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# Predicting the visual impact of onshore wind farms via landscape indices: A method for objectivizing planning and decision processes

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## HIGHLIGHTS

- We tested landscape indices to predict the visual impact of onshore wind farms.
- 400 respondents from four countries evaluated images of 32 landscapes.
- 5 out of 12 landscape indices describing relief and land cover were significant.
- We present a method for predicting the visual impact of onshore wind farms.
- The method helps to objectivize planning and decision processes.

## ARTICLE INFO

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## ABSTRACT

Visual impact is one of the main factors influencing the acceptance of wind farms by the public and by the authorities. It therefore often sets the environmental and social limits of energy policy and energy use. However, the assessment of visual impacts is subjective, as is often pointed out by critics of the evaluation process. The study presented here for the first time uses accurately and objectively measurable landscape indices to directly predict the visual impact of onshore wind turbines. The method also for the first time evaluates map-based landscape indices in a panoramic simulation, and this provides a better match of visual preferences with landscape indices than the cartographic projection used until now. 400 respondents from four Central European countries (Austria, Germany, Poland and Czechia) provided an evaluation of their scenic perception of 32 different landscapes, in each case with and without wind turbines. At the same time, we analysed 12 indices characterizing the principal landscape components (relief, land cover and landscape pattern) on the basis of the 32 landscape photographs. These were further tested as predictors of visual impact. The most prominent predictors of visual impact were the Percentage of Industrial Area (including Commercial, Logistic and Mining Areas), Percentage of Forest Cover, Density of Technical Infrastructure, Number of Elevation Landmarks, and Elevation Variation. None of the three landscape pattern indices was statistically significant. On the basis of a regression model that is able to predict the potential visual impact in large areas of four Central European countries (over 830,000 $km^2$), we present the general principles of an objectivized method for predicting the visual impact of onshore wind farms. The method makes an automatic assessment of the visual impact in large areas of entire regions or countries via a GIS analysis of Sentinel data and DEM data. This forms a good basis for both preventive evaluation and causal evaluation, and provides significant support for objectivizing the planning and decision process in order to mitigate negative environmental and social impacts of the use of wind energy.

## 1. Introduction

The visual impacts of wind turbines (WTs) are usually a decisive element in the decision to reject or permit their construction [1]. A need has therefore arisen to establish a method that can be used for making a visual impact assessment of WTs. Some recent methods have used visual impact assessments that are limited to the visibility of WTs. They have aimed to define visual thresholds [2] or a maximum visible distance [3], without taking into account the qualities of the impacted landscape. With the easy availability of GIS data and techniques, an assessment of this kind is nowadays not very difficult to make.

Methods for assessing the visibility and the qualitative attributes of

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landscapes, and how they are visually impacted by objects such as wind turbines, face issues that are typical for any aesthetic evaluation. These methods may be classified into: (i) expert approaches using subjective evaluations made by appropriately educated and experienced assessors [4,5], (ii) approaches based on landscape classifications, which generalize the impact of WTs for individual landscape types [6–8], (iii) approaches using specific multi-criterion indicators of visual impact [9], including the so-called Spanish Method [10], and (iv) approaches using exactly measurable map-based indicators [11–13]. These methods have until now been used for evaluating the visual qualities of WTs, rather than for making a visual impact assessment of WTs.

Assessments of visual impacts for planning or decision-making purposes are highly subjective. The outcome therefore depends to a large extent on the assessor, his/her attitudes, experience and other relevant characteristics, and this is frequently criticized [14]. This drawback is due to the high degree of subjectivity that is inherent in the scenic perception of landscape.

Lothian [15] discussed objectivist and subjectivist paradigms as two contrasting views of landscapes. According to Zube [16] and Daniel [17], the aesthetic quality of a landscape is a joint product of particular visual features of the landscape (objective component of the assessment) interacting with relevant psychological – perceptual, cognitive and emotional – processes in the human observer (subjective component). However, the subjective component of aesthetic quality evaluation is often a matter of contention between investors and their opponents in the WT approval process. In the interests of reaching a justifiable conclusion, the subjective element in assessments of landscapes and in the assessment of the influence of WTs on a landscape therefore needs to be reduced as far as possible. In other words, the evaluation process needs to be objectivized.

There are several ways to objectivize a visual impact assessment of WTs: (1) consensus among multiple experts, (2) evaluations performed by a recognized authority, (3) evaluations performed by an expert whose competence has been proved by specialized examinations, (4) the use of a rigorous and transparent methodology, (5) a sociological survey by representatives of the public, or (6) an analysis of precisely measurable visible landscape indices followed by a statistical evaluation. A combination of options (5) and (6) forms the principle of the method presented in this paper.

