To See or not to See: A Critical Investigation of Validity in Visibility Analysis for Assessing Landscape Impacts of Energy Infrastructure

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Abstract

Visibility analysis plays a crucial role in the planning process and for the acceptance of renewable energy projects. There is a need for visual impact analysis in Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Impact Mitigation Regulation (IMR) in state-wide, regional and municipal/local planning processes. In planning practice, basic methods for visibility analysis are often used, without knowing about the validity of the specific analysis. We empirically investigated how DEM/DSM resolution, accuracy and precision, GIS software package and algorithms used, representation of the impacting object, and other factors influence the validity of visibility analyses. Based on our results, we conclude that the validity of visibility analyses and thus the whole subsequent visual impact analysis can be significantly increased by carefully choosing the adequate visibility analysis approach.

1 Introduction

With the recent developments in renewable energy production systems all over Europe, and the subsequent need for new transmission and storage infrastructure, for example power lines to transport the electricity generated by North Sea offshore wind farms to Southern German industries, visual landscape impact analysis has gained importance all over Europe (cf. ELLIS et al. 2009, RODRIGUES et al. 2010, CHIAS & ABAD 2013). One basic step in this process is the delimitation of the area impacted by the energy infrastructure, be it wind turbines, photovoltaic installations, biomass power plants or high-voltage transmission lines. In academic literature a critical perspective on the validity of visibility analyses can be observed for some decades (cf. FISCHER 1991, TÄUBER & ROTH 2010, MANCHADO et al. 2013, CHAMBERLAIN & MEITNER 2013). However, in planning practice, basic methods of

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visibility analysis are still used, without questioning how the results of such visibility analysis are influenced by DEM/DSM resolution, accuracy and precision, GIS software package and algorithms used, representation of the impacting object, and other factors. With the validity of the visibility analysis often in doubt, the whole visual impact analysis can be questioned.

The validity of visibility analysis can be tested empirically by conducting a series of visibility studies with variation in the factors mentioned above and statistically comparing the results with each other and/or with field observations (ground trothing). This paper presents the combined results of a variety of empirical studies conducted in research projects dealing with renewable energies.

At the moment, valid and transparent visual impact analysis methods and results are crucial for effective and efficient planning processes to achieve the ambitious renewable energy goals. A large and ever-growing gap between the academic knowledge on visibility analysis and the practical implementation in specific planning projects, environmental impact analysis (EIA), strategic environmental analysis (SEA) and impact mitigation regulation (IMR) can be observed. Often, both planners and the population affected are believing in an uncritical way in the objectivity of outputs from GIS-analysis. When projects such as wind turbines or transmission lines are realized and the results projected do not match the actual situation, planners and authorities lose credibility. The acceptance of landscape planning as a conflict mitigator early in the process might then be weakened for subsequent planning applications.

2 Methodology and Data

We systematically investigated how different factors influence the output of GIS-based visibility analysis:

- Different digital terrain models (DTMs) and digital surface models (DSMs), based on laser scanning, radar-interferometry, stereoscopy, or digitalization of contour lines,
- different GIS software systems and algorithms (ESRI ArcGIS, GRASS GIS, Q-GIS),
- different visibility analysis methods (binary, frequency, cumulative visibility) and
- different representations of the impacting installations (points at various heights of wind turbines, different locations of wind turbines in concentration zones, transmission pylons with or without including the cables, etc.) influence the validity of the visibility analyses' results. This is partly done by ground truthing, partly by various statistical analyses.

The following table 1 gives an overview of the studies included in the meta-analysis presented here. They were all conducted, co-authored and/or supervised by the authors of this paper. In contrast to specific software solutions that were developed to analyse (inter)visibility for relatively small spaces (such as ENGEL & DÖLLNER 2009), the studies presented here had to deal with areas of investigation between around 100 to several thousands of square kilometres, which influenced the choice of DEM/DSM (and their resolution), as well as the choice of software package and visibility algorithm. Both data and analytical approaches/software packages used reflect widely available solutions also used in planning practise.

