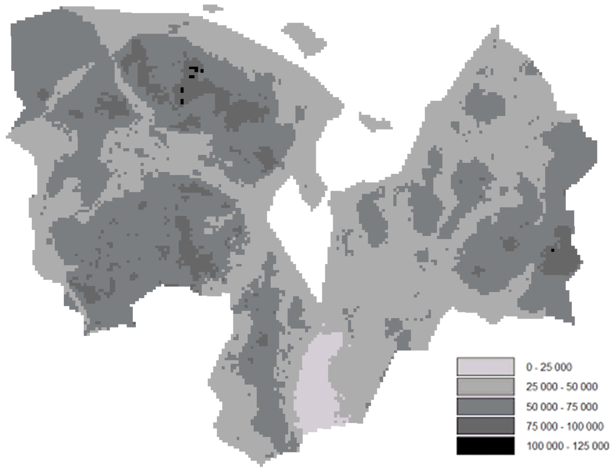

Figure 3: Results: weighted visibility calculation.

Furthermore, the requirement may be conditioned on certain properties, i.e. the requirement is valid if only a forest is larger than a certain size. The analysis may be performed analysing specific turbines (to test if existing or planned WTGs fulfil demands) or by selecting an area for production of a distance demand map. The area calculation is performed using fixed turbine parameters. Input to the analysis is typically turbine data and a digital vector map (GIS data). The distance demands can be evaluated divided into three groups:

Demands: Zones where all criteria must be met. Examples from the Danish regulations are from WTG to: Neighbour: Min. 4 x total WTG height, min. 300 m to forest if forest area is larger than 20 hectares, streams min. 150 m, the sea min. 300 m.
Exempted: Zones where exemptions may open for the WTG-development based on more detailed evaluations. Examples: 500 m to neighbours, 3,000 m to churches
Recommended: Zones where recommendations may apply. Examples: 100 m to railroads and roads, 5,000 m to civilian airports.

The three groups will appear in results together with the fourth showing:

No restrictions: Areas not evaluated, as within one of the above-mentioned three zones, are marked as having no restrictions.

An overview of the Danish legislative requirements can be found in the reference [5]. All these demands have been incorporated in the case study analysis.

Figure 4: Conflict analysis map (750 kW turbine).

In the current case study, we have loaded the GIS data into layers containing 33 different area classifications. Turbine parameters were fixed at 750 kW power, rotor diameter 44 m, hub height 53 m and total height 75 m. These values correspond to the largest turbine within the municipality. Figure 4 shows the results from the conflict analysis. The map shows that the main area part of the municipality is not available for erecting turbines of this size. A succeeding sensitivity analysis showed that this is caused by the strict distance demands to the nearby neighbours. Only 1.8% of the municipality area has no current restrictions.

Demanded	86.6 %
Exempted	11.6 %
Recommended	0.0 %
No restrictions	1.8 %

The analysis on the 66 existing turbines within the municipality showed that only 29 turbines are situated in areas with no current restrictions. Again it showed that most turbines are subjected to restrictions due to nearby neighbours. However, if the neighbours are also the owners of the WTGs then, this is normally accepted.

5. Wind Resource Weighted Planning

The idea behind wind resource weighted planning is to weight the protection interest versus the available wind resource. Initially, the user must specify the protection interests and wind resource within a certain area. Then new polygons/areas with unique wind classifications and specific protection values are generated through a polygon dividing and merging algorithm. The new polygons are given properties according to a user defined decision table (see Table 1). The method was developed and successfully applied, when developing the wind plan for the Spanish region Castilla y León [6, 7]. A similar spatial planning procedure is reported from Irish region Cork [8]. Now the method is also implemented as an easy accessible computer-aided tool through the WindPRO software package.

As indicated above, the input to this method is classifications of landscape sensitivity. These data must be areas (polygons) assigned an integer protection value between 0 and 9. In the Nibe case, we choose to use objective measures for the landscape sensitivity, as we are adapting the results from the visibility analysis and the conflict analysis in order to identify the landscape sensitivity: very visible areas are given a high protection values (approximately 3-4) while less visible areas are given smaller values. Furthermore, the conflict check has identified areas that must be discarded. These are given the protection value 9, while the areas with fewer restrictions are given 4 (exemptible zones) and 1 recommended. Zones with no restrictions contain the value 0.

Prot. value	Wind resource interval [m/s]			
	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0
0	Free	Free	Free	Free
1	Free	Free	Free	Free
2	Free	Free	Free	Free
3	Limited	Free	Free	Free
4	Limited	Limited	Limited	Free
5	Limited	Limited	Limited	Limited
6	Limited	Limited	Limited	Limited
7	Restricted	Restricted	Limited	Limited
8	Restricted	Restricted	Limited	Limited
9	Restricted	Restricted	Restricted	Restricted

Table 1: Decision table used in the weighted planning.

The wind resource weighted planning procedure, requires the specification of a decision table. This table specifies how a polygon with a certain annual mean wind speed and certain protection value should be classified. An example from the Nibe case study is shown in Table 1. This table shows three distinct area types (user defined), generated during the actual calculation: Areas with no limitations - classified as free, areas with limited possibility for WTG erection and finally restricted areas. Table 1 shows, that a wind resource 7.5-8.0 m/s allows turbine development in areas with protection values up to the value 4 (inclusive).

