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Title page

Annoyance of residents induced by wind turbine obstruction lights: A cross-country comparison of impact factors

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Highlights:

Stress effects from obstruction lights at wind turbines are assessed.

Obstruction lights can induce strong stress effects under certain conditions.

Perceived fairness and stress during planning process are significant predictors.

Distance to wind turbines is not correlated with obstruction light annoyance stress.

Annoyance of residents induced by wind turbine obstruction lights: A cross-country comparison of impact factors

Abstract

Larger wind turbines are developed to harvest greater amounts of wind energy. This development increases the dilemma between ensuring aviation safety through obstruction lights and reducing citizen annoyance and possible stress effects caused by obstruction lights. In this study, a unique Danish sample is contrasted with a combined German-Swiss sample. Stronger stress effects due to the lights for the Danish sample compared to the German-Swiss study were found, an issue that could be related to the specific technical and site conditions. The prevalence of strongly annoyed residents was low. Significant factors for predicting obstruction light annoyance stress were identified, including: perceived fairness, consideration of the interests of the community, landscape change annoyance stress, number of visible wind turbines and age. It is recommended to enhance the planning process to reduce the stress among citizens, e.g. through improved communication, and to enhance the participation of residents in a way that allows for a meaningful consideration of people's concerns.

1 Introduction

As part of the green transition of the energy sector, many countries have high ambitions of increasing the amount of land-based or nearshore wind energy. For example, the share of wind energy accounted for 14.0% of EU's electricity demand in 2018 (Wind Europe, 2019), and is estimated to increase to a share between 21.6% and 37.6% by 2030 (Wind Europe, 2017). The increase in wind energy capacity is promoted by technology development that provide taller and more efficient wind turbines (WTs), which result in reductions in the levelised cost of energy (LCoE), higher output, and increased value of wind energy in electricity markets through steadier output (Duffy et al., 2020; Kirkegaard et al., 2021; Wiser et al., 2016). Current 6 MW and 7 MW turbines are expected to be replaced by next generation turbines of 12 and 15 MW (Wood Mackenzie, 2019), and especially for offshore wind, this development is predicted to continue to even larger WTs beyond 250 meters of height.

While the increasing height of WTs has economic benefits in terms of cost efficiency (reducing LCoE), it also imposes societal challenges. The physical and visual presence of tall WTs in general and the height of turbines in particular have been discussed as central issues within spatial planning (Harper et al., 2019; Ohl & Eichhorn, 2010; SNH, 2017; van Rendsburg et al., 2015), particularly related to community acceptance (Borch, 2018; D'Souza & Yiridoe, 2014; Hoen et al., 2019; Jones & Eiser, 2010; Landeta-Manzano et al., 2018; Lombard & Ferreira, 2014; Walter, 2014). Yet, particular dimensions of visual impacts (Batel & Devine-Wright, forthcoming) or visual implications of particular elements of wind turbines have rarely been explored.

A particular challenge of spatial planning and community acceptance comprises obstruction lights mounted on wind turbines. Obstruction lights serve to increase the visibility of WTs for pilots of civil, military as well as ambulance aircrafts and to ensure a low risk of collisions under all circumstances. However, they can also cause visual annoyance for local communities. Research on annoyance of obstruction lights on wind turbines has documented that acceptance of wind projects is related to perceived annoyance of the lights (Pohl et al., 2012; Rudolph et al., 2017). Obstruction lights thus become one of the parameters that energy policy and policy implementation have to consider. However, while previous studies have examined people's perceived annoyance by obstruction lights, there is still a lack of knowledge of what factors contribute to the annoyance caused by obstruction lights.

Currently, there is no guidance on how to work with obstruction lights in terms of mitigating citizen annoyance and increasing acceptance. This is problematic for several reasons. First, since visual externalities and hub heights of wind turbines have been identified, not only as a trigger of local resistance, but also as a key reason for rejecting planning approval (van Rendsburg et al., 2015), the development of taller wind turbines may encounter further barriers when seeking planning approval, especially in light of repowering projects. Second, in absence of any guidance, project developers and authorities may end up ignoring or underestimating the importance of obstruction lights, or they risk deciding on mitigation initiatives without any effect on citizen annoyance. An increased understanding of what factors contribute to the annoyance caused by obstruction lights is key to inform guidance.

The article is intended as a contribution to the discussion about the impacts and the management of obstructions lights. This paper will compare citizen self-reported annoyance and possible stress effects from obstruction lights based on investigations in the three countries Denmark, Germany and Switzerland. The comparison will be used as a point of departure for synthesizing scientific evidence in research literature to provide the basis for policy initiatives. The study is methodologically inspired by previous comparative studies (Hübner et al., 2019; Pohl et al., 2012). Analytically, it is based on well-proven stress concepts (Lazarus & Cohen, 1977), that are used as a framework for studying impacts of obstruction lights on the experiences and behaviour of nearby residents. The concepts are furthermore used for deriving reliable indicators for ambient stressors (Baum et al., 1984; Bell et al., 1990). According to this concept the process of developing stress starts with the perception of possible stressors (e.g., obstruction lights), followed by the evaluation of those stressors (e.g., they annoy), then psychological and physical reactions to or symptoms due to those stressors, and finally emotional, cognitive and behavioural coping strategies to mitigate those stressors (e.g., changing location of activities).

The comparison is designed by a rare consideration of contrasting and deviant cases. This allows for the identification of significant differences between the current development of regular wind turbine projects (represented by the German-Swiss sample) and what can be seen as a technologically special case that may be seen to represent the future development with larger wind turbines (the Danish case). This will allow insights into how annoyance and acceptance is affected by WT size and further factors contributing to stress effects.

The following section 2 will outline the current state-of-the-art on knowledge about obstruction lights and stress effects. Section 3 will describe the countries and cases before the methods will be explained in more detail in section 4. Section 5 will describe the results and section 6 will discuss and contextualise the findings. Finally, section 7 will draw general conclusions and sketch out policy implications.

2 Obstruction lights of wind turbines and stress effects: State-of-the-Art

Among other factors, the acceptance of wind farms has been identified to be influenced by the annoyance of WT emissions. Several studies found moderate negative correlations between annoyance and acceptance. That means that the more residents felt annoyed by noise, landscape change or obstruction marking, the less they accepted the wind farm (e.g., Hübner & Löffler, 2013; Hübner & Pohl, 2015; Hübner et al., 2019; Pawlaczyk-Łuszczynska et al., 2018; Pedersen et al., 2009; Pohl et al., 1999, 2012, 2018, 2020). The way the planning process is experienced is also related to annoyance and acceptance of the wind farm. Some studies found moderately strong correlations between e.g. stress during the planning and installation process with acceptance of the wind farm ($r = -.58$, $r = -.61$) or planning process fairness with acceptance of the wind farm (r = .64, r = .57, r = .67; Hoen et al., 2019; Hübner & Löffler, 2013; Pohl et al., 2018) or planning process annoyance and planning process fairness with noise annoyance stress (r = .49, r = –.40; Hübner et al., 2019).

In particular, visual impacts have been widely considered as a central matter of contestation when wind farms are proposed. Nevertheless, while doing so, visual impacts have often been employed as a shorthand for any relation between wind turbines and space (Batel & Devine-Wright, forthcoming), obscuring the complexity of the visual-spatial dimension. As Wolsink (2018) argues, such a simplified and narrow understanding of the visual impact does not only easily connote and charge wind turbines with negative attitudes, which spurred numerous studies applying economic valuation approaches, such as choice experiments and willingness-to-pay studies (e.g., Ladenburg & Dubgaard, 2007). It also reduces the visual impact to pure visibility of wind turbines and likewise construes the visual impact as the mere physical-material presence of turbines in a certain environment grounded on certain features, such as height and shape.

In consequence, research has so far mostly considered the significance of visual impacts with regard to individual perceptions of wind turbines or quantitatively measured and evaluated the visibility in terms of the physical appearance of wind turbines in a landscape (e.g., Lothian, 2020; Meyerhoff et al., 2010), often highlighting geographical distance as a proxy for annoyance and acceptance. In particular, the latter approach has been utilised and advanced in numerous studies (e.g., Tsoutsos et al., 2009; Mirasgedis et al., 2014). Yet, particular dimensions of visual impacts or visual effects of particular elements of wind turbines have rarely been specified and dissected, which has also resulted in a lack of a nuanced qualification of what may cause annoyance by visual impacts.

There are several factors influencing WTs visibility, e.g., distance, perceived size, rotating vs. stationary blades, height, number of WTs, landscape features, contrast to the surrounding (for an overview see Molnarova et al., 2012). Yet, there seems to be no clear causality between visibility and acceptance of a wind farm. Although Jalalil et al. (2016) found a moderate negative correlation in a small sample (r = –.61, N = 31), Hübner and Löffler (2013) and Pohl et al. (2018) reported small negative correlations (r = –.34, N = 467; r = –.35, N = 212), while in a representative U.S. sample the association was negligible (r = -.11, N = 1705, Hoen et al., 2019). Of greater relevance seems to be the variable landscape fit which correlated moderately positive with attitude (r = .57, Hoen et al., 2019). For a review of effects of visibility and visual features of WTs on annoyance and health indicators see Freiberg et al. (2019) and on acceptance see Rand and Hoen (2017).

