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# Acceptance and stress effects of aircraft obstruction markings of wind turbines

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## RESEARCH HIGHLIGHTS

- Wind turbine obstruction markings influence the social acceptance of wind energy.
- Residents exposed to xenon lights reported more intense stress responses than exposed to LED or colour markings.
- Synchronised lights were found to be less annoying under certain weather conditions.
- Markings with light intensity adjustment proved to be advantageous.
- Evidence of substantial annoyance caused by obstruction markings was not found.

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## ABSTRACT

A dominant resistance factor against wind power projects seems to be their visual impact on the landscape. In addition stress effects from aircraft obstruction markings are an emerging topic related to acceptance. As the height of wind turbines increases, so does the number of mandatory obstruction markings. Recently, obstruction markings have caused a growing number of complaints from residents. Whether obstruction markings indeed cause stress or even substantial annoyance remains an open question. To analyse the stress impact of obstruction markings, we used environmental and stress psychology methodologies. Residents ($N$=420) with direct sight of turbines at 13 wind farms participated in a questionnaire survey. Evidence of substantial annoyance caused by obstruction markings was not found. However, residents exposed to xenon lights reported more intense and multifaceted stress responses than exposed to LED or colour markings on blades. Moreover, xenon lights negatively affected the general acceptance of wind energy. Additionally, synchronised navigation lights were found to be less annoying than non-synchronised lights under certain weather conditions. Markings with light intensity adjustment proved to be advantageous. To reduce stress and increase social acceptance of wind power, xenon lights should be abandoned, navigation lights synchronised, and light intensity adjustment applied.



## 1. Introduction

### 1.1. *Aircraft obstruction markings—an emerging acceptance problem*

Wind turbines (WT) have become the most successful renewable technology in terms of the share of renewable electricity provided in several countries, including Denmark (Danish Energy Agency, 2011) and Germany (BMU, 2011). However, along with the successful expansion of WT, problems of local acceptance have increased (Huber and Horbaty, 2010). Though the problem of local acceptance was neglected in the 1980s (Wüstenhagen et al., 2007), social acceptance factors have since been addressed rather successfully in some countries in the last decade. In Germany, for example, regulations concerning the total duration of shadow-casting on neighbouring properties (e.g., MLUR-Brandenburg, 2003), as well as ecological standards, have been introduced. However, despite successful policies to increase general social and local acceptance, some people living near WT still complain.

Besides changes to landscape scenery, neighbours of wind farms frequently point out two additional sources of annoyance: noise caused by WT and light emissions from aircraft obstruction markings. While noise emissions have been discussed elsewhere (e.g., Pedersen and Larsman, 2008; Pedersen et al., 2009, 2010; for a review on health effects, see Colby et al., 2009) it remains an

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open question whether obstruction markings cause stress or even substantial annoyance to residents living in the vicinity of wind farms. Indeed, the example of Germany shows that obstruction markings may affect the social acceptance of wind farms. Due to air safety, onshore WT that reach a certain height must be equipped with aircraft obstruction markings. These markings are mandatory in Germany for turbines with a total height above 100 m (General Administrative Regulation for Marking of Aviation Obstructions, 2007) and above 150 m in the Netherlands. In recent years, with an increasing number of tall WT, residents have complained about obstruction markings to German local authorities (DStGB, 2009; HiWUS, 2008; Nowak, 2006).

Light emissions are well known environmental stressors which might even cause severe problems. For example, certain visual patterns – such as flash lights – can lead to migraine attacks or epileptic seizures (Fisher et al., 2005). Less harmful, but still annoying, seem to be public light sources with medium light intensities, such as greenhouses (van Oel et al., 2007; Vos and van Bergem-Jansen, 1995) and tennis courts (Health Council of the Netherlands, 2000). Further, the noted studies provide significant evidence that there is no simple dose-effect relationship between light intensity and annoyance. Rather, the degree of annoyance seems to be influenced by certain moderators, e.g., socio-demographic variables (duration of residency, education level) and psychological variables (familiarity with the light source, health worries). Although the aforementioned research provides a better understanding of light emissions as an environmental stressor, for two reasons these results are not transferable in order to estimate the impact of WT obstruction markings. First, they refer to steady light sources, while aircraft obstruction markings are blinking. Second, the light intensity ranges differ too much to be comparable. Therefore, to systematically analyse the stress impact of WT obstruction markings, we conducted a survey based on environmental and stress psychology methodologies.

