Beyond Viewshed Analysis: Extended Approaches to Visibility Analysis in Energy Transition Landscapes

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Abstract: This paper is to be understood in the context of the German energy transition process and introduces specific approaches to visibility analysis to be applied in different planning phases. It focuses on specific criteria, where current planning practice lacks legal requirements. Based on these requirements, the development of a GIS-toolset for sequent planning phases (regional planning as well as design and location approval of specific projects) will be described.

Keywords: Energy transition, visual landscape assessment, visibility, wind farms, encirclement

1 Introduction

The German energy transition process to renewables is mainly based on increasing the amount of wind and solar energy. In 2016, onshore wind energy contributed a quota of 35,2 % to nationwide electricity generation from renewables (UBA 2017). One of the strategic components to assure the successful development is to discover the remaining suitable areas and to support repowering of older turbines in existing wind farms. To foster this process in numerous German federal states, existing regional plans have been revised and supplemented by contributions for suitable areas as well as priority areas for wind energy. In theory, this could lead to rising public acceptance if problematical wind farms from previous dynamic stages of development are corrected during this process. In practice, the contrary effect can be observed. Ambitious political strategies conflict with the interests of residents and stakeholders affected by planning proposals. In fact, numerous plans consider neither the principle aspects of cultural landscape assessment and transition nor justiciable criteria for weighting between public and private interests at an adequate level. One of these, is the visual impact and pressure of wind farms on settled areas caused by encirclement effects. This paper introduces an approach and set of GIS-Tools which enable planners to model and evaluate the visual pressure of wind farms caused by encirclement. The methodology and toolset is adapted to state level as well as to regional and local requirements.

2 Status Quo in Visibility Analysis and Assessment

2.1 Methodology

In Germany, the works of Werner NOHL (NOHL 1993, 2015) set a methodical framework for visual landscape assessment and aesthetic evaluation of disturbing effects. As the most important aspects for aesthetic damages he specifies: loss of scale and character, technical alienation, break of natural character, damages in the field of view, pollution of the horizon, abuse of exposed landscape sites, disturbance by movement of rotor blades, loss of tranquility and disturbance of nocturnal landscape (NOHL 2015, 249). SULLIVAN (2017, 155f.) refers to

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quite similar criteria as visual signatures and visual contrasts of onshore wind facilities: vertical line contrast, color contrast, form and scale, motion, shadow flicker, lighting at night.

Visual impact analysis (VIA) approaches the phenomenon from two different perspectives. On the one hand, the existing landscape visual character has to be assessed. On the other hand the disturbing effects of wind farms have to be considered. As a synthesis of both perspectives, the visual impact on landscape character can be assessed. Several methods are available and used in current planning processes. The latest meta-study in Germany was published by ROTH & BRUNS (2016), from an international perspective APOSTOL et al. (2017) give a fundamental overview. HILDEBRANDT (2015) compared environmental impact studies (EIA) from Germany and the U.S./U.K. and came to the conclusion, that nearly no German studies include criteria like pollution of the horizon and visual pressure from encirclement effects. Most studies rely on the methodology of NOHL (1993), although it is not explicitly designed for wind turbines. Even though VIA and EIA have been established in German planning processes for decades, it has to be considered, that there is an existing lack of operationalization in planning practice. There are currently no standards available in Germany for assessing encirclement effects, only one methodical framework based on court decisions but not on scientific findings is available (MEIL-MV 2013).

2.2 Status Quo in GIS – Operationalization of VIA

In the context of German wind energy projects at a state and regional level, GIS-analysis is almost limited to the 2D-analysis of landscape visual character. 3D viewshed-analysis is implemented on local or project level only, when possible locations of wind turbines become concrete. It depends on the individual project which level of detail has to be implemented, but in the last 15 years the following general procedure has been found in most EIA as a part of project approval procedures.

- GIS based viewshed analysis, based on line of sight (LOS) analysis from wind turbines to each grid in the project area.
- The required input data is: location of wind turbines (2D point data with height attributes) and digital surface model (DSM) of the project area (often substituted by digital terrain model (DTM) and additional height derived from landuse data).
- The standard procedure contains LOS-analysis from the highest point of turbines to each grid; the extended procedure contains iterative LOS-analysis from different levels up to highest level of turbine, ascertain how much of each turbine is visible.
- The criteria of "distance" between wind turbine and affected area is weighted, mostly using the methodology of NOHL (1993) or NLT (2014).
- The result is presented as 2D-map with binary information on the qualitative level whether wind turbines could be seen or not. 2D maps are often supplemented with photomontages of specific views or 3D-visualizations derived from the above mentioned geodata.

Interactive 3D-visualizations based on augmented or virtual reality concepts to be used in public participation processes are the subject of current research in landscape architecture (e. g. WISSEN-HAYEK et al. 2016) but not common in formal EIA procedures.