By considering the visual annoyance associated with wind turbines beyond a constringed representation of the visual impact, only few studies have started to focus on obstruction markings and lights as specific constituents of the visual impact (Pohl et al., 2012; Rudolph et al., 2017). Thus, knowledge about the role of annoyance from obstruction lights at wind farms for citizens' acceptance of wind energy is, however, still limited. The first studies with a specific focus on obstruction lights (Pohl et al., 2012; Rudolph et al., 2017) document a notable annoyance of obstruction lights that is related to citizens' acceptance in the countries studied. Pohl et al. (2012) termed this annoyance "an emerging acceptance problem" (p. 592), however, with only a few studies available it is still unclear, which factors contribute to annoyance caused by obstruction lights.

In the study by Pohl et al. (2012), 15.4 % of the respondents reported to be rather or very annoyed by day marking and 25.5 % by night marking, but very seldom report symptoms associated with obstruction marking (< 2.0 %). In the study by Rudolph et al. (2017) the percentages of annoyed residents were 11.2 % (during daylight) and 51.8 % (in the evening darkness). There are other studies not exclusively focusing on obstruction markings: e.g., Michaud et al. (2016) found 9.9 % very or extremely annoyed participants by obstruction markings and Motosu and Maruyama (2016) found 12 % very annoyed respondents by obstruction markings. Strong annoyance with stress symptoms induced by landscape change has so far only been observed from a few residents. Hübner et al. (2019) found 1.5 % in an U. S. sample and 0.0 % in an European sample. On the other hand, laboratory studies with visual stimuli have shown that WTs in the landscape can trigger emotional reactions and physiological arousal and influence preferences of different renewable energy systems (Maehr et al., 2015; Spielhofer et al., 2021).

While annoyance and stress effects related to WTs have mainly been considered with regard to noise and landscape change, stress effects from obstruction markings have not gained attention yet. Considering the largely neglected role of obstruction lights in wind farm planning and unknown predictors of stress effect from obstruction lights, this study seeks to explore two research questions.

1) How do stress effects induced by obstructions lights differ between a technologically special case in contrast to regular wind farms?
2) What factors contribute to stress effects from obstruction lights?

3 Contextualisation of countries and contrasting cases

The case study of Denmark – representing the technologically special case - concerns what is said to be the world's biggest test site for large WTs (State of Green 2017). It is located near the village of Østerild in the north-west of Denmark (see figure 1). The data draws from a study from 2015 with the aim to explore the perception of, annoyance and possible stress effects induced by the aircraft obstruction lights. The test centre was established in October 2012, after a political decision in the Danish Parliament, followed by a top-down planning process that did not provide much leeway for the consideration of public concerns (Larsen et al., 2015; Rudolph et al., 2017). By the time of the study, the test site consisted of seven turbines with a height of up to 222 m that are spatially arranged in a straight line. Given the particular purpose of testing prototypes and the resultant regular replacement of turbines, the row of turbines is marked with a light mast at each end. The two 250 m tall towers do not reflect general legislation for wind farms (see table 1), but instead constitute a special requirement to account for the particular purpose of the site. Each mast carries high-intensity flashing white LED lights mounted at three different levels, instead of having individual markings mounted on each WT as per usual legislation for commercial wind farms in Denmark. The synchronized lights have three intensity levels that are automatically adjusted according to the time of the day and weather conditions. After the study, the test centre has been expanded, however, this has not affected the data. More detail about the particularities of the test centre and location can be found in Rudolph et al. (2017). The Danish case thus represents a special case insofar as it comprises a unique technical solution as well as a centralised and restricted planning process. The juxtaposition of a special case with more regular cases allows for the identification of significant differences in and upper limits of potential stress effects and other factors influencing stress as well as potentially relevant coping strategies.

[insert figure 1 here]

In contrast, the German-Swiss (G-S) sample comprises several cases studies. Although the two countries of Germany and Switzerland vary in history and capacity in wind energy, they are grouped to strengthen the dataset in this comparative study with Denmark. As mentioned above, the German-Swiss data represents normal commercial land based wind farms adhering to the legislative schemes (see table 1), while the Danish case can be seen as a special case as a test site for tall turbines of up to 330 meters of height. The data from Germany is based on two studies[1]. One study with the focus on obstruction markings included 13 wind farms across seven German federal countries and focused on residents living in the view shed of the wind farms (Pohl et al., 2012). The aim of this study was a comparison of people's perception of, and annoyance and possible stress effects induced by different types of aircraft obstruction markings across different terrains. In the other German study, the focus was on the noise effects of a wind farm, but the effects of obstruction lights were also investigated (Pohl et al., 2018). The Swiss study included seven wind farms with a minimum capacity of 0.6 MW per WT[2]. In addition, in this Swiss study, annoyance through visual impacts of obstruction

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[1] For more information about the 14 German wind farms see Pohl et al. (2012, 2018).

[2] For more information about the 7 Swiss wind farms see Hübner & Löffler (2013) and a map with Swiss WTs from 2015 (https://www.energieschweiz.ch/tools/windenergieanlagen/)

markings were comparatively examined along with other perceived impacts on people's well-being and livelihood (Hübner & Löffler, 2012).

[Insert table 1 here]

4 Methods

4.1 Survey designs and samples

Despite the differences in purpose and context, the surveys in the three countries were based on the same structure and with largely similar content. The surveys covered four aspects: A) attitudes, perceptions of the obstruction lights, and potential feelings of being negatively affected, B) questions on psychological aspects, including physical and psychological well-being, C) the efficiency of individually adopted coping strategies, and D) questions related to respondents' background (age, profession, etc.) and contact information. The assessment of annoyance was based on a single annoyance item and on the "Annoyance Stress-Scale" (AS-Scale; Hübner et al., 2019; Pohl et al., 2018).

Some questions were asked in all three German-Swiss studies, others only in one or two studies depending on the focus of the study. Therefore, there are different sample sizes in the combined German-Swiss sample (see the information in the results tables). Some Danish items were recoded to get comparable scale levels / values with the German-Swiss studies.

Table 2 illustrates different features of the data collection and the included wind farms. All data were collected between 2009 and 2016.

[Insert table 2 here]

4.2 Recruitment of survey participants

In the German-Swiss sample, the recruitment of participants in the two studies was based on several steps: 1) randomly selected addresses from public telephone directories, 2) personal letters and telephone calls to these households, 3) at a community meeting and 4) via local contacts. The overall response rate was 28.0% (Hübner & Löffler, 2013; Pohl et al., 2018). In the other study, questionnaires were randomly distributed to households. The overall response rate was 25.0% (Pohl et al., 2012). Incentives were offered in two studies: 15 EUR or participation in a lottery for a 25 EUR Amazon voucher (Pohl et al., 2012), and two balloon rides (Hübner & Löffler, 2013).

In the Danish sample, the participants for the survey were recruited randomly by means of leaflets disseminated face-to-face, a public meeting, a Facebook site, posters in local shops, and newspaper articles (see Rudolph et al., 2017). As incentives, participants took part in a lottery for wine and chocolate.

4.3 Sample comparison and characteristics

To justify sample pooling of the German and the Swiss cases, we checked the samples' comparability for demographic and central variables, such as attitudes toward the local wind farm, emotions, impact on quality of life and place attachment (see Hübner & Pohl, 2015). We also checked correlations between attitude toward the local wind farm and a set of variables including visibility, strain during the planning process, setback distance and impact on landscape. All results showed comparable patterns. Furthermore, in one German study (Pohl et al., 2018) and the Swiss study (Hübner & Löffler, 2013), we could conduct non-response analyses based on four questions. In both samples we did not find relevant differences between responders and non-responders concerning a) attitude toward the local wind farm, b) age, or c) visual impact.

The Danish and the pooled German-Swiss samples are similar on most demographic factors, only showing non-significant differences (Table 3). Significant differences can be found in the factors; marital status, job situation, duration of residency and financial participation in wind project, in which case effect sizes are small. The demographic distribution is thus similar in the two samples.

[Insert table 3 here]

When it comes to attitudes and actions taken in the planning phase of the wind project, the Danish case, however, differs somewhat from the Swiss and German cases. When looking at both attitudes towards the wind farm as well as whether they have been active in the planning process, it is evident that the Danish sample contains a significantly larger proportion of active citizens, who are opposed to the project (31.0%) compared to the German-Swiss sample (only 11.3%). Reversely, the Danish sample only holds 29.7% passive citizens, who were in favour of the wind project, compared to 68.3% in the German-Swiss sample ($p < .0001$, $w = 0.327$, medium effect size). Hence, in relation to attitudes and actions, it is two rather different cases we are comparing, as represented by the unique test centre and commercial wind farms.

