Digital Participatory Landscape Planning for Renewable Energy – Interactive Visual Landscape Assessment as Basis for the Geodesign of Wind Parks in Germany

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Abstract

In our paper, we present results of a research project dealing with renewable energy production and visual landscape quality, using a regional planning case study in the federal state of the Saarland, Germany. Innovative methods of visual impact analysis based on GIS tools and methods, as well as state-of-the-art digital landscape data and web-based participatory approaches were used to determine the most suitable locations for wind turbines and provide an empirical basis for the region-specific geodesign of multiple wind parks. Complementing theory- and data-driven GIS methods, digital participatory approaches were used. Experts and lay people, living in the area affected by the planning proposal provided the empirical basis and validation for our landscape assessment method in order to ensure a maximum compatibility between renewable energy production and the maintenance of high visual landscape quality.

1 Introduction

Germany has ambitious goals for the transition towards renewable energy: Until 2050, the German government has set a minimum of 60% of the national gross energy usage and 80% of the national electricity usage to be produced from renewable energy sources. Wind energy will contribute the largest part of the renewable energy production. Until 2007, Germany was leading globally in terms of wind powered electricity generation, and now is only outperformed by China and the USA. Whereas in China and the USA, large wind parks are often installed in areas with lower population densities, wind turbines in Germany have been, are and will be placed often in densely populated regions, and close to human settlements.

The formal regional and land use planning system in Germany guides the siting of wind turbine installations by designating priority zones for wind power generation. Once these priority zones are formally established in a planning area, no wind turbines can be build outside these zones (preclusive effect of priority zones for wind turbines).

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It is increasingly understood that public acceptance becomes a constraining factor for realizing renewable energy goals (JONES & EISER 2010; READ et al. 2013; BIDWELL 2013; HALL et al. 2013; KONTOGIANNI et al. 2014). Perceived landscape change and loss of landscape quality have featured heavily in the concerns raised by members of the public, although renewable energy may offer potentials for sustainable development, especially in economically disadvantaged regions. Both the formal planning process, and the participation process to ensure public acceptance take considerable time. With the compensation for wind power generated electricity fed into the grid decreasing over time, an effective and efficient planning process, from the so-called "macro-siting" in regional planning over the "meso-siting" in land-use planning to the "micro-siting" and design of wind-turbines in wind-park planning are crucial to meet renewable energy goals and ensure revenue for the operators of wind parks.

Geographical Information Systems (GIS) have played a vital role in the macro-siting of commercially viable wind parks and the consideration of so-called hard exclusion factors such as minimum distances to ensure safety of traffic infrastructure and acceptable noise levels for settlement areas. Nowadays, perceived landscape quality becomes more and more important in the public discussion, and social acceptance of wind turbines is the main constraining "soft" exclusion factor to be handled by planners. A landscape-specific geodesign of wind parks can help to minimize and mitigate conflicts with visual and cultural landscape qualities as well as touristic aspects (cf. SCHÖBEL 2012). This includes the placement of individual wind turbines in the 3D (virtual) landscape instead of planning merely on 2D maps, and the relation to natural land forms such as horizon lines.

MILLER (2012) defines geodesign as "the thought process comprising the creation of an entity in the planet's life zone (geo-scape)", including the science and value base for design, combining them to an integral, holistic and multidisciplinary design process. SCHWARZ-VON RAUMER & STOCKMAN (2012) identify three dimensions of geodesign: technology, the role of geo-information, and the function of the (geo-)design process. BATTY (2013) stresses the importance of participation for geodesign.

Thus said, geodesign seems to be the perfect idea for bridging the gap between the scientific analysis of wind power generation potentials, the legal restrictions for wind park realizations and the "soft" aspects of visual landscape quality and public participation in wind park planning and design.

2 Material and Methods

MANCHADO et al. (2013) emphasize the importance of not restricting the analysis of landscape impacts caused by the installation of wind turbines to merely quantitative aspects such as visibility, but to also include qualitative aspects, such as visual impact analysis and the "modification of the character of a landscape [which] is particularly significant in the case of wind farms, in which a number of very large and highly visible structures are placed on a fairly extensive area". Following this line of argumentation, in the study described here, a twofold approach to analyzing the landscape impacts of wind turbines was followed, consisting of (a) visibility analysis, including individual and cumulative viewshed analysis, and (b) visual impact analysis, including the assessment of the present landscape quality and character, and the assessment of wind turbines' impact on landscape quality and character.