3 Beyond Viewshed – Visual Pressure Caused by Encirclement Effects (State/Regional Level)

More importance should be given to the wholistic treatment of all criteria mentioned in chapter 2 during formal project approval procedures. Current methodological overviews like HILDEBRANDT (2015) discover a serious lack of consideration for the criteria of horizontal dispersion / pollution and encirclement of settled areas caused by wind farms. This has led to an increasing amount of legal disputes, especially at regional levels. During 2016, the German federal state "Schleswig-Holstein" revised all regional plans and determined suitable areas as well as priority areas for wind energy (> 700 sites). The state government asked for an approach to calculate the risk of visual pressure by encirclement effects for all settled areas (> 1400 towns and villages).

In fact only one methodical framework (MEIL-MV 2013) exists for modelling the criteria of "visual encirclement" on a conceptual level. It is based on the human's physiological visual field and expresses a minimum view angle which has to be free of visual pollution in each direction to provide encirclement effects. The requirements to prevent settled areas from visual encirclement effects are defined as follows (see fig. 1):
Within a 180° viewing angle into each direction

- a maximum of 120° is allowed to be covered by wind farms (priority areas);
- a minimum of 60° has to be completely free of wind farms;
- existing wind farms have to be considered.

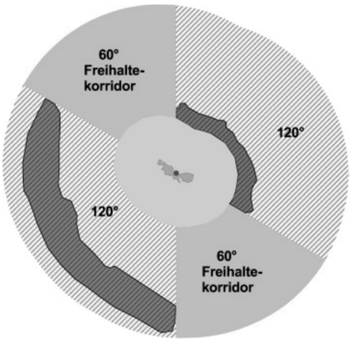


Fig. 1: Conceptual framework to provide encirclement effects on settled areas (MEIL-MV 2013, 18)

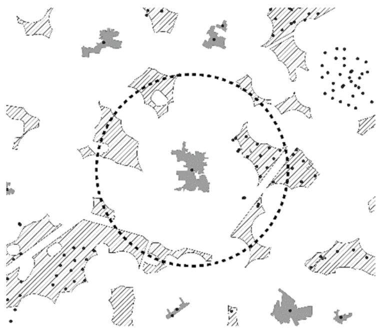
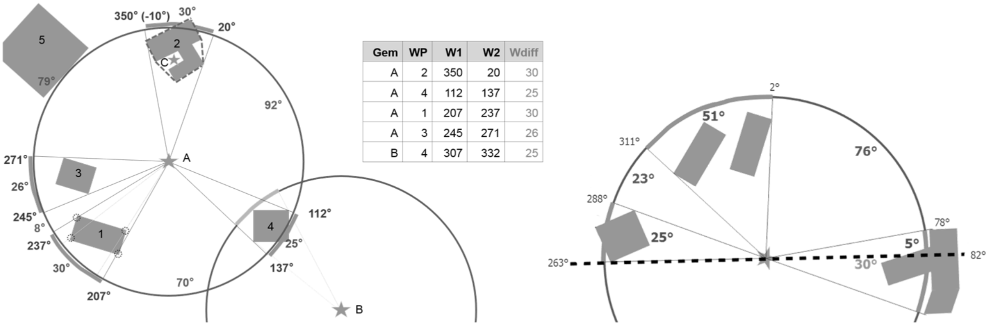


Fig. 2: Required geodata: settled area (center point), investigation area, priority areas, existing turbines

The constraints of the project required an approach which is easy to use, is able to process the above mentioned data volume (see fig. 2) rapidly and produces information as to which towns would be affected by encirclement effects and which priority area is involved in the problem.

The conceptual model uses trigonometric functions to calculate the specific conditions around each center point to identify problematic situations of encirclement.



Gem	WP	W1	W2	Wdiff
A	2	350	20	30
A	4	112	137	25
A	1	207	237	30
A	3	245	271	26
B	4	307	332	25

Fig. 3: Modeling encirclement effects using trigonometric functions: step 1 (left) – analyzing the existing conditions in the full circle representing town "A",
step 2 (right) – testing iterative view fields of 180° for encirclement (>120° covered or <60° completely free of wind farms). The surrounding circle represents the relevant distance and border (horizon) of the investigation area around towns

The algorithm starts clockwise from north (0°) and records all relevant angles to an attribute table. As shown in fig. 3 it starts with a horizon covered by wind farm 2, the final angle of 20° (W2) is added to the table. The next section covered (by wind farm 4) starts at angle 112° (W1) and ends at angle 137° (W2). After a full circle analysis the following information is available in the table: affected town (Gem), wind farm involved or priority area (WP), starting angle (W1), final angle (W2), covered horizon in degree (Wdiff).