4.4 Stress indicators and moderators

Stress indicators and moderators assessed in the Danish and German-Swiss studies are presented in this section.

4.4.1 Indicators

A single annoyance item was used to assess annoyance related to specific WT impacts (obstruction lights, shadow-casting, landscape change, noise). From a psychological perspective a single item annoyance scale assesses a general evaluation of immissions in the sense of liking or disliking. The participants were asked to rate their experiences on a 5-point annoyance scale for each impact: 0 (''not at all''), 1 (''slightly''), 2 (''somewhat''), 3 (''moderately'') and 4 ("very"). Annoyance due to other sources, such as noise from agricultural machinery, was also assessed using the same scale. This annoyance scale was used in several earlier studies of the Hübner and Pohl research group (e.g., Hübner & Löffler, 2013; Hübner & Pohl, 2015; Hübner et al., 2019; Pohl et al., 2012, 2018, 2020). In a longitudinal study the retest reliability for noise annoyance was r = .85 (Pohl et al., 2018). The correlation between noise annoyance and the ICBEN Q. V. Scale (Fields et al., 2001) was r = .88 (Hübner et al., 2019).

The participants were also asked under what time of day and weather conditions the obstruction lights were perceived as annoying.

The frequency of symptoms linked to WT impacts was assessed, ranging from 0 ("never") to 4 ("about every day"). The Danish respondents reported the symptoms in a free format and the German-Swiss respondents used a list of psychological and somatic symptoms belonging to different domains, e.g., general performance, emotions and mood, somatic complaints and sleep.

Negative impact on daily activities induced by obstruction lights was assessed using a unipolar rating scale, from 0 (''not at all'') to 2 ("to a large degree").

Cognitive and behavioural coping responses were also assessed. Here, participants reported if and which behavioural strategies they applied to reduce the obstruction lights annoyance (e.g., using blinds or curtains) and to what extent the measures were effective in reducing obstruction lights annoyance (3-point scale from 0 ("no effect") to 4 ("strong reduction")).

The single annoyance item might be interpreted as an indicator of attitude. To get a reliable stress indicator we combined the ratings from the annoyance and symptom scales in the 5-point AS-Scale (Hübner & Löffler, 2013; Hübner et al., 2019; Pohl et al., 2018). If a resident did not perceive any WT light emission, level 0 was assigned. Level 1 was given if a respondent perceived a WT emission without annoyance. If “slightly annoyed” was reported on the single annoyance item level 2 was assigned. If someone was at least “somewhat annoyed”, but reported no symptoms level 3 was given. To be considered as “strongly annoyed” (level 4), a resident must be at least somewhat annoyed and experienced at least one physical or psychological symptom per month induced by WT. Additionally, for each WT emission an AS-Scale was constructed, e.g., the Obstruction Lights Annoyance Stress Scale (OLAS-Scale), which has the same levels as the AS-Scale, but is related only to aircraft obstruction lights.

4.4.2 Moderators

The influence of several possible moderators of OLAS-Scale levels were analysed. These moderators have also been used in various studies on the acceptance of wind energy (e.g., Firestone & Kirk, 2019; Hoen et al., 2019; Hübner et al., 2019; Pohl et al., 2018; Russell & Firestone, 2021).

- Attitude: The attitude towards the local wind farm and the attitude towards WTs in general were evaluated by a semantic differential with three pairs of bipolar adjectives in the Danish questionnaire and with six pairs of bipolar adjectives (for example “unnecessary – desirable”) in the German-Swiss version. The mean value over these items was used as an indicator for attitude, ranging from −3 (''very negative “) to +3 (''very positive”). The participants were also asked whether they had undertaken actions to promote their attitude.
- General stress indicators, light and noise sensitivity: Acute stress (during the past 4 weeks for a short time) and chronic stress (lasting at least one year) were assessed independently of any relationship to the local wind farm, and light and noise sensitivity were rated on four unipolar scales each with a range from 0 (“not at all”) to 4 (“very”).
- Evaluation of the planning process: Perceived fairness and stress during the wind farm planning process were assessed on three unipolar rating scales each ranging from 0 (''not at all'') to 4 ("very").
- Physical features: The residents reported the number of WTs visible from their property. The distance from the nearest WT was measured from using maps of the area.

4.5 Statistical analyses

To analyse group differences for interval-scaled variables, descriptive statistical values, such as the arithmetical mean and standard error of the mean (SEM) were used. For nominal-scaled variables, absolute and relative frequencies (%-values) are reported. Pearson-correlations to identify moderator variables were calculated. We consider only coefficients of 0.30 or higher (a medium effect size according to Cohen, 1988) as relevant. A multiple regression analysis was run for each sample by several variables to predict the OLAS-Scale. We understood Beta weights as effect sizes (Nieminen et al., 2013), and a cut-off of > l0.15l was used to indicate an influential predictor. Chi²-tests for inferential analysis of frequency distributions were used. Mean values of two groups were compared via t-tests. In the case of unequal variances, Welch's t-tests were chosen.

The data analysis and description is based on the principles of Abt's (1987) "Descriptive Data Analysis." Therefore, reported p-values of the two-tailed significance tests serve a descriptive purpose to characterize the extent of group differences. Since the analysis is not a confirmatory data analysis, no alpha-adjustment was made, despite multiple significance tests. We consider p-values of .05 or less as statistically significant. Furthermore, the effect size parameters *d* and *w* were calculated to report practical significance (Cohen, 1988). The effect size categories (small, medium, large) mentioned in the results section are related to statistically significant group differences.

5 Results

Inspired by Hübner et al. (2019) and Pohl et al. (2012, 2018), the presentation of the results follows the steps of a stress process. We start with the residents' perception of impacts, their evaluation measured by annoyance, followed by the physical and psychological reactions to the impact and finally the coping strategies they employ in order to mitigate the impacts (first research question). The analysis furthermore adds to the understanding of impacts from obstruction lights by putting them into context of other possible negative impacts from WTs, such as shadow flicker, landscape changes and noise. In the second main part of the results chapter, the analysis considers the factors (moderators) contributing to stress effects, like attitude, general stress indicators, evaluation of the planning process, and physical features (second research question).

5.1 Perception and annoyance

A considerably higher percentage of Danish residents than German-Swiss residents perceived obstruction lights inside the house and outside the house (Table 4). In the Danish sample, a smaller percentage of the people had shadow perceptions outside the house compared to the respondents of the German-Swiss sample. Furthermore, in the Danish sample, a smaller percentage perceived noise outside the house compared to the German-Swiss sample. The same effect with regard to noise perceptions was found inside the house.

[Insert table 4 here]

The average annoyance induced by WT impacts and other local sources ranges between low and moderate (Table 5). Concerning day obstruction markings, there was no difference of annoyance level between the two samples regardless of the type of markings (LED, Xenon, white or coloured stripes), but the Danish residents reported a slightly higher mean value for the night marking. Very few Danish residents were annoyed by shadow casting (n = 3). The Danish sample showed a slightly higher average annoyance by landscape change and a much higher average annoyance by WT noise than the German-Swiss sample. Hence, even though fewer Danish residents noticed the noise impacts from the WTs, the ones that did were far stronger annoyed by it, compared to the Germany-Swiss residents. The Danish residents thus seem to be more annoyed by noise than the German-Swiss residents, given the unique Danish case. A result that is underlined by the comparison of annoyance is caused by general agricultural machinery noise by which the Danish residents are also slightly stronger annoyed than the German-Swiss residents. Finally, comparing the means for annoyance caused by obstruction lights to annoyance caused by noise and landscape changes, it is also evident that obstruction lights are not the most important impact to consider when trying to understand what causes stress amongst residents.

[Insert table 5 here]

When investigating the impacts from obstruction lights more thoroughly, it is evident, that a much higher percentage of Danish residents than German-Swiss residents were annoyed by obstruction lights, not only during night, but also during all assessed times of the day and weather conditions (Table 6). Most noticeable is the strong annoyance during night in both samples, but also under condition with clear sky and in cloudy conditions in the Danish sample. Annoyance data for specific times of day and weather conditions are based on items with yes-no answers.

[Insert table 6 here]

Generally, the Danish residents evaluate the impacts from WTs more negatively than the German-Swiss residents. This is especially evident in the case of impacts from obstruction lights, to which they are also more attentive compared to the German-Swiss residents. This pattern is also evident when investigating the impact on different daily activities. On average, the negative impact was relatively small (Table 7), but the Danish residents reported a marginally stronger negative impact than the German-Swiss residents on activities in the house, while taking a walk, while doing sports, while relaxing, while driving a car, during conversations and while hosting guests. Thus, supporting the pattern of respondents in the Danish case being more annoyed by obstruction light than residents in the German-Swiss case. The activities where residents, Danish, German and Swiss alike, are most disturbed by obstruction lights are generally outside activities, such as gardening, walking and driving. This could be related to the local features of the Danish site, which are characterized by flat landscape, remoteness and associated darkness.