2.1 Area of investigation and digital data used

The Regional Planning Association Saarbrücken (Regionalverband Saarbrücken – RVS) covers an area of around 411 km² and is the responsible authority for the inter-municipal land use plan, designating the priority and concentration zones for wind turbines.

With the impacts of wind turbines on landscape quality reaching into surrounding areas of the RVS administrative region as well, the area of investigation had to be extended to avoid border effects in the visibility assessment and to include neighbouring municipalities in the participation process. As the RVS district is located at the French-German border, data sources covering also French territory had to be used. According to recommendations for the visual impact outreach of wind turbines found in literature referring specifically to Germany (ADAM et al. 1986; NOHL 1993; GERBAULET 1994; GALLER 2000; GERHARDS 2003 and TÄUBER & ROTH 2011) it would be desirable to perform visbility and impact analysis at least 10 km around the proposed wind turbines. International literature suggests even higher maximum distances of 15 to 35 km for landscapes of different configuration (SCOTTISH NATURAL HERITAGE 2006). Due to financial constraints for data acquisition the base data was acquired for the RVS administrative region and a 5 km buffer around it. In terms of the digital terrain model both interferometric synthetic aperture radar as well as a stereoscopic analysis of orthophotos have been used. This data has been specifically mapped for the project described here, in order to establish a high-precision, up-to-date, seamless data base. In addition, a wide array of vector data (land use data, topographic map data, habitat mapping, touristic infrastructure etc.) has been used.

To provide a homogenous basis for empirical landscape quality assessment and to be used for wind turbine visualizations, a photographic documentation of the area, consisting of around 900 photographs taken at 150 different locations was established, following standards for photographic landscape documentation as described by ROTH (2012: 171-176).

In terms of the suggestions for wind turbine priority zones, the RVS provided a GIS dataset of 27 areas derived from the state-wide wind potential analysis, which were subsequently reduced to 16 areas over the course of the project by eliminating the "hard" exclusion factors as mentioned above. Within those areas, two scenarios for wind parks were used as input for the analyses described below: A 2-MW scenario with wind turbines of 100 m hub height, 80 m rotor diameter and thus a total height of 140 m, and a 3-MW scenario with wind turbines of 150 m hub height, 100 m rotor diameter and thus a total height of 200 m.

2.2 Quantitative impact analysis: GIS-based visibility analysis

Even though visibility analysis is a standard function within today's GIS software packages, it must not be overseen, that the results of such analysis are highly dependent on input data quality and resolution (cf. TÄUBER & ROTH 2011 who analysed the effect of different DEM data sets of varying resolution on visibility calculation accuracy), as well as algorithms used by the respective GIS software package (cf. SCHULTE-BRAUCKS 2011, who statistically compared ArcGIS and GRASS GIS viewshed derived from the same DEM input data sets.). CHAMBERLAIN & MEITNER (2013) illustrate the limits of out-of-the box binary visibility analysis in commercial GIS products. WHEATLEY (1995) states possible errors in viewshed analysis, especially when calculating cumulative viewsheds, which is a highly relevant setting for the application in the project described here, as the cumulative viewsheds for multiple wind parks, each consisting of one to several wind turbines, have to be calculated. FISHER (1991) who systematically analysed those errors, urges caution over the uncritical use of black-box viewshed calculation tools which only deliver binary visibility as an output (i.e., a location is either in or out of a viewshed).

In order to yield reliable and valid results, a modification of standard binary visibility concepts was used, taking also into account cumulative effects of wind turbines in multiple concentration zones. Table 1 illustrates the 12 different types of visibility analysis carried out, reaching from the binary visibility of individual wind turbine concentration zones to the cumulative visibility of the whole scenarios consisting of all concentration zones for wind turbines. Whereas CHAMBERLAIN & MEITNER (2013) use the term "cumulative visibility" for the frequency a certain structure (or grid cell within the DEM/DSM) can be seen, we use the term "frequency visibility" for this gradual (times seen) visibility and reserve the term "cumulative visibility" for cumulative effects in the meaning of environ-

Table 1: Different types of visibility analysis carried out to assess the quantitative (visibility) impacts of wind turbines.

