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Wind turbines location: How many and how far?

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HIGHLIGHTS

- Negative impact of wind turbines (WTs) diminished with distance from observer.
- Impact disappeared at 5–10 km with respect to landscape's aesthetic quality.
- Negative effects increased with number of WTs in an approximately linear manner.
- A cumulative effect of higher numbers of WTs was not confirmed.
- Distance and numbers interacted significantly with landscape aesthetic quality.

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ABSTRACT

Existing research relating to visual impact of wind turbines (WTs) affirms this to be an essential parameter for public acceptance in most cases as well as for the planning process and permitting of planned wind farms. This study brings new findings about the impact of two crucial factors: numbers of WTs (1–25) visible and distances of WTs (0.75–15 km) from the observer (e.g. from residential buildings, landmarks, observation points). Photographs of three aesthetically varying landscapes with various numbers of WTs (Vestas V90, height 105 m, rotor diameter 90 m) at various distances were evaluated in terms of visual preferences. The results show significant effect from the aesthetic value of a given landscape on the impact of both tested factors. An important finding is that the landscape with the highest aesthetic quality initially was evaluated to be the absolute worst after the addition of WTs and vice versa. Increasing numbers of WTs in the least attractive landscape had less visual impact than did doing so in the two more attractive landscapes. This helps explain strong public opposition to locating WTs in aesthetically valuable landscapes and their greater acceptance in less-attractive landscapes. Increasing stepwise from 1 to 25 WTs within a given landscape progressively decreased visual preferences, although the cumulative effect of a higher number of WTs was not confirmed. We also established threshold distances after which the negative visual impact of a WT disappeared (10 km for the most attractive landscape, 5 km for the least attractive one). Based on these findings, visibility zones were proposed for practical assessment of WTs' visual impact. The study's results can make a substantial contribution towards reducing negative visual impact in WT planning and thus achieving greater public acceptance of these devices.

1. Introduction

Visual impact has become the most distinctive among public perceptions of wind turbines (WTs), ranking higher than such other environmental concerns as the impact on bird populations [1] and noise annoyance [2]. According to the Ministry of the Environment of the Czech Republic, for example, 85% of proposed wind farm projects in the country have been cancelled due to their visual impacts. Despite the obvious importance of visual impact, public authorities still lack understanding regarding the inter-relationships between WT placement, landscape, and public perceptions.

Considering that rapid development of wind energy is one of the main means of reaching renewable energy targets and that negative public attitudes are emerging, there is a need for comprehensive research on visual preferences regarding wind turbines and associated influencing factors. Existing research findings on the visual impact of WTs indicate two general types of variable factors influencing the visual assessment of WTs. These can be termed "physical attributes" and "respondents' characteristics". Molnarova et al. [3] reviewed the main papers focused on visual assessment, and almost

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all of those studies allude to respondents' characteristics. Meanwhile, other factors have not yet all been rigorously evaluated. The main characteristics of respondents have been identified as socio-demographic (gender, age, education, general attitude towards wind energy), occurrence of WTs near the respondents' homes, daily contact with WTs [4], and prior experience with WTs [5].

In order to understand public behaviour, papers often refer to the phenomenon of NIMBYism (Not In My Backyard), which has been analysed due to the many cases of wind projects being rejected in certain areas [6–9]. This issue was reviewed by Petrova [10], who explained the reasons for opposition to establishing WTs. Petrova concluded that the NIMBY syndrome does not adequately explain visual and landscape concerns. Most often the reasons for opposition are aesthetic degradation and visual impact, in which cases it is more important to consider the affective and symbolic association of these structures with the landscape. The NIMBY effect has been the background motive for most research on WT acceptance, and it has consisted of case studies analysing the preferences for WTs already erected or for those planned in selected regions and comparing the evaluation of inhabitants living at various distances from wind parks [11–13]. In addition, recent studies have been based also on choice experiments whereby respondents select from several presented possibilities that option most tolerable for them with regard to their acceptance of new wind farms locations [14,15].

The major physical attributes of importance, meanwhile, include the characteristics of the WTs themselves (height, number, colour, rotor diameter and moving blades), landscape qualities, and distance from the observer. Specifically, distance from the observer means distance from such visually sensitive areas and structures as residential and recreation buildings, cultural features, and landmarks.