[Insert table 7 here]

5.2 Physical and psychological stress reactions to impacts and coping responses

To evaluate the residents' stress level caused by WT impacts, an AS-scale was constructed for each emission. On average, the annoyance-stress induced by WT emissions was low to medium in both samples (Table 8). At an overall level, however, shadow casting and noise annoyance stress was slightly higher in the German-Swiss sample whereas landscape change annoyance stress was markedly higher among the Danish residents. The obstruction lights annoyance stress-level was much higher in the Danish case, indicating that the Danish residents' stress reactions to annoyance were stronger than the German-Swiss residents´. Finally, the analysis of the AS-level supports earlier results that negative impacts from obstruction lights might not be the most important negative impact from WTs, but it is evidently a contributing factor to creating stress among residents.

[Insert table 8 here]

The percentages of strongly annoyed residents for each of the WT emissions was relatively low (Table 9), but there was a small percentage of residents which reported at least somewhat moderate annoyance and symptoms associated to obstruction lights in the Danish sample and to noise in the German-Swiss sample.

[Insert table 9 here]

The German-Swiss residents employed different coping mechanisms compared to the Danish residents when trying to deal with the negative impacts from obstruction lights. E.g., a higher percentage of German-Swiss residents than Danish residents changed location of outdoor activities due to obstruction lights and had thoughts about moving away due to the wind farm (Table 10). Generally, the German-Swiss residents were more inclined to introduce coping initiatives compared to the Danish residents.

[Insert table 10 here]

Concerning the ones employing coping mechanisms, the effectiveness of the measures taken were rather similar. To reduce lightning annoyance, installing and using blinds or curtains were the relatively strongest measures (DK: M = 1.38, SEM = 0.09; G-S: M = 1.50, SEM = 0.06, scale 0 to 2, no significant group differences). Other strategies had negligible effects, e.g., talking to others, drinking, smoking, taking sedatives.

5.3 Moderators of obstruction lights annoyance-stress

Following the holistic approach to WT induced stress (Hübner et al., 2019; Pohl et al., 2012, 2018), it is not appropriate to only consider the direct impacts and emissions from WTs on residents´ stress, but also to investigate factors which have a moderating effect on stress reactions.

Commonly used moderators are citizens' attitudes towards WTs in general and locally and citizens' evaluation of the planning process. In both samples, the mean values of attitudes toward the local wind farm and WT in general were positive and of comparable strength (Table 11). With regard to feelings of being heard in the planning process, the community interests have been given slightly less consideration in

Denmark than in Germany / Switzerland according to the residents. The Danes felt slightly more stressed during the planning and construction process.

[Insert table 11 here]

Further moderating factors, that are commonly used to evaluate stress, include pre-existing sensitivity towards negative impacts, such as light sensitivity (Pedersen & Waye, 2004; Pohl et al., 2012), noise sensitivity (Carlile et al., 2018; Hübner et al. 2019) and pre-existing conditions of stress (Pohl et al., 2018). On average, the Danish residents reported a markedly higher light sensitivity than the German-Swiss ones. There was no significant difference in noise sensitivity (Table 12) and the Danish respondents perceived slightly weaker acute and chronic stress than those of the German-Swiss sample.

[Insert table 12 here]

Besides these possible moderating factors, the analyses also investigated the influence of socio-demographic factors (age, gender, education and length of residency) and factors related to the visibility of the obstruction lights (distance to nearest WT/light mast and number of WTs visible from home).

The analysis of moderating factors of obstruction lights annoyance stress started with Pearson correlations of the factors mentioned in Table 13 with the OLAS-Scale. In both samples we found five relevant correlations (criterion: $r \geq |0.30|$ at least a medium effect size) with the same variables: The more residents were stressed by landscape change or during planning process, the more they were stressed by obstruction lights (DK: r = .59, r = .46; G-S: r = .43, r = .51). The less the attitude toward local wind farms, personal or community interests were considered, the more they were stressed by obstruction lights (DK: r = −.49, r = −.53, r = −.58; G-S: r = −.65, r = −.34, r = −.39). Four further relevant correlations could be found in the German-Swiss sample:

The less the attitude toward WTs in general (r = –.51), the more they were stressed by obstruction lights. The more respondents were stressed by shadow casting or WT noise or the more WTs they saw from the residents, the more they were stressed by obstruction lights (r = .61, r = .63, r = .44).

The correlation coefficients concerning distance to the nearest WT, sensitivities, personal stress and sociodemographic variables are negligibly small (all |r| between .02 and .27).

In order to understand which combined factors precisely had influence on the stress related to obstruction lights, we performed a multiple regression analysis for each sample in order to predict the OLAS-Scale. Our model explained a large part of citizens' annoyance with an R^2 adjusted on 0.661 for the Danish sample and 0.555 for the German sample.

We found five relevant predictor variables in the Danish sample and two in the German-Swiss sample (Table 13). Here, relevance is based on beta weights and p-values; a beta weight > |0.15| is considered relevant for any coefficient with $p \leq .05$. In the Danish sample "my personal interests have been heard to a sufficient degree", "the community interest had been heard" and "landscape change annoyance stress" showed the strongest relations. The other relevant factors in the Danish sample were "age" and "stressed during planning and construction process". In the German-Swiss sample "number of WTs visible from home" and "stressed during planning and construction process" were relevant predictors. The latter factor was the only factor the both samples had in common.

The other factors were negligible, including "Attitudes toward local windfarm" and "Attitudes toward WTs in general". It indicates that one or more of the included factors in the full regression model suppresses the effects from the residents' attitudes.

[Insert table 13 here]

6 Discussion

Increased contestations due to visual and noise impacts of WTs have resulted in reactive responses of policy-makers in Denmark who urge a reduction of the number of onshore WTs through repowering (Danish Energy Agreement, 2018), while the numbers of newly installed capacities in Germany have radically dwindled due to lengthy planning processes, changing support systems and local opposition. The issue of citizen annoyance due to obstruction lights has therefore also received political attention. For example, the political agreement for the Danish National Test Centre for large WTs included a demand for adopting best available mitigation technology for the obstruction lights (The Danish Government, 2017).

In this study, we have explored possible stress effects caused by obstruction light markings of WTs, which reflects an increasingly significant safety requirement as wind turbines grow in size. In doing so, we identified and analysed factors influencing stress effects and compared them between a special case and regular cases.

The main finding from the comparison of stress effects from obstruction markings in the contrasting cases of Denmark and Germany-Switzerland is that the results show stronger stress effects due to the lights for the Danish sample (DK: $M = 2.16$ vs. G-S: $M = 1.27$, $p < .0001$, medium effect size). Following the outlined stress concept, more Danish residents notice obstruction markings (indoors: DK 73.1% vs. G-S 30%; outdoors: DK 89.2% vs. G-S 37.7%), therefore, we have more Danish respondents perceiving direct emissions. They were slightly stronger annoyed at night, but not during daylight, independent of weather conditions. Daily activities were more disturbed. The annoyance stress level was considerably higher (OLAS-Scale) but only few (6.1%) of the residents were strongly annoyed, reporting symptoms related to obstruction lights. Fewer residents in the Danish case got used to it (cognitive coping) and changed the location of outdoor activities (behavioural coping). They reported greater light sensitivity. The stress process in the Danish case seemed to have started during the planning and construction process, because the centralised process was perceived as more stressful. Not only obstruction lights, but also the perceived landscape change led to annoyance stress. The stress effects due to obstruction lights seem to be specific because the Danish residents reported only marginally acute and chronic stress related to personal factors. The Danish case demonstrated that under special local conditions obstruction markings could lead to stress.

These findings are interesting taking the contrasting cases into account; the Danish case is a national test centre for very tall WTs located in a remote area with a distinct system of obstruction lights applied (white high-intensity blinking lights in Denmark compared to red medium intensity lights at night in the German-Swiss sample). Due to the special technical features of obstruction markings and due to the top-down planning process, the results concerning the Danish site cannot be generalized. However, this was not intended. The methodological approach was to compare a special site with more regular sites (21 German-Swiss wind farms) to obtain an upper estimate of stress effects. Moreover, the comparison of the Danish and German-Swiss samples only refers to items that were formulated in a comparable way and where the scales were the same or where they could be adjusted. As a result, not all of the available information could be evaluated. Furthermore, the results need to be viewed in light of the contemporary regulatory context in both countries, which changes over time.

Overall, the regression analysis showed six significant predictors of obstruction light annoyance in both samples but varying between the countries. The differences will be discussed towards other studies in the following.

First, landscape change is an important and significant predictor of obstruction light annoyance stress in the special case of Denmark, but not in the regular cases of Germany/Switzerland. For citizens in the Danish sample their concern about changes in landscape is highly related to their annoyance by obstruction lights. The importance of landscape change for annoyance related to WTs tends to be in line with the common nature-technology dualism often described in place attachment literature, where perceived disruptions to emotional, productive, memorable and historical bonds with a place are regarded as a trigger of resistance (e.g., Devine-Wright, 2009; Kim & Chung, 2019) to place-related changes and where oppositional activities are then usefully discussed as place-protective action (Devine-Wright & Howes, 2010). This study contributes to the existing knowledge by highlighting how landscape changes may be of particular importance for understanding citizen annoyance in more special cases.