Visibility analysis method	Subtype of vis. anal. method	Base scenario	Planning question to be answered
Individual wind turbine concentration zone visibility	Binary visibility	2 MW: turbine height 140 m	From which area can the wind park with 2 MW turbines on concentration zone X be seen?
		3 MW: turbine height 200 m	From which area can the wind park with 3 MW turbines on concentration zone X be seen?
	Frequency visibility	2 MW: turbine height 140 m	How many of the 2 MW wind turbines on concentration zone X can be seen from which area?
		3 MW: turbine height 200 m	How many of the 3 MW wind turbines on concentration zone X can be seen from which area?
Total scenario visibility (16 concentration zones)	Binary visibility	2 MW: turbine height 140 m	Which areas will the realization of the whole 2-MW scenario impact in terms of wind turbine visibility?
		3 MW: turbine height 200 m	Which areas will the realization of the whole 3-MW scenario impact in terms of wind turbine visibility?
	Frequency visibility	2 MW: turbine height 140 m	How many wind turbines from the whole 2-MW scenario can be seen from which area?
		3 MW: turbine height 200 m	How many wind turbines from the whole 3-MW scenario can be seen from which area?
Cumulative visibility (additional visibility of one concentration zone as compared to the whole scenario)	Binary visibility	2 MW: turbine height 140 m	What is the additional effect of a wind park with 2 MW turbines on concentration zone X in terms of visibility area?
		3 MW: turbine height 200 m	What is the additional effect of a wind park with 3 MW turbines on concentration zone X in terms of visibility area?
	Frequency visibility	2 MW: turbine height 140 m	What is the additional effect of a wind park with 2 MW turbines on concentration zone X in terms of visibility area and number of visible wind turbines?
		3 MW: turbine height 200 m	What is the additional effect of a wind park with 3 MW turbines on concentration zone X in terms of visibility area and number of visible wind turbines?

mental impact assessment (EIA). Thus, cumulative visibility is used to identify the additional area impacted by the realization of a wind park in one concentration zone as compared to the realization of the whole scenario without this single concentration zone.

2.3 Qualitative impact analysis: Visual landscape quality survey

Based on the photographic documentation of the area described above, an internet survey investigating perceived visual landscape quality in the area was conducted, following the method described by ROTH (2006 and 2012). Around 40 of the photographs were modified with GIS-based simulations of various numbers of wind turbines virtually installed in the potential concentration zones for wind turbines, to investigate the perceived impact of wind turbines on visual landscape quality, including both the 2-MW and the 3-MW scenarios.

Over 600 participants from the region completed the online questionnaire, each assessing at least 10 landscape photographs according to 4 assessment criteria derived from the German federal nature conservation act (visual diversity, scenic landscape characteristics, scenic beauty, and perceived naturalness). The participants were acquired by newspaper articles in local / regional newspapers, during public hearings in the municipalities involved in the planning process and via website / email invitation. By complementing online with face-to-face acquisition methods, the selectivity of participant recruiting that is often seen as a potential weekness / bias in online surveys could be overcome. The survey produced nearly 6,000 complete assessment datasets, establishing a broad empirical basis for the subsequent GIS-analysis.

The online survey was pre-tested by an expert survey carried out during a workshop on wind energy and landscape quality in which 23 experts from the Saarland federal state involved in the planning and assessment of wind parks took part. Using a digital audience response system, these experts rated a subset of the photographs included in the online survey. An instant analysis of the experts' responses followed by an in-depth discussion of the results was used to identify relevant assessment criteria and check the methodology applied for transparency.

3 Results

3.1 Individual and cumulative visibility analysis

Based on the methodology described above, seven indicators were selected for the final assessment of each of the 16 potential concentration zones proposed by the RVS.

- The total area of the (binary) viewshed for the respective concentration zone with wind turbines from the 2-MW scenario, assuming that a bigger viewshed will contribute to a higher landscape impact.
- The total area of the (binary) viewshed for the respective concentration zone with wind turbines from the 3-MW scenario.

- The ratio of the area of the (binary) viewshed from the 3-MW scenario divided by the area of the (binary) viewshed from the 2-MW scenario, assuming that this ratio will help to balance landscape impacts versus energy productivity.
- The area-weighted number of visible wind turbines (from the frequency viewsheds) for the respective concentration zone with wind turbines from the 2-MW scenario, assuming that not only the mere size of the viewsheds but also the number of visible wind turbines will contribute to higher landscape impacts.
- The area-weighted number of visible wind turbines (from the frequency viewsheds) for the respective concentration zone with wind turbines from the 3-MW scenario.
- The respective concentration zone's contribution to cumulative visibility with wind turbines from the 2-MW scenario, assuming that concentration zones with higher cumulative visibility will cause higher landscape impacts than those with a lower cumulative visibility.
- The respective concentration zone's contribution to cumulative visibility with wind turbines from the 3-MW scenario.

Figure 1 shows that both for the overall (binary) viewshed areas and for the cumulative visibility, there are large differences between the potential concentration zones, allowing for a differentiation between the quantitative (visibility) impacts of the respective wind turbine concentration zones.