The derivation of the decision table is by no means an easy task, but may be a part of a political and/or iterative process. One political requirement may be the desire to have a certain amount of the area available for WTG-development within the municipality. However, the availability of a computer-aided tool enables the test of a relatively large number of configurations. Thus, the decision makers have the possibility to decide from the best possible background knowledge.

Figure 5 shows the final wind resource weighted wind plan for the case study of the municipality of Nibe. The map has been calculated using the restrictions shown in Figure 4 (conflict check), the visibility data as indicated in Figure 3 (but with a 10 km distance function and 200 m grid) and the wind resource as shown in Figure 2. Clearly the potential areas are removed when comparing it to the conflict calculation in Figure 4. Please note, that the WTG-area at Nørrekær enge is available (no restrictions) while the other ones are only available for limited development (exemption often required). The below table shows the distribution of the different areas is.

Restricted area	91.6 %
Limited	6.6 %
No restrictions	1.8 %

6. Other Computer-aided Tools Included in WindPlan

Terrain profiles: Some citizens may experience some conceptual difficulties when presented for certain sophisticated analysis results, most people, however, easily do understand the terrain profile drawings. Using the new computer-aided features; it is a matter of a few minutes to generate a terrain profile. The terrain profile is automatically generated from the orography and any turbines included are also rendered, see Figure 6. Here, the height is exaggerated (Denmark is a flat country). The terrain profile generation comes with the option of adding other 3D objects, photos of characteristic buildings (in the correct scale) onto the profile as well as user defined labels.

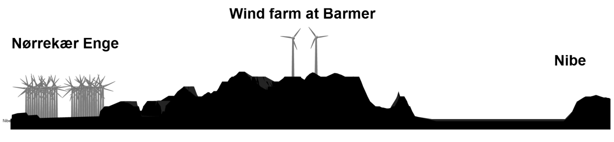

Figure 6: Terrain profile (Nørrekær Enge to Nibe City).

Saved pollution and resources: A model for calculating different types of environmental benefit from a wind farm has been implemented in WindPRO [3]. This model assumes a baseline scenario, i.e. the clean energy savings may vary in time as more advanced and possibly less pollution technology is incorporated into the conventional power plants. Any substance specified as amount per energy unit may be included in the study (such as grams CO_2 per kWh produced power or square kilometres of land use per MJ produced power). Also included is the option for including accumulated impacts from different substances, e.g. the CO_2 equivalent contribution from unburned methane and N_2O. The WindPRO software includes a number of pre-defined scenarios; assuming that the wind power replaces conventional power, such as conventional Danish coal fired power plants [9] or other European power suppliers [10]. According to the WindSTAT database [1] the turbines in the municipality if Nibe are registered to produce approximately 36,800 MWh per year. One may assume that the wind power replaces a coal fired power plant or an average type of power, i.e. power generated through a mixture of plants fired using coal, gas, waste and bio-gas. Assuming a conventional coal fired power plant, the energy produced equivalents a CO_2 reduction of 31,280 tonnes annually or approximately 325.6 thousands of tonnes throughout an expected lifetime of 20 years. The actual report in WindPRO allows a detailed analysis of the saved emission through the different years.

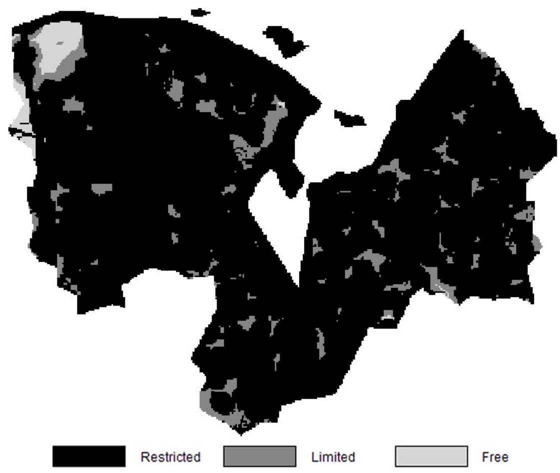

Figure 5: Results: Wind resource weighted planning.

Map Composing: The map composer is a new tool for generating highly customisable maps, including user defined legends, colour and symbol settings as well as specifying the dpi and colour code options (CMYK or RGB). The map composer tool delivers maps ready to print or ready to paste into text processing tools, like Word, Publisher or PageMaker. The tool eases the production of reports to be printed in a professional quality, like spatial planning reports that plays an important part of the political decision process.

7. Conclusion

A new set of computer-aided tools for environmental impact assessment and special planning purposes have been developed and implemented into the WindPRO software package. The tools are included in the WindPRO/WindPLAN module. The models have been successfully tested through a case study based on the municipality of Nibe, identifying strategic areas suitable for wind farm development. Furthermore, the case study has proved that the tools are very helpful and efficient when performing environmental impact analyses.

Acknowledgement

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