Second, people's perception of the extent to which their personal interests were heard in the planning process has been identified as a significant predictor of obstruction light annoyance stress in Denmark, but not in Germany and Switzerland. This difference may be related to the top-down deployment process for the Østerild wind farm test centre in Denmark (Rudolph et al., 2017), through which the location was decided by the government without consulting the local population (Lyhne, 2011), while the issue of light pollution has emerged as a key concern during the planning process (Borch, 2018). In turn, even though this was not identified as a significant predictor of obstruction light annoyance in the German-Swiss study, it cannot simply be assumed that people perceive the role of the planning process in these countries as less meaningful. For example, the planning process fairness has a significant impact on noise annoyance and acceptance of the wind farm (e.g., Hoen et al., 2019; Hübner & Löffler, 2013; Hübner et al., 2019; Pohl et al., 2018). Furthermore, numerous quantitative and qualitative studies emphasized the significance of the planning process in shaping local community responses, in particular the perception of procedural fairness as part of the participatory process (Ellis & Ferraro, 2016; Firestone et al., 2018; Firestone et al., 2020; Gross, 2007; Liebe et al., 2017). In particular, the possibility of having a say in the process and influencing the outcome has been identified as a significant predictor of procedural fairness (Firestone et al., 2018). In the same vein, our findings from Denmark do not only reiterate the importance of a fair and transparent planning process in informing people's acceptance, but corroborate the finding that early shortcomings can perpetuate over time and permeate people's annoyance later on (e.g., Hübner et al., 2019; Pohl et al., 2018).

Third, the top-down process described above could explain why the predictor "community interests have been heard to a sufficient degree" was positively related to obstruction lights annoyance stress. The more community interests are evaluated to have been taken into account, the stronger was the annoyance stress. The results reflect the discrepancy between personal and community interests concerning the planning process. Likewise, procedural fairness and trust in authorities, in terms of how people perceive the consideration of their interests, have been identified as crucial factors determining support or opposition to a proposed project in general as well as stress effects in particular (Firestone et al., 2020; Hoen et al., 2019; Pohl et al., 2018). Other studies have shown that among the motivations of the most engaged citizens in planning processes community concerns are more prominent than direct personal interests (Lyhne et al., 2018).

This is also directly related to a *fourth* predictor. Citizens' perception of stress during the planning process is a significant predictor in both countries. This is slightly more important in Germany/Switzerland than in Denmark. The Danish test centre was met with local opposition (Borch, 2018), and the significance is therefore not surprising. According to some of the interviewees, the obstruction lights were a daily reminder of their stress during the planning process (see Rudolph et al., 2017). Stress during the planning and construction process may not only refer to the perceived fairness of the process, but can also hint at the significance of communication (Friedl & Reichl, 2016) and the perception of physical impacts during the construction. Lack of information provision and communication both from developers about ongoing activities and for local residents to convey complaints can result in uncertainty and stress. Limited communication at the development stage can exacerbate preconceived fears and permeate annoyance later on. Transparent and continuous communication is again particularly relevant for the Danish case which does not exhibit a stable and complete wind farm, but a test centre whose WTs are regularly being changed and replaced.

Fifth, the number of WTs visible from home is a significant predictor in the German-Swiss sample, but not in the Danish one. This indicates a cumulative effect in which citizens may get increasingly annoyed by visual impact of turbines. The importance of the number of turbines visible is in part supported by previous studies. Ironically some previous Danish studies (Ladenburg, 2006; Ladenburg et al., 2013; Möller, 2006; also Molnarova et al., 2012 for Czech Republic) support the importance of the number of turbines in the view shed, whereas other Danish studies (Ladenburg, 2015) only found a weak relationship between cumulative effects based on the number of onshore turbines seen daily. Likewise, a study including the German samples and an U.S. sample did not find this variable significant (Hübner et al., 2019). Ladenburg (2006) finds that "everything else equal, the attitude towards existing and more turbines becomes more negative the higher the number of turbines installed" (p. 38). The varying results seem to indicate that the effect of number of turbines on obstruction lights annoyance is also related to other variables, such as noise and shadow casting. In general, this may also hint at a threshold where people consider themselves as being overburdened with WTs and their impacts, and also challenges the notion that familiarization can lead to appeasement.

Sixth, age is a significant predictor of obstruction light annoyance stress in Denmark, but not in the German-Swiss sample. This may have multiple explanations, hereunder older people may be more sensitive to the impact of emissions, and retired people having more time to engage with their surroundings and thus to become annoyed. The role of age may also appear stronger because the Danish study is based on a single case, whereas the German and Swiss cases were pooled together. It is worth noticing that besides age, demographic characteristics do not predict annoyance or relate to stress symptoms. The importance of age is in part supported by previous studies. It is supported by previous research on attitudes in Denmark (Hevia-Koch et al., 2018), but it was not a significant predictor for WTs noise annoyance in the comparative study between U.S. and European samples (Hübner et al., 2019) and a German study (Pohl et al., 2018).

Among the parameters that other literature identified as significant predictors related to WTs but not this study, are attitudes towards WTs in general and the local wind farm. This is surprising since Hübner et al. (2019) found this kind of attitudes were significant predictors for WT noise annoyance. Similarly, attitudes towards WTs in general is not found to be significant predictor. This is aligned with international literature (Bell et al., 2005, 2013; Wolsink, 2000). One reason why these attitudes are no significant predictors in our study may be suppression effects, which can occur in multiple regression analyses when predictors are highly correlated. In our study, the bivariate correlations of attitudes with the OLAS-Scale are in a small to medium range.

Another often debated parameter that is not found significant in this study is distance or proximity to the WTs. This parameter is particularly reflected in accusations of Not-in-my-backyard attitudes (NIMBY), which claim that local people selfishly oppose WTs because of the proximity to where they live. However, such claims do not consider any rationales as to why people may be annoyed by or opposed to wind farms. Yet, in practice, spatial regulation is often based on distances in the understanding that annoyance is reduced by distance, which reflects that “planning authorities and energy developers are still led by the presumption that the population local to a proposed project will exhibit NIMBY concerns” (Petrova, 2013, p. 586). As an example, the Danish spatial regulation involves distances in terms of noise and compensation (Danish Ministry of Environment, 2015). The finding that distance or proximity do not give any indication of annoyance is in line with Devine-Wright (2009), Hübner et al. (2019), Hübner and Pohl (2015), Rudolph et al. (2017) and Warren et al. (2005), who tend to refute NIMBY rationales (Jones & Eiser, 2010) and Willingness-to-Pay approaches (e.g., Ladenburg & Dubgaard, 2007). Others (Groth & Vogt, 2014; Hoen et al., 2019) found that proximity might even lead to more positive attitudes in general. However, it remains ambiguous again whether familiarization leads to contentment or indifference over time.

The regression analysis does not include technological differences, however, both population samples were asked about their preferences in terms of demand-oriented obstruction lights (lights switched on only when aircrafts approach). This showed a majority of citizens preferred demand-oriented lights in Denmark (56.3%, n = 197) and in Germany-Switzerland (58.6%, n = 413).

7 Conclusions and policy implications

With limited research on citizen annoyance of obstruction lights, policy-makers currently base their decisions on limited evidence for what causes annoyance.

This paper therefore aims to advance the scientific knowledge about citizen annoyance of obstruction lights by providing insights into how stress effects induced by obstructions lights differ between a technologically special case in contrast to regular wind farms, as well as insights into what factors influence stress effects from obstruction lights. By juxtaposing these new findings with broader literature on citizen annoyance of wind turbines, the paper suggests the following five main conclusions in regards to wind energy policies, especially in a European context:

1) Annoyance of obstruction lights is an issue to consider in wind energy policy. Although annoyance due to obstruction lights and related stress effects are not a widespread issue and annoyance levels are generally low, e.g., compared with WT noise impact, they can have significant effects for a certain number of people. Considering the advanced research on annoyance caused by WT noise, it is striking that the annoyance caused by obstruction lights on average is higher than the annoyance caused by noise in both samples. This is, however, not reflected in the percentage of strongly annoyed residents, where annoyance from noise is equal or more widespread than annoyance from obstruction lights. This points to a need for attention to the cumulative aspects of obstruction lights and the implications of a negative effect on residents that is geographically more widespread than e.g., noise.

2) Annoyance of obstruction lights is influenced by citizens' stress during planning process. A clear finding from this comparative study is that both stress during the planning process and people's perception of being heard during the planning process are significant predictors of obstruction lights annoyance stress. Since this is in line with previous research, it sheds again critical light on the meaning of the planning process and procedural fairness as crucial elements in shaping people's reactions and perception, also after the completion of a project. Experiences of the planning process do not just pervade people's experiences of the

outcome, but also co-shape their everyday relations with wind farms. This has two important implications for policy-makers: a) to enhance the planning process to reduce the stress among citizens, e.g., through improved communication, and b) to enhance the participation of residents in a way that allows for a meaningful consideration of people’s concerns that goes beyond mere information provision and one-sided consultation procedures.