Table 1: Overview of the studies included in the meta-analysis

Study	Study area and size	Analysed objects	Software used	DEM used	Land use height source / DSM used
TÄUBER & ROTH 2011	Test area in the city of Haltern, North Rhine-Westphalia, 314 km²	Wind turbines	ESRI ArcGIS	• SRTM (90 m res.) • ATKIS DGM 25 (digitized contour lines) • ATKIS DGM 10 (laser scanning)	• CORINE Land Cover • ATKIS DLM (vector land use data) for extrusion
SCHULTE-BRAUCKS 2011	City of Hattingen (71 km²) and city of Paderborn (180 km²)	Landscape intervisibility independent of specific objects	ESRI ArcGIS, GRASS GIS	• SRTM (90 m res.) • DGM 1 (laser scanning)	• DOM 1 (laser scanning) • ATKIS DLM (vector land use data) for extrusion • ALK (vector land use data) • Corine Land Cover
HAUBAUM 2013	City district of Dortmund, 280 km²	Power transmission lines (pylons and cables)	ESRI ArcGIS	• DGM 1 (laser scanning), derivated to DGM 2	• DOM 1 (laser scanning, derivated to DOM 2
ROTH & GRUEHN 2014	Regional district of the Saarbrücken Regional Planning Association, 411 km²	Wind turbines	ESRI ArcGIS	• DGM 5 (radar interferometry)	• DOM 5 (autostereoscopy)
JUNKER 2014	Regional district of Middle Hesse, 5.381 km^2	Wind turbines	ESRI ArcGIS, QGIS	• ATKIS DGM 25 (digitized contour lines) • ATKIS DGM 10 (laser scanning)	• ATKIS DLM (vector land use data) for extrusion

The main focus of the study published by TÄUBER & ROTH (2011) was the influence of different digital terrain models and different land use data (used for land use height extrusion) on visibility analysis for wind turbines. Three different DTMs were used for this study: The free 90 m resolution SRTM (Shuttle Radar Topography Mission) data, the (old) German ATKIS DGM 25 with 25 m resolution (derived from digitized topographic map contour lines), and the ATKIS DGM 10 with 10 m resolution, based on aerial laser scanning data. The latter two DTMs were and still are quite costly for the users. For the extrusion of land use heights (which is a necessity in visibility analysis), the free Corine Land

Cover data was used, as well as the again costly vector land use data set from the state surveying authority. A statistical comparison and an exemplary ground truthing of the different analyses were conducted.

SCHULTE-BRAUCKS (2011) investigated the intervisibility of the landscape without focusing on a specific project type. Instead, different target heights (0 m, 2 m, 5 m, 10 m, 20 m, 50 m, 100 m) were used to produce results usable for various developments on the planning level of municipal land use planning. In this study, a comparison of ESRI ArcGIS versus GRASS GIS was included. SCHULTE-BRAUCKS (2011) investigated how different eye-heights, different observer point densities, and different DEM resolutions influence landscape intervisibility. In addition, a comparison between native laser scanning digital surface models and digital surface models based on land use height extrusion on top of the terrain model was included in this study. The whole study was conducted for two different investigation areas, one in a relatively flat area, the other in a hilly to mountainous area, to be able to analyse the influence of the relief on visibility.

HAUBAUM (2013) focused on the question how the results of transmission lines' visibility change, when not only the transmission pylons but also the cables (on various height levels and various distances from the center-line) are included in the visibility analysis. In planning practice in Germany, the visibility of transmission infrastructure for wind electricity produced offshore (North Sea) to Southern Germany is a common issue at the moment. Usually, only the visibility of the pylons is analyzed in visual impact analyses.

ROTH & GRUEHN (2014) compared different methods of visibility analysis (binary, frequency and cumulative visibility analysis). This was part of larger study also including qualitative visual impact analysis based on an empirical internet-based survey of scenic beauty and wind turbine impacts.