The research has quite often taken into consideration awareness of the imposing size and height of these structures. The height factor has been analysed in most studies, predominantly with an emphasis on cumulative effect and interaction with numbers of WTs. Warren et al. [16] and Devine-Wright [8] found that the public has a clear preference for smaller wind farms, even if this means having more than one wind farm in a given locality. Moreover, people prefer reducing the number of turbines by replacing smaller turbines with larger ones even though larger ones might be visible from a larger number of residences [4]. Other results show a less positive attitude for more than five on-land turbines and a cumulative effect for five turbines encountered per day in long thresholds [17]. Research in Denmark demonstrated similar findings. Replacement of 400 old turbines with 50 new, larger ones did not increase the overall visibility of wind turbines in the region. Long-range visibility caused by the smaller turbines was reduced while the short- to middle-range visibility of the large turbines was amplified [18].

Compared to the amount of research done on numbers of wind turbines, only a few studies have so far evaluated the distance factor as a visual threshold. Moreover, the results for those studies are diverse and no clear conclusion for the role of this attribute has yet been established. Research in South Australia, for example, did not substantially prove a reduction of negative visual effects of a wind farm with greater distance [19], whereas research in the Czech Republic showed a positive relationship between visual preferences and increasing distance [3]. A recent study by Vries et al. [20] found that distance decay of impacts is stronger for barns and business parks than for turbines. The maximum distances at which wind turbines can still be distinctly perceived (in this case a wind turbine on a tower 50 m high with a 3-blade rotor having blades 26 m long) were determined by Bishop [21] to be 10 km in "ideal" conditions (clear visibility and stormy sky) and 6 km in prevailing conditions (slightly hazy, sky other than stormy). In view of their rapid development and increasing size, turbine towers 100 m tall are today considered to be usual, and so the relevance of these findings may not fit the current state of the art. A usual methodology for assessing the impact of vertical structures on landscape character takes an approach similar to that of visual thresholds and barriers to determine the so-called Affected Landscape Area. Application of the methodology involving visibility zones as a general approach could be used in any situation [22]. Other studies detecting the visibility are using, for instance, GIS methods [23,24] or other visibility software [25]. Although the distance factor remains an open issue in relation to visual assessment of wind parks, it is a factor needing to be incorporated into research with a detailed focus on determining thresholds and its relationships to other factors.

The public perception of WTs might be influenced by such other attributes as the aesthetic and visual quality of the landscape where they are to be located. Type of landscape has been determined to be an important factor in visual assessment of a landscape in which a turbine is situated [26], although just a few papers have verified this affirmation. Research in the Netherlands has unambiguously shown minimal acceptability for turbines in wetlands of a natural protected area, that landscapes with mountainous morphology and natural elements are considered to be more beautiful, and thence that siting the structures in such areas would be less welcome [27]. Similarly, research in South Australia has tested 68 coastal and inland locations where wind farms could be located, both without wind farms and with wind farms digitally added to the scene. Wind farms were generally viewed as having a negative effect on landscapes of higher scenic quality but a positive effect on landscapes of lower scenic quality. The study concluded that wind farms should avoid areas of higher perceived scenic quality, particularly on the coast, and be located in areas of lower scenic quality [19,28]. Research in the Czech Republic has shown significantly stronger preferences for wind turbines in landscapes of low visual quality than in visually attractive landscapes [3,29]. Vries et al. [20] confirmed that wind turbines have always had a considerable negative impact on scenic beauty, especially when the landscape is considered to be very attractive.

Although each of the physical attributes distance from the observer, number of WTs, and type of landscape has been tested separately and affirmed to be a significant factor, there is still a lack of dimensional research on consistent evaluation of these attributes. In order to understand the interaction between these factors, research needs to be undertaken which uses comprehensive statistical analysis to explain various situations which can be very changeable. A proposal that might be accepted in one type of landscape, for example, might be rejected in another one. Consequently, the goal of the present study was to verify and furthermore specify the effect of distance from the observer and number of WTs located in various landscapes on the perception of those landscapes. Regarding distance from the observer, the aims were to (1) establish whether and how the impact of increasing distance on visual preferences of landscapes changes, and (2) determine distance thresholds after which the negative visual impact of WTs disappears. In terms of WT numbers, the aims are to (3) find out how increasing numbers of WTs influence the visual preferences of landscapes, and (4) establish if the cumulative effect could be affirmed from the perspective of visual preferences, which could abruptly decrease the visual preferences beyond a certain number of WTs. An additional objective of this study was to (5) analyse the effect of interaction between number and distance of WTs on visual preferences of aesthetically varying landscapes.