3) Landscape change related to taller turbines may amplify annoyance of obstruction lights. The comparison of the technological special case and the regular cases indicates that some factors influencing annoyance are more important with taller turbines. This is true for perceived landscape change and refers to the location of the WTs and their fit with the surrounding landscape. Hence, the selection of sites as a first step in the deployment of WTs becomes particularly important with taller turbines.

The perceived impacts of obstruction lights points to the need for demand-side mitigatory solutions, such as on demand radar-controlled lights at night, that can help to reduce the emission and physical impacts in the first place, but also for when a larger number of WTs are deployed locally.

4) Annoyance of obstruction lights cannot easily be solved with distance. In line with previous studies, our findings demonstrate that spatial distance or proximity are not a significant predictor for annoyance, which at least questions the effect of proximity-based monetary measures, such as benefits, payments and compensations for only nearest neighbours, as recently proposed both in Denmark and Germany.

5) Although attitudes towards wind energy in general and towards the local wind farms in particular did not prove to be significant predictors in the multiple regression analysis, it can be expected, based on the moderately strong correlations, that measures for reducing obstruction light annoyance can also increase acceptance.

Although this paper has provided relevant insights in factors influencing annoyance of obstruction light, more studies are required, especially exploring the importance of cultural context for perceived annoyance. This will allow a solid platform for developing meaningful guidance for how to deal with obstruction lights in future wind energy policies.

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References

Batel, S., Devine-Wright, P., 2021. Using a critical approach to unpack the visual-spatial impacts of energy infrastructures. In: Batel, S. & Rudolph, D. (Eds.), A critical approach to the social acceptance of renewable energy infrastructures: Going beyond green growth and sustainability. Palgrave Macmillan (forthcoming).

Baum, A., Singer, J.E., Baum, C.S., 1984. Stress and the environment. In: Evans, G.W. (Ed.), Environmental stress (pp. 15–44). Cambridge University Press, Cambridge.

Bell, B., Gray, T., Haggett, C., 2005. The 'Social Gap' in wind farm siting decisions: explanations and policy responses. Environmental Politics 14, 460–477. DOI: 10.1080/09644010500175833

Bell, P.A., Fisher, J.D., Baum, A., Greene, T.C., 1990. Environmental psychology (3rd ed.). Holt, Rinehart, and Winston, Ford Worth.

Borch, K., 2018. Mapping value perspectives on wind power projects: the case of the Danish test centre for large wind turbines. Energy Policy 123, 251–258.

Carlile, S., Davy, J.L., Hillman, D., Burgemeister, K., 2018. A review of the possible perceptual and physiological effects of wind turbine noise. Trends in Hearing 22, 1–10.

Cohen, J., 1988. Statistical power analysis for the behavioral sciences. Erlbaum, Hillsdale.

Danish Ministry of Environment [Miljøstyrelsen], 2015. Vejledning om planlægning for og tilladelse til opstilling af vindmøller. [Guidance on Planning and Permission for building wind turbines]. https://naturstyrelsen.dk/media/131731/vejledning_06012015_web.pdf

Devine-Wright, P., 2009. Rethinking NIMBYism: The role of place attachment and place identity in explaining place-protective action. Journal of Community & Applied Social Psychology 19 (6), 426-441.

Devine-Wright, P., & Howes, Y. 2010. Disruption to place attachment and the protection of restorative environments: A wind energy case study. Journal of Environmental Psychology 30 (3), 271-280.

D'Souza, C., Yiridoe, E.K., 2014. Social acceptance of wind energy development and planning in rural communities of Australia: a consumer analysis. Energy Policy 74, 262–270.

Duffy, A., Hand, M., Wiser, R., Lantz, E., Dalla Riva, A., Berkhout, V., Stenkvist, M., Weir, D., Lacal-Arantegui, R. 2020. Land-based wind energy cost trends in Germany, Denmark, Ireland, Norway, Sweden and the United States. Applied Energy 277, 114777.

EEA (European Energy Agency, 2009. Europe's onshore and offshore wind energy potential. EEA, Copenhagen. https://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential

Ellis, G., Ferraro, G., 2016. The social acceptance of wind energy: where we stand and the path ahead. EUR 28182 EN, doi: 10.2789/696070

Fields, J.M., de Jong, R.G., Gjestland, T., Flindell, I.H., Job, R.F.S., Kurra, S., Lercher, P., Vallet, M., Yano, T., 2001. Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation. J. Sound. Vib. 242, 641–679.

Firestone, J., Hoen, B., Rand, J., Elliott, D., Hübner, G., Pohl, J., 2018. Reconsidering barriers to wind power projects: community engagement, developer transparency and place. Journal of Environmental Policy and Planning 20, 370–386.

Firestone, J., Hirt, C., Bidwell, D., Gardner, M., Dwyer, J., 2020. Faring well in offshore wind power siting? Trust, engagement and process fairness in the United States. Energy Research & Social Science 62, 101393.

Firestone, J., Kirk, H., 2019. A strong relative preference for wind turbines in the United States among those who live near them. Nature Energy 4, 311–320.

Freiberg, A., Schefter, C., Hegewald, J., Seidler, A., 2019. The influence of turbine visibility on the health of local residents: a systematic review. International Archives of Occupational and Environmental Health. (Published online 23. January 2019)

Friedl, C., Reichl, J., 2016. Realizing energy infrastructure projects – a qualitative empirical analysis of local practices to address social acceptance. Energy Policy 89, 184–193.

Gross, C., 2007. Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance. Energy Policy 35, 2727–2736.

Groth, T.M., Vogt, C., 2014. Residents' perceptions of wind turbines: an analysis of two townships in Michigan. Energy Policy 65, 251–260.

Harper, M., Anderson, B., James, P.A.B., Bahaj, A.S., 2019. Onshore wind and the likelihood of planning acceptance: Learning from a Great Britain context. Energy Policy 128, 954–966.

Hevia-Koch, P., Ladenburg, J., Petrovic, S., 2018. Preferences for offshore-onshore wind power development in Denmark – Accounting for spatial Data. USAEE working paper no. 18-330. Available at SSRN: https://ssrn.com/abstract=3121495

Hoen, B., Firestone, J., Rand, J., Elliot, D., Hübner, G., Pohl, J., Wiser, R., Lantz, E., Haac, T.R., Kaliski, K., 2019. Attitudes of U.S. wind turbine neighbors: analysis of a nationwide survey. Energy Policy 134. (DOI 10.1016/j.enpol.2019.110981)

Hübner, G., Löffler, E., 2013. Wirkungen von Windkraftanlagen auf Anwohner in der Schweiz: Einflussfaktoren und Empfehlungen (Impact of wind turbines on residents in Switzerland: impact factors and recommendations). Halle (Saale): Institut für Psychologie der Martin-Luther-Universität Halle-Wittenberg, Forschungsbericht (research report).

Hübner, G., Pohl, J., 2015. Mehr Abstand – mehr Akzeptanz? Ein umweltpsychologischer Studienvergleich (More distance – more acceptance? An environmental psychological comparison of surveys). Berlin: Fachagentur Windenergie an Land.

Hübner, G., Pohl, J., Hoen, B., Firestone, J., Rand, J., Elliot, D., Haac, T.R., 2019. Monitoring annoyance and stress effects of wind turbines on nearby residents: a comparison of U.S. and European samples. Environment International, 132. (DOI 10.1016/j.envint.2019.105090)

Jalali, L., Bigelow, P., McColl, S., Majowicz, S. Gohari, M., Waterhouse, R., 2016. Changes in quality of life and perceptions of general health before and after operation of wind turbines. Environmental Pollution 216, 608–615.

Jones, CR., R.J. Eiser, 2010. Understanding ‘local’ opposition to wind development in the UK: how big is a backyard? Energy Policy 38 3106–3117.

Kim, E.-S., Chung, J.-B., 2019. The memory of place disruption, senses, and local opposition to Korean wind farms. Energy Policy 131, 43–52.

Kirkegaard, J.K., Cronin, T., Nyborg, S., Karnøe, P. 2020. Paradigm shift in Danish wind power – the (un)sustainable transformation of a sector. Journal of Environmental Policy and Planning 23 (1), 97-113. DOI: 10.1080/1523908X.2020.1799769

Ladenburg, J., 2006. Attitudes towards wind power development in Denmark. IFRO Working Paper, No. 3. Frederiksberg: Den Kgl. Veterinær- og Landbohøjskole, Fødevareøkonimisk Institut.

Ladenburg, J., Dubgaard, A. 2007. Willingness to pay for reduced visual disamenities from offshore wind farms in Denmark. Energy Policy 35 (8), 4059-4071.