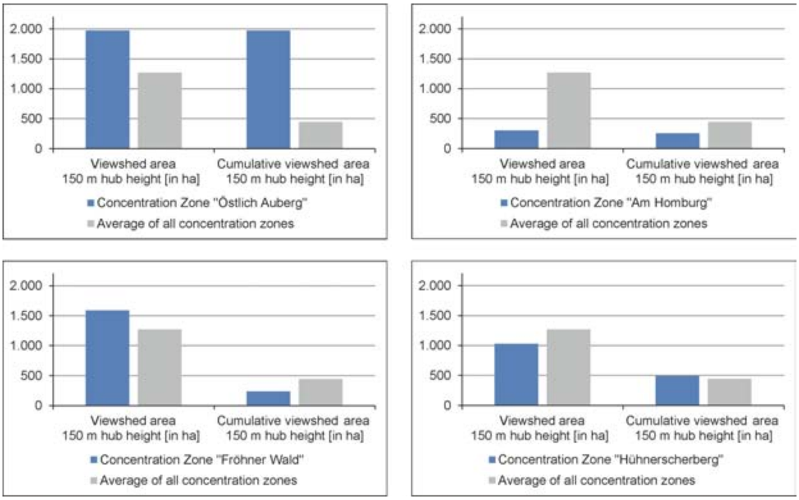

Fig. 1: Comparison of viewshed areas and cumulative visibility for different wind turbine concentration zones: Above average absolute and cumulative visibility (top left), below average and cumulative visibility (top right), above average absolute but below average cumulative visibility (bottom left), below average absolute but above average cumulative visibility (bottom right).

3.2 Landscape quality and qualitative landscape impact analysis

Based on the results of the online survey, a statistically significant differentiation between the different landscape types and the different assessment criteria could be observed. With the participants rating the respective landscape photographs on an 9-point ordinal scale, average values between 2.12 and 6.95 for visual diversity, between 3.29 and 7.60 for scenic landscape characteristics, between 1.78 and 8.36 for scenic beauty, and between 1.45 and 8.20 for perceived naturalness were yielded, which shows, that the participants made use of the full rating scale. It is also very interesting that certain landscapes yielded top marks for one criterion while at the same time very low marks for another criterion. This applies, for example, to the Völklingen Ironworks World Cultural Heritage Site that reached a top mark (average 7.39 out of 9 points) for scenic landscape characteristics but very low marks (average 2.04 out of 9 points) for scenic beauty. On the other hand, well-structured, diverse undulating semi-open landscapes and semi-natural forests yielded high results for all criteria.

In the expert survey during the expert workshop, some experts argued that wind turbines could possibly also increase the aesthetic value of a landscape. In contrast to this opinion, both in the expert survey but also in the online lay person survey, a loss of aesthetic landscape quality could be observed for all criteria included.

One surprising outcome of the online survey was the fact, that there seems to be a clear preference for even over odd numbers of wind turbines installed, which applies to all criteria investigated. Linking the outcome of the GIS-analysis and the results of the online survey with the (geo-)design process, one recommendation for the specific design of wind parks would be to install an even number of wind turbines where possible, to minimize visual impacts as perceived by the local/regional population.

Looking at the effects of wind turbines of different heights, the general impacting effect (the more wind turbines the higher the impact on visual landscape quality) stays the same, but the effect of the wind turbine heights is different for each of the criteria investigated, as can be seen from figure 2.

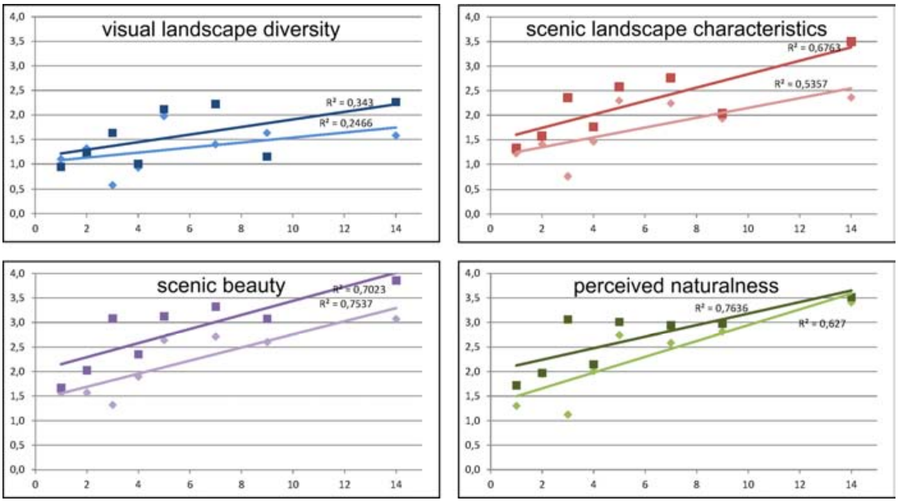

Fig. 2: Loss of visual quality (y-axis) for the four different assessment criteria depending on number of wind turbines installed (x-axis) for different wind turbine heights (darker dots and lines: 200 m; lighter dots and lines: 140 m).