JUNKER (2014) performed a very large-area visibility analysis (covering over 5,000 km^2) using a regional planning process for wind turbine location as an example. She compared how ESRI's ArcGIS differs in terms of visibility analysis results from QGIS. A second focus of her work was the investigation how different representations of planning zones for wind turbines (center points, regular patterns of points within the area, points on edges at regular distance) influence visibility analysis, both in terms of the results yielded, but also computing time. Additionally, different maximum distances, different DEM resolutions, different methods for land use height extrusion and partial visibility was included.

3 Results and Discussion

There are a large number of variables (parameters; model representations for observers, target structures and terrain/surface; software package, methodological approach; etc.) in visibility analysis. Various combinations of those variables can cause potential effects on the validity of visibility analysis. With the enormous number of permutations possible when systematically changing all those variables, systematic and representative studies covering the variety of German landscapes are hardly possible. Nevertheless, the results of the studies conducted so far and described above allow to give first empirically-based recommendations and to direct further research:

3.1 DEM Resolution and Accuracy

It is clear that higher resolution and vertical accuracy of DEMs lead to better, more valid results in visibility analysis. At the same time, the cost for those data (which are quite costly in Germany) and the computation time needed for the analysis increases significantly. Thus, finding the appropriate data resolution and accuracy and balancing validity of the visibility analysis vs. practical issues is critical, especially from a practical planner's perspective. From the studies described above, we can conclude that today, a 10 m resolution DEM, based on laser scanning is the minimum requirement (TÄUBER & ROTH 2011, JUNKER 2014). Coarser resolutions do not allow to include structures such as tree lines, buildings, hedges, etc. that are highly relevant for (in-)visibility. When using 5 m resolution DEMs (ROTH & GRUEHN 2014) or 2 m derivates of 1 m resolution DEMs (HAUBAUM 2013), the validity of the results increases, as individual buildings, hedges, etc. can be included in the model far better. Using the original 1 m DEMs does not significantly increase the visibility analysis' validity (SCHULTE-BRAUCKS 2011), but increases the computation time massively.

These recommendations apply to the usual planning scales for impact analysis of renewable energy project from regional planning (1:50,000) to municipal land use planning (1:10,000).

3.2 Land Use Representation

Often, native digital surface models are not available or double the cost of data included in visibility analysis. Therefore, land use extrusion on top of digital terrain models is still very common in planning practice. If high resolution land use data from habitat mapping or official topographic data is used, the results of visibility analysis are similar in open space areas. However in forested, densely built or well-structured agricultural landscapes, the large block of extruded forests, settlements or the visually impermeable structures lead to a massive underestimation of visibility. When investigating landscape intervisibility, SCHULTE-BRAUCKS (2011) calculated a statistically highly significant but very low correlation of only 0.077 between the analyses based on laser scanning DSM and DTM plus extruded land uses.

Thus, we recommend using native DSMs whenever possible, be they based on laser scanning (SCHULTE-BRAUCKS 2011, HAUBAUM 2013) or radar interferometry or aerial photography stereoscopic analysis (ROTH & GRUEHN 2014). When using native DSMs is not an option, we recommend – based on the investigations by JUNKER (2014) – to include at least built-up areas and forested areas in the extrusion. Hedgerows, treelines and other woody structures can be included, but their representation in official German digital topography data does not significantly increase the validity of the visibility analysis.

3.3 Eye Height

In her very systematic analysis of eye height impact on landscape intervisibility, SCHULTE-BRAUCKS (2011) found statistically highly significant correlations of above 0.99 for all eye-heights between 1.20 m and 1.80 m. Because of the very weak influence of eye height on GIS-based visibility analysis, we recommend to use the mean value of eye height for the adult population in the respective population. For the German population this is about 1.60 m.

3.4 Target Height and Target Structure Representation

Especially with wind turbines, a persistent discussion is which parts of the turbine to use for the visibility analysis in visual impact analysis. One could use the tip of the upper blade, the hub, the lowest point of the rotor, or the ground height. Of course, the visual impact is different whether the full turbine is visible or only the tip of the upper blade. From a GIS-based visibility analysis perspective, the question was investigated, how visibility of common turbines (100 to 150 m hub height, 60-100 m rotor diameter) changes in the landscape, when the different reference points as described above are used.