Ladenburg, J., Termansen, M., Hasler, B., 2013. Assessing acceptability of two onshore wind power development schemes: a test of viewshed effects and the cumulative effects of wind turbines. Energy 54, 45–54.

Ladenburg, J., 2015. Does more wind energy influence the choice of location for wind power development? Assessing the cumulative effects of daily wind turbine encounters in Denmark. Energy Research & Social Science 10, 26–30.

Landeta-Manzano, B., Arana-Landín, G, Calvo, P.M., Heras-Saizarbitoria, I., 2018. Wind energy and local communities: a manufacturer’s efforts to gain acceptance, Energy Policy 121, 314–324.

Larsen, S.V., Hansen, A.M., Lyhne, I., Aaen, S.B., Ritter, E., Nielsen, H., 2015. Social impact assessment in Europe: a study of social impacts in three Danish cases. Journal of Environmental Assessment Policy and Management, 17(4).

Lazarus, R.S., Cohen, J.B., 1977. Environmental stress. In: Altman, I., Wohlwill, J.F. (Eds.), Human behaviour and environment: advances in theory and research, Vol. 2 (pp. 90–127). Plenum Press, New York.

Liebe, U., Bartczak, A., Meyerhoff, J., 2017. A turbine is not only a turbine: the role of social context and fairness characteristics for the local acceptance of wind power. Energy Policy 107, 300–308.

Lombard, A., Ferreira, S., 2014. Residents' attitudes to proposed wind farms in the West Coast region of South Africa: a social perspective from the South. Energy Policy 66, 390–399.

Lothian, A., 2020. A survey of the visual impact and community acceptance of wind farms in Australia. Australian Planner 56 (3), 217-227.

Lyhne, I., 2011. Between policy-making and planning: SEA and strategic decision-making in the Danish energy sector. Journal of Environmental Assessment Policy and Management 13, 1–23. DOI: 10.1142/S1464333211003912.

Lyhne, I., Aaen, S.B., Nielsen, H., Kørnøv, L., Larsen, S.V., 2018. Citizens' self-mobilization, motivational factors, and the group of most engaged citizens: the case of a radioactive waste repository in Denmark. Land Use Policy 72, 433–442. https://doi.org/10.1016/j.landusepol.2017.12.053

Maehr, A.M., Watts, G.R., Hanratty, J., Talmi, D., 2015. Emotional response to images of wind turbines: a psychophysiological study of their visual impact on the landscape. Landscape and Urban Planning 142, 71–79.

Meyerhoff, J., Ohl, C., Hartje, V., 2010. Landscape externalities from onshore wind power. Energy Policy 38, 82–92, https://doi.org/10.1016/j.enpol.2009.08.055.

Michaud, D.S., Feder, K., Keith, S.E., Voicescu, S.A., Marro, L., Than, J., Guay, M., Denning, A., McGuire, D., Bower, T., Lavigne, E., Murray, B.J., Weiss, S.K., van den Berg, F., 2016. Exposure to wind turbine noise: perceptual responses and reported health effects. J. Acoust. Soc. Am. 139, 1443–1454.

Mirasgedis, S., Tourkolias, C., Diakoulaki, D., 2014. Valuing the visual impact of wind farms: An application in South Evia, Greece. Renewable and Sustainable Energy Reviews 39, 296-311.

Molnarova, K., Sklenicka, P., Stiborek, J., Svobodova, K., Salek, M., Brabec, E., 2012. Visual preferences for wind turbines: location, numbers and respondent characteristics. Applied Energy 92, 269–278.

Motosu, M., Maruyama, Y., 2016. Local acceptance by people with unvoiced opinions living close to a wind farm: a case study from Japan. Energy Policy 91, 362–370.

Möller, B., 2006. Changing wind-power landscapes: regional assessment of visual impact on land use and population in Northern Jutland, Denmark. Applied Energy 83, 477–494.

Nadaï, A., 2007. "Planning", "siting" and the local acceptance of wind power: some lessons from the French case. Energy Policy 35, 2715–2726. https://doi.org/10.1016/j.enpol.2006.12.003.

Nieminen, P., Lehtiniemi, H., Vähäkangas, K., Huusko, A., Rautio, A., 2013. Standardised regression coefficient as an effect size index in summarizing findings in epidemiological studies. Epidemiology Biostatistics and Public Health 10, e8854-1–e8854-15.

Ohl, C., Eichhorn, M., 2010. The mismatch between regional spatial planning for wind power development in Germany and national eligibility criteria for feed-in tariffs — a case study in West Saxony. Land Use Policy 27, 243–254. https://doi.org/10.1016/j.landusepol.2009.06.004.

Pawlaczyk-Łuszczynska, M., Zaborowski, K., Dudarewicz, A., Zamojska-Daniszewska, M., Waszkowska, M., 2018. Response to noise emitted by wind farms in people living in nearby areas. International Journal of Environmental Research and Public Health 15, 1575. (Published online 25 July 2018)

Pedersen, E., Waye, K. P., 2004. Perception and annoyance due to wind turbine noise – a dose response relationship. J. Acoust. Soc. Am. 116, 3460–3470.

Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., 2009. Response to noise from modern wind farms in the Netherlands. J. Acoust. Soc. Am. 126, 636–643.

Petrova, M.A., 2013. NIMBYism revisited: public acceptance of wind energy in the United States. WIREs Climate Change 4 (6), 575-601.

Pohl, J., Faul, F., Mausfeld, R., 1999. Belästigung durch periodischen Schattenwurf von Windenergieanlagen [Annoyance due to periodical shadow flickering of wind turbines]. Kiel: Institut für Psychologie der Christian-Albrechts-Universität zu Kiel.

Pohl, J., Gabriel, J., Hübner, G., 2018. Understanding stress effects of wind turbine noise − the integrated approach. Energy Policy 112, 119−128.

Pohl, J., Hübner, G., Mohs, A., 2012. Acceptance and stress effects of aircraft obstruction markings of wind turbines. Energy Policy 50, 592−600.

Pohl, J., Hübner, G., Liebig-Gonglach, M., Hornberg, C., 2020. Verbundvorhaben: Objektive Kriterien zu Erschütterungs- und Schallemissionen durch Windenergieanlagen im Binnenland (TremAc); Schlussbericht zu den Teilvorhaben: Umweltpsychologische Analyse der Windenergie-Immissionswirkungen auf Akzeptanz und Wohlbefinden der Anwohner (MLU) und Umweltmedizinische Analyse der Wirkung von Windenergieanlagen auf Gesundheit und Wohlbefinden von Anwohnern/innen (UBI). [Joint project: objective criteria for vibration and noise emissions from inland wind turbines (TremAc); final report on the subprojects: environmental psychological analysis of wind energy immission Effects on acceptance and well-being of residents (MLU) and environmental medical analysis of the effects of wind turbines on health and well-being of residents (UBI)]. Halle (Saale) und Bielefeld: Institut für Psychologie, Arbeitsgruppe Umwelt- und Gesundheitspsychologie, Martin-Luther-Universität Halle-Wittenberg und Fakultät für Gesundheitswissenschaften, Arbeitsgruppe 7 Umwelt & Gesundheit, Universität Bielefeld.

Rand, J., Hoen, B., 2017. Thirty years of North American wind energy acceptance research: what have we learned? Energy Research & Social Science 29, 135−148.

Reuters, 2019. Germany presents plan to strengthen onshore wind power after lull. https://www.reuters.com/article/us-germany-windpower-plan/germany-presents-plan-to-strengthen-onshore-wind-power-after-lull-idUSKBN1WM12S

Rudolph, D., Kirkegaard, J., Lyhne, I., Clausen, N.-E., Kørnøv, L., 2017. Spoiled darkness? Sense of place and annoyance over obstruction lights from the world's largest wind turbine test centre in Denmark. Energy Res. Soc. Sci. 25, 80–90.