For the impact on scenic beauty, the two lines in the diagram are parallel, which means that the same number of higher wind turbines have about the same higher impact on scenic quality, no matter how many wind turbines are installed. For visual landscape diversity and scenic landscape characteristics the effect is different: If only few wind turbines are visible, it does not make a big difference which height they are, whereas the negative impact of higher wind turbines is much more severe if a higher number of wind turbines are visible. For the criterion of perceived naturalness, the effect is inverse: If only one or few wind turbines are visible, smaller wind turbines cause a much lower impact on perceived naturalness, whereas in case of 10 or more wind turbines are installed, there is not really a big difference between the impacts of wind turbines of different heights.

Thus said, when designing specific wind parks, it might make sense to plan for more of the lower wind turbines or fewer of the higher wind turbines to produce the same amount of electricity, depending on the local specifics, overall size of the wind park and scenic quality regarding the respective criteria in the area.

4 Discussion and Conclusion

By complementing theory- and data-driven GIS methods with workshop- and web-based digital participatory planning approaches, we contributed towards ensuring a better acceptance of wind energy production by avoiding and mitigating conflicts much earlier in the research / planning / design process, than traditional modes of public participation, which usually are used towards the end of the planning process, would allow. MANCHADO et al. (2013) state that "usually visibility studies and Visual Impact Assessments (VIA) are expressed as reports that are carried out only when design of projected structures is already completed". In the case described here, this weakness of a visibility study and VIA that comes too late to influence the planning process and wind park design substantially were overcome by allocating the analyses at a higher planning level, that is a preparatory pre-requisite for the subsequent planning and design of individual wind parks.

JONES & EISER (2009) emphasize "that the key to reducing levels of opposition and increasing general acceptance of wind turbines lies in the early and continued involvement of host communities in the planning and decision-making process". This involvement was not only ensured by conducting participatory workshops, hearings and the quantitative online survey, but also by open comment fields in the online survey of which about one third of the participants made intensive use. These valuable inputs were forwarded to the RVS planning authority and helped them to start and establish a broad dialogue with the population affected by the future installation of wind turbines.

The formal planning process with its requirements for public participation at certain stages was complemented by region-specific foundations for the design of specific wind parks that will follow the regional planning process were provided. The use of validated digital methods with a solid empirical basis also helped to de-emotionalize the planning and design discussions about wind turbine localization and wind park design.

The link between formal planning processes, scientific visual quality and impact analysis and the geodesign of wind parks was established also by means of visualizations of potential wind turbine scenarios that were both used in the online survey, but also in public hearings and workshops. Although it was always clearly communicated that these visualizations do not represent actual planning applications for specific wind parks, they were helpful in keeping the discussion with the local / regional population based on facts.

In contrast to the more common approach in Germany to base impact analysis on the transfer of past findings from empirical or hermeneutical research in other areas, with other landscape features, other populations and other preconditions, a specific, local, up-to-date science base for the impact assessment was established in the study described.

Realizing a holistic process of geodesign, as described by MILLER (2012), a continuous information flow from scientific method development over regional / inter-municipal planning to the subsequent planning and design process of wind parks was set up. A solid and valid empirical science base, a democratically legitimated value base, and a sustainable dialogue between the affected population, planning authorities and future wind park designers were established.

In terms of the visibility analysis, better, more accurate, high-performance algorithms and software tools such as the one developed by CHAMBERLAIN & MEITNER (2013) might help to overcome restrictions caused by common commercial GIS software packages.

Regarding future applications in similar projects, establishing standards for visual impact analysis and public participation, as well as their links to formal planning processes and subsequent wind park design will be the key issue in promoting holistic, multi- and transdisciplinary approaches of geodesign for renewable energy, according to the authors' opinion. If this challenging process can be successfully handled, then several current partitions that can be observed currently in German landscape planning could be overcome, such as the ongoing separation between landscape planning and landscape architecture, and the separation between planning research and planning practice.

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