This paper presents data from the first systematic research on the environmental stress impacts of WT obstruction markings on people living in the vicinity of wind farms. First, this research aims to analyse whether obstruction markings have the potential to cause substantial annoyance in general or influence only a sensitive minority. Second, recommendations for policy strategies are derived how to promote the social acceptance of wind energy. Since the total height of WT continues to grow – potentially to nearly 200 m (BWE, 2010) – the question of how to deal with possible stress impacts of obstruction markings is of international interest.

Besides possible stress effects, the present study analysed whether obstruction markings influence the general social acceptance of wind energy. Social acceptance is a broad term that encompasses market, local community, and socio-political acceptance (Wüstenhagen et al., 2007). Here, we concentrate on local community acceptance—more specifically, residents' acceptance of local wind farms.

### *1.2. Stress concept*

The study's core question is whether aircraft obstruction markings induce stress to people living in the vicinity of wind farms. From a psychological point of view, environmental stress is a complex theoretical construct that includes several domains (Baum et al., 1984; Bell et al., 1990; Lazarus and Cohen, 1977). Therefore, broad stress assessment by several indicators is required. Relevant domains are subjectively experienced annoyance caused by an environmental condition – such as light signals – as well as changes in psychological and physical well-being, and impacts on ordinary behaviour. Furthermore, of interest is whether humans compensate for the experienced annoyance and, if so, which of these coping responses are employed. Additionally, humans experience stress differently. Therefore, reliable research on the stress impacts of WT must take into account moderator variables that influence the relation between the physical stress stimulus and the psychological and behavioural responses. Possible moderators, for example, are the distance from WT, light sensitivity, and heightened vulnerability due to pre-existing health problems. Moderators such as these can increase or attenuate the stress impact of a stressor such as light emissions.

Different types of aircraft obstruction markings are in use, and WT are installed in different landscape sceneries. So far it remains unclear whether different types of landscapes influence the possible stress impacts of obstruction markings. For example, it seems possible that markings of WT located in complex areas might be experienced less intrusively than WT markings in flat, simple areas. Therefore, to test the possible stress effect of different marking technologies, the following obstruction marking systems were analysed in comparison:

1. three types of day markings (white xenon lights, white LED, colour markings on blades, for example red–white–red stripes);
2. markings in simple (flat ground, rural area, low building density) vs. complex (hilly ground, suburban area, high building density) landscape scenery;
3. day and night markings (red lights in the night);
4. synchronised (the same blink rhythm for all wind farm lights) vs. non-synchronised markings;
5. markings with and without light intensity adjustment depending on visibility, that is, low light intensity in the case of clear sky, and high light intensity in the case of unclear sky.

## 2. Method

### *2.1. Research design*

To allow for causal as well as transferable results and recommendations, we set up a quasi-experimental research design. The aforementioned obstruction markings conditions were combined in two research designs.[1] The first research design aimed to tackle the specific impact of different day markings (Table 1). The effect of the three types of day markings – white xenon lights (Xenon), white LED, and colour markings on blades (Colour Markings) – was compared in two different landscape sceneries, simple and complex. Simple landscape was defined as flat ground or rural area with low building density; complex as hilly ground or suburban area with high building density. In this design, the wind farms included were only those equipped with (a) light intensity adjustment depending on visibility (intensity adjustment) and (b) synchronised lights. For all wind farms, the night marking was a special red light called "Fire W, red." The 281 respondents of the first research design lived in the vicinity of eight wind farms in six German states.

The second research design served to analyse the effect of synchronised compared to non-synchronised light markings in simple vs. complex landscape scenery (Table 2). The wind farms included in this research design had no intensity adjustment. The day markings used were either white Xenon or white LED,

[1] To allow for generalisation, we compared certain obstruction marking conditions—such as xenon vs. LED markings. More specifically, we aimed to draw conclusions independent from specific wind farms. Therefore, we controlled several variables and wind farm features instead of making case studies. However, the design is quasi-experimental because we indeed fixed the conditions, but we could not randomly assign the participants because they are residents living near a certain wind farm (Cook and Campbell, 1979).