JUNKER (2014) statistically analysed correlations between those different reference points and found statistically highly significant correlations of around 0.9 or higher for the three levels of the rotor (upper tip, hub, lowest point of rotor). This correlation massively drops when the full (or nearly full) pylon is included in the visibility analysis. Combined with findings of qualitative impact analysis, we recommend using the hub height of wind turbines for visibility analysis. Then, one half of the rotor is visible and the object is recognizable as a turbine due to its movement.

Another solution could also be to show in visibility maps which parts of the turbine(s) are visible, as TÄUBER & ROTH (2011) did: They used 5 classes (completely invisible, tip of upper blade visible, upper half of rotor visible, full rotor visible, full turbine including pylon visible) instead of the often used binary visibility.

When the visibility of electricity transmission infrastructure is investigated, this is often done solely based on the pylons. HAUBAUM (2013) proved empirically, that in an average German landscape, the viewshed of a power line can increase up to 10 % when not only the pylons, but also the cables are included in the visibility analysis. These findings include the fact that the maximum visible distance of the cables is far less as compared to the pylons, due to their smaller diameter.

JUNKER (2014) showed that in regional planning, when the exact locations of wind turbines within the proposed concentration zones are not yet known, a careful placement of points as representation of wind turbines can help to balance computation time needed and validity in visibility analysis. She found out that placing wind turbine locations each 500 m on the perimeter of the concentration zones[1] produces a higher correlation in terms of the calculated visibility with potential wind farm layouts than when placing wind turbine locations at a 500 m wide raster within in the concentration zones. At the same time, this helps to considerably save computing time for the visibility analysis due to a reduced number of target points (wind turbine locations) in the viewshed calculation.

3.5 GIS Software Package

Based on the comparisons between ESRI's ArcGIS and Grass GIS using both the r.cva and r.los algorithm (SCHULTE-BRAUCKS 2011) a systematic overestimation of visibility in ArcGIS' viewshed tool as compared to GRASS GIS can be observed. In frequency visibility analysis, correlations of only 0.6 (yet statistically highly significant) could be observed.

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1 500 m were used as this equals 5 times the rotor diameter of an average wind turbine, which is a usual distance to prevent turbulences between the individual turbines in wind farm.

The comparison between ESRI's ArcGIS and QGIS (using the Viewshed Analysis Plugin) (JUNKER 2014) revealed, that ArcGIS systematically underestimates visibility as compared to QGIS. However, correlations between both software packages' results were very high (above 0.97) and statistically highly significant, both in binary and in frequency visibility analysis.

4 Conclusion and Outlook

We conclude that without the need for additional software, very expensive data or specialist training, the validity of visibility analyses and thus the whole subsequent visual impact analysis can be significantly increased. Carefully choosing the adequate visibility analysis approach is the most important task to increase validity. Besides choosing between binary, frequency and cumulative visibility, this includes the appropriate DEM resolution, surface representation including vegetation/buildings, observer parameters, target structure representation, and visibility analysis method/algorithm.

We are convinced that reaching a critical level of validity in visibility analysis is a basic prerequisite to the subsequent visual impact analysis and the final (geo-)design of individual renewable energy infrastructure. Valid visibility analysis can play a vital role in ensuring public acceptance of a shift towards green energy.

Until now general recommendations for the different data, models, parameters, methods and software packages included in visibility analysis cannot be given. So far sufficient data has not been analysed and a representative sample of areas across Germany has not been investigated, nor have profound ground truthing studies been conducted. Thus, planers and academics should always communicate the insecurity inherent in the studies conducted together with their results. From our observations in planning practice and planning related academic publications, GIS-based visibility analyses and their results are often communicated as being100 % valid. We have to remember, that BOX & DRAPER's (1987, p. 424) quote is also true for visibility modelling: "Essentially, all models are wrong, but some are useful." We believe that visibility modelling and analysis in planning for renewable energy is even more useful when users know about the variation in visibility based on the above mentioned factors instead of believing in an uncritical way in the objectivity of outputs from GIS-based visibility analysis.

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