The second step is used to identify situations where threshold values for encirclement are exceeded. Now the algorithm tests whether a view angle of 180° (representing human's visual field) contains at minimum 60° horizon which is consistantly free of wind farms. To do this, it starts from any position until it reaches the next minimum angle of a wind farm. It stops at that point (fig 3 at 263°), adds 180° to the value (83°) and analyses the resulting section. The example in Fig. 3 (right) indicates a situation where the constraint of being free from encirclement effects is fulfilled. A coherent section of 76° is free of wind farms and the covered horizon contains overall only 81° (25 + 51 + 5).

At the end of the process the user is able to discover all settled areas where threshold values for encirclement are exceeded. Using the data derived from both steps, any wind farm or priority area which is causing problems can be identified, initiating a planning process to modify proposed priority areas and consequently starting the GIS-analysis once again. The procedure had been successfully implemented into the *ESRI© ArcGIS* environment using *Python* as scripting language. For technical details see TAEGER & ULFERTS 2017.

4 Beyond Viewshed – Visual Pressure Caused by Encirclement Effects (Local or Project Scale)

After having been applied successfully at state level, the "Schleswig-Holstein" Ministry of the Interior required a further development appropriate to a more detailed local scale to support community development planning or design and location approval. These critical factors had been identified:

- The center point of a settled area is not the relevant site for analysis. On local scale the affected urban fringe is relevant. In addition it should be possible to distinguish between different types of land use to concentrate on vulnerable areas.
- Using the center point is not appropriate to analyze long drawn-out street villages.
- It should be possible to integrate the result of the above mentioned viewshed analysis into the process to consider topography, vegetation and buildings as visual barriers.
- In addition to that, the state authority came to the decision to no longer follow the constraints of the above mentioned methodical framework (MEIL-MV 2013), but to use instead more general relative classes of visual disturbance instead.

That led to a different conceptual model, which uses percentage of covered horizon instead of view angles to model the visual impact. Input data required:

- Shape of settled areas (derived from landuse data – ATKIS DLM)
- Planned priority areas for wind energy (as polygon data)
- Existing wind farms (available as point data, clustered to polygon data)
- Outline border of investigation area (representing the observed horizon)
- Optional: DSM for viewshed analysis

The approach is based on buffer distances generated from outline borders of settled areas (see fig. 4). At first, a minimum distance (800 m) around settled areas, based on legal requirements, is generated. In the direction of the horizon, they are subsequently followed by additional buffer distances of 100 m (see fig. 5) until the outline border of the investigation area is reached. All buffer rings are intersected with polygons of exiting wind farms and priority areas. The resulting buffer sections (see fig. 5, red lines) are buffered once again, but only into left direction (towards the horizon, see fig. 5, yellow polygons). In a final step, all buffer polygons which overlay each other will be dissolved into one.

These polygons are used to identify the amount of covered and uncovered sections of the horizon (see fig. 5, green outline sections). The result enables the user to analyze the outline of the investigation area as the relevant distance or rather the horizon which is covered by wind farms. In addition to that, various distances from settled areas can be chosen as relevant in a flexible way. That approach enables the planner to integrate the criteria of "distance" between settled area and wind farms to assess the visual impact according to NOHL (1993). Furthermore it is possible to ignore land use parcels with no relevance for visual connections into the landscape (e. g. industrial areas) where no impact has to be assessed. The results have been classified into 3 classes of risk for settled areas to be affected by visual pressure caused by encirclement effects.

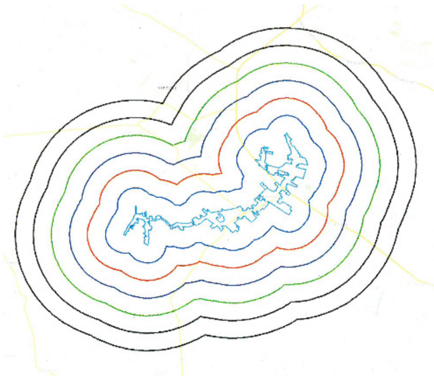


Fig. 4: Buffer distances around settled areas are used to identify sections of the horizon which are covered by wind farms

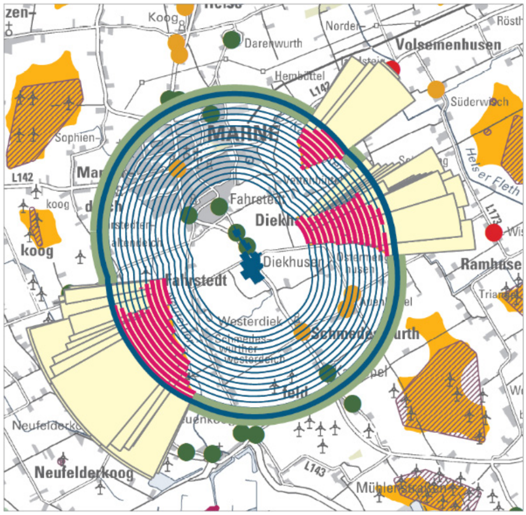


Fig. 5: Conceptual overview: settled area (blue), buffer rings (blue), priority areas (orange) intersection between buffer ring and priority areas (red), buffers generated from intersections (yellow), uncovered sections of horizon (green) (HARMS 2017)