Past experience has shown that one of the decisive determinants of the visual impact of WTs on the landscape is the quality of the landscape itself. Studies published so far have highlighted the significance of landscape type [6], perceived naturalness and wildness [7], and landscape aesthetic value [8]. Classifying all these categories, of course, often involves a subjective element. The use of these categories in predicting the impact of WTs on a landscape therefore further increases the subjectivity of the entire evaluation process.

However, the use of partial, objectively measurable landscape indices (metrics) can provide a way to limit the subjective element in the evaluation process. This method not only enhances the objectivity of the evaluation and decision making, but also, thanks to the detailed scale of values of the individual indices, enhances the objectivity of the assessment itself. In addition, the method provides repeatability, and therefore makes it easier to audit the results and conclusions. However, insufficient exploration of these evaluation methods remains the principle impediment to their implementation.

Landscape indices are most commonly used for landscape assessment in the landscape ecological context [18,19]. However, there is a lack of studies where landscape indices are tested as indicators of visual characteristics or of landscape quality [20]. In this sense, Dramstad et al. [21] made a pioneering study testing the relationships between visual landscape preferences and map-based indicators of landscape pattern. Palmer [11], Svobodova et al. [12] and Frank et al. [13] successfully used spatial metrics to predict the scenic perception of landscapes. All three studies used GIS tools to evaluate map data for predicting the visual perception of landscapes. They therefore provide the basis for a large-scale and objectivized assessment of landscape visual qualities.

The use of accurately measurable landscape indices cannot take into account all landscape factors relevant to scenic perception or aesthetic evaluation. There are aspects, phenomena and landscape features that are not measurable, but that affect the scenic perception of a landscape. To point out just a few examples, we can mention here the distinctiveness of a landscape or, in particular, the 'genius loci', which is probably the best-known phenomenon in this sense [22].

In our study, we investigate whether significant landscape indices can adequately explain the variability of the visual impact of WTs. The aim is to evaluate significant predictors of the visual impact of WTs from a set of indices describing landscape relief, landscape cover and landscape pattern. We present a method for objectivized prediction of the impact of onshore wind farms based on these significant variables.

## 2. Methods

The assessment methodology can be divided into five steps: (1) take photographs of the landscape and visualize the WTs, (2) evaluate public visual preferences, (3) analyse the landscape indices, (4) make a statistical analysis of predictors of visual impact, and (5) predict the visual impact of WTs on the landscape.

The study areas were located on the territories of four Central European countries – Germany, Austria, Poland and Czechia. In each of these countries, 4 study areas 50 × 50 km in size were defined, all of them in locations where wind farms are currently present (Fig. 1). The study areas were selected with regard to the presence of different types and qualities of the surveyed landscapes, in such a way that the tested indices are represented in a wide range of values.

### 2.1. Landscape photography and visualization of WTs

In each of the 16 study areas, ground landscape photographs without WTs were taken. The photographs were taken between the beginning of June and the end of August 2015, on days with clear weather conditions, using a digital camera with a focal length of 50 mm and a tripod set to a height of approx. 170 cm (an "adult man's eye view"). The photographs were composed in such a way that the sky occupied approximately the upper quarter of the height of the image. Placing landscape features of significant interest according to the rules of the Golden Section or the Rule of Thirds was avoided, as this type of composition may have a significant effect on the observer's perception [23]. A total of 185 pictures of different landscapes were taken, from which 32 photos of landscapes were selected for the final set.

For each of these 32 photographs, Adobe Photoshop was used to digitally add a wind farm with a total of 10 WTs. The WTs were of the Vestas V90 type (hub height 105 m, rotor diameter 90 m). This is one of the most common types set up in Central Europe in recent years. The positions of the blades were rotated differently, in order to obtain a realistic photomontage. The apparent distance of each wind farm from the observer was in all cases from 3 to 4 km, which corresponds to the medium visibility range [8]. The resulting 32 pairs of landscapes (with and without the wind farm, a total of 64 images) were printed in colour with dimensions of 280 × 190 mm.

The landscape photos were numbered, and were assigned to 16 sets of 16 photos, using a random number method. Each landscape was represented in 4 sets. Each set consisted of photos of 8 landscapes with and without WTs in order to allow a calculation to be made of the differences in preferences for each landscape, with and without WTs, for each respondent, and thus to obtain the dependent variable – Visual Impact. The sequence of photos in the set was random, the only condition being that photos of the same landscape with and without WTs would not immediately follow each other.