In addition to that, as a first step towards quantitative analysis and assessment, another function has been implemented into the procedure. To give the user the possibility to estimate which amount of horizon will be covered with wind farms, a virtual representation is created, comparable to a vertical backdrop (see fig. 6, red: settled area in neighborhood, black hatched: shape of existing or proposed wind farms). The result illustrates the vertical impression of the horizon, created from an observer point, moving along the outline of a settled area. As input data the polygons of settled areas, existing wind farms and proposed priority areas must have an attribute, specifying their vertical height. The procedure draws a LOS from the outline of settled areas (moving observer point) to the highest 3D-position of the land use categories mentioned above. The result is drawn like a silhouette on a vertical horizon, which is positioned on one of the blue buffer lines, shown in fig. 5.

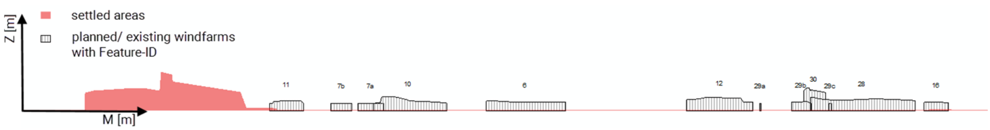


Fig. 6: Virtual horizon, illustrating the vertical height of objects at a selected distance from settled areas

These procedures have also had been implemented into the *ESRI© ArcGIS* environment using *Python* as scripting language. All scripts are optimised for easy implementation into other GIS environments like QGIS.

An optional final step is to integrate the result of a viewshed analysis in order to limit the result to areas where real visual connections are given. In numerous regions of "Schleswig-Holstein", it would be possible to neglect that because of the homogenous topography, but when transferring the procedure into other landscapes with heterogenous topography it is recommended to come to results appropriate to scale.

5 Conclusion and Outlook

The procedures described above enable the modelling of effects of visual pressure on settled areas, caused by encirclement effects in two different levels of detail. One more step towards new information could be a quantitative approach of modelling visual pressure on the horizon in the human's visual field. It is actually possible to analyse whether a section of the horizon is covered by wind farms or not (see fig. 3 and 5). The result has a binary character like "yes" or "no". However a new level of information would be achieved, if it were possible to visualize the quantitative impact on an observer's visual field more detailed (see fig. 7).

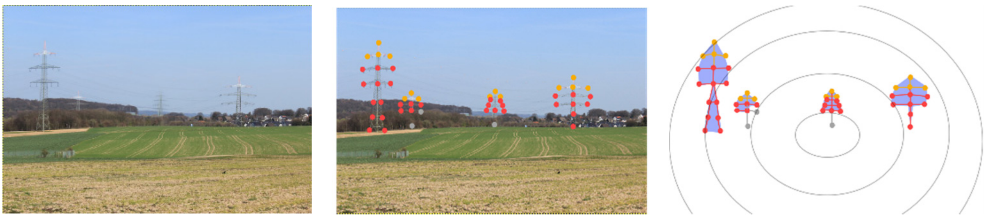


Fig. 7: Quantitative view field analysis, objects are represented by marker points, covered areas in the visual field can be calculated

An approach, based on high resolution LIDAR point clouds, is currently being developed in a research project dealing with concepts to increase the public acceptance of the network expansion of high voltage transmission lines in Lower Saxony. The required input data is:

- Observer position (as 3D point data)
- LIDAR point cloud (used similar to DSM)
- Planned objects which cause potential visual impact (represented by 3D marker points and their attributes like construction details)

The conceptual model is quite similar to a line-of sight (LOS) analysis, but uses a 3D tube instead of a line, which links observer point and any marker point of any object in the visual field (see fig. 7). Instead of a grid based DSM the original LIDAR point cloud is used. The 3D tubes between observer and marker points are used to cut out all relevant LIDAR points from the whole LIDAR point cloud. The aim is to reduce data volume in a first step and to provide high resolution and data accuracy from original LIDAR points. The following step analyses whether the marker point can be seen from the observer point and adds a correspondent attribute to the marker point. From all marker points of an object carrying the attribute “visible”, the visible part of the object is drawn in the observer’s visual field. By iteration of this procedure until all objects are analyzed and drawn, the observer’s visual field is finally covered with a specific amount of “technical objects” which could cause visual impact. The result provides detailed quantitative information for further visual impact assessment. The current challenge is to prove a correlation between subjective perceptions of people affected by planning proposals and the digital representation of an impact.

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