Russell, A., Firestone, J., 2021. What’s love got to do with it? Understanding local cognitive and affective responses to wind power. Energy Research & Social Science 71. (Published online 5 November 2020)

SNH (Scottish Natural Heritage), 2017. Siting and designing wind farms in the landscape: guidance. Version 3. https://tethys.pnnl.gov/sites/default/files/publications/SNH-2017-Siting-Designing-Wind.pdf

Spielhofer, R., Thrash, T., Hayek, U.W., Grêt-Regamey, A., Salak, B., Grübel, J., Schinazi, V.r., 2021. Physiological and behavioral reactions to renewable energy systems in various landscape types. Renewable and Sustainable Energy Reviews 135. (Published online 28 September 2020)

State of Green, 2017. Test Center Østerild – Masters of Wind Turbines. https://stateofgreen.com/en/partners/green-team-thy/solutions/test-center-osterild-masters-of-wind-turbines/ (Retrieved 12-03-2021)

Terma, DTU and AAU, 2018. Final report to the EUDP: radar controlled obstruction lights at the National Test Centre in Østerild. https://www.energiteknologi.dk/sites/energiteknologi.dk/files/slutrapporter/journal_nr_64014-0563_-_projekt_rapport_final.pdf

The Danish Government, 2017. Aftale mellem regeringen (Venstre, Liberal Alliance og Det Konservative Folkeparti) og Socialdemokratiet, Dansk Folkeparti og Socialistisk Folkeparti om etablering af yderligere testpladser til prototypevindmøller ved Østerild og Høvsøre. [Agreement between the government (the Liberal Party of Denmark, Liberal Alliance and the Conservative People's Party) and Social Democracy, the Danish People's Party, and the Socialist People's Party on establishing additional test sites for proto type wind turbines at Østerild and Hovsøre] https://www.regeringen.dk/media/3140/aftale-om-yderligere-testpladser-til-prototypevindmoeller.pdf

Tsoutsos, T., Tsouchlaraki, A., Tsiropoulos, M. Serpetsikadis, M., 2009. Visual impact evaluation of a wind park in a Greek island. Applied Energy 86, 546–553.

van Rensburg, T.M., Kelley, H., Jeserich, N., 2015. What influences the probability of wind farm planning approval: evidence from Ireland. Ecological Economics 111, 12–22. https://doi.org/10.1016/j.ecolecon.2014.12.012.(ISSN 09218009.

Walter, G., 2014. Determining the local acceptance of wind energy projects in Switzerland: the importance of general attitudes and project characteristics. Energy Res. Soc. Sci. 4, 78–88.

Warren, C.R., Lumsden, C., O'Dowd, S., Birnie, R.V., 2005. 'Green on Green': Public perceptions of wind power in Scotland and Ireland. Journal of Environmental Planning and Management 48 (6), 853-875.

Wind Europe, 2017. Wind energy in Europe: scenarios for 2030. https:// windeurope.org/wp-content/uploads/files/about-wind/reports/Wind-energy-in-Europe-Scenarios-for-2030.pdf

Wind Europe, 2019. Wind energy in Europe in 2018: trends and statistics. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf

Wiser, R., Jenni, K., Seel, J., Baker, E., Hand, M., Lantz, E., Smith, A. 2016. Expert elicitation survey on future wind energy costs. Nature Energy 1, 16135.

Wood Mackenzie, 2019. Next-generation wind turbine models. https://www.woodmac.com/reports/power-markets-next-generation-wind-turbine-models-2019-328241

Wolsink, M., 2000. Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support. Renewable Energy 21, 49–64. DOI: 10.1016/S0960-1481(99)00130-5

Wolsink, M., 2018. Co-production in distributed generation: renewable energy and creating space for fitting infrastructure within landscapes. Landscape Research 43 (4), 542-561.

Figure(s)

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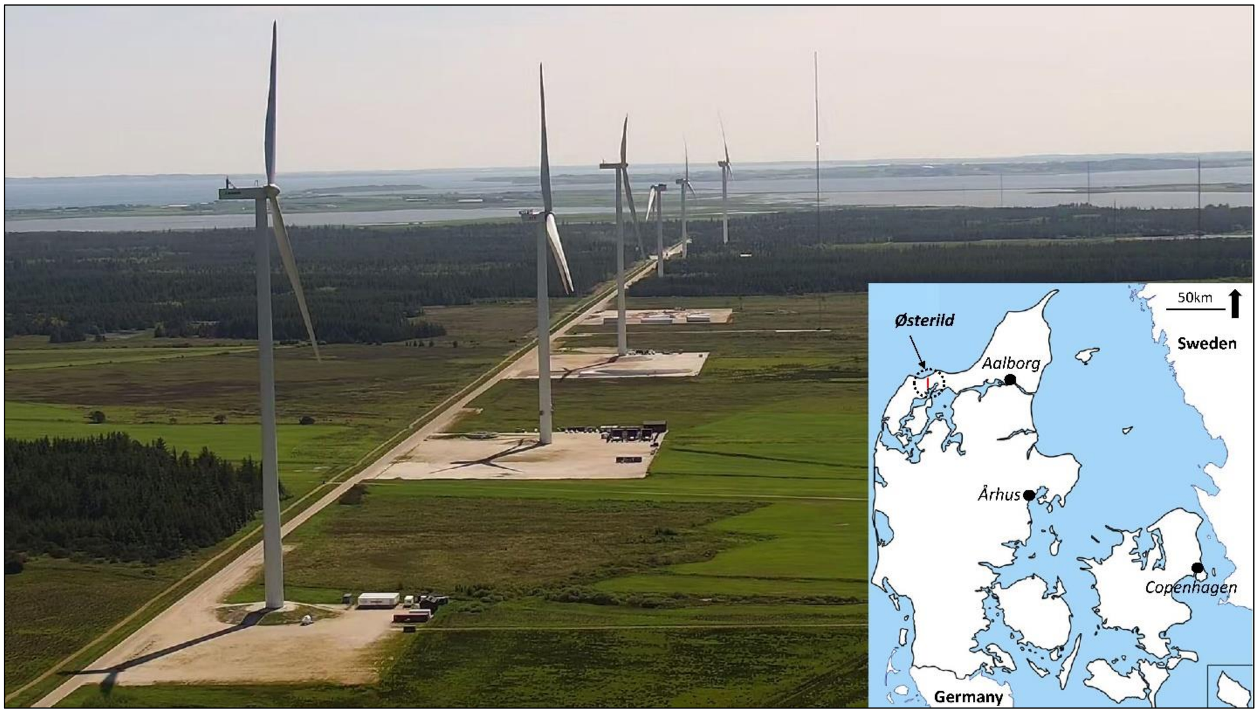

Figure 1: Test Centre Østerild including southern light mast, facing south; and map of location of Østerild in Northern Denmark (photo: Poul Falk Nielsen)

Table(s) Click here to access/download;Table(s);Table 1.docx

Table 1: Comparison of requirements to aviation marking of WTs on land in Denmark, Germany and Switzerland. For simplicity, the table includes the two most commonly used schemes for Germany more than 5 km from airports. NOTE: L.I. = low intensity; M.I. = medium intensity; H.I. = high intensity

Aviation markings for land-based WTs				
	Denmark	**Germany**		**Switzerland**[1]
Reference and version	BL 3-11 – 2018	1-950-17 – 2017 (two options)		AD I-006 D – 2019
Height* < 100 m	No requirements	Blades: red tips	Blades: red tips	2 L.I. red lights at nacelle
150 m > height > 100 m	2 L.I. red lights at nacelle	DAY: 2 M.I. blinking white lights; blades: red tips NIGHT: 2 M.I. blinking red lights	DAY: blades: red tips and one 6 m red marking NIGHT: 2 L.I. blinking red lights	2 M.I. blinking red lights at nacelle Tower:4 M.L. blinking red lights
Height > 150 m	DAY: 2 M.I. white blinking lights; NIGHT: 2 M.I. red blinking lights. Tower 3 L.I. red fixed lights	DAY: 2 M.I. blinking white lights; blades: red tips; NIGHT: 2 M.I. blinking red lights Tower: 4 L.I. fixed red lights; 3m red band	DAY: Nacelle red marking, blades: red tips and one 6 m red marking; NIGHT: 2 L.I. blinking red lights Tower: 4 L.I. fixed red lights; 3m red band	One H.I. white blinking light; 2 M.I. blinking red lights at nacelle Tower:4 L.I. fixed red lights at two heights
Blade painting	No	Yes	Yes	Red tips
Alt. marking, e.g. radar	Yes for turbines > 150 m	Yes during night	Yes during night	No

*Total height to tip. [1]Red lights are inclusive infrared.

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Table 2: Summary of studies, samples and wind farms

	DK Dataset	**Combined Dataset (G-S)**	**Pohl et al. (2012)**	**Pohl et al. (2018)**	**Hübner & Löffler (2013)**
Country	Denmark	Germany, Switzerland	Germany	Germany	Switzerland
Data collection year	2016	2009–2013	2009	2012	2012–2013
Sample size (N)	197	1099	420	212	467
Number of wind farms	1	21	13	1	7
WTs per wind farm	7	1–18	5–18	9	1–16
WT total height (m) **Light mast height (m)**	150–222 250	72–150 no mast	118–150 no mast	150 no mast	72–148 no mast
WT capacity (MW)	2.0–8.0	0.6–2.3	0.8–2.3	2.0	0.6–2.0
Distance range to home (km)	0.92–17.80	0.23–16.25	0.44–16.25	1.25–2.89	0.23–5.00
Average distance to home (km)	5.85	1.79	1.49	1.90	1.99

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Table 3: Sample demographic statistics

	DK	**G-S**	**Effect size (d, w) p-value (t-test, Chi^2-test)**
Age (mean, SEM, range)	52.46 (1.05)	52.28 (0.45)	p = .888
	20–80	17–93	
	n = 152	n = 1085	
Gender			
Male	45.1%	52.0%	p = .111
Female	54.9%	48.0%	
	n = 153	n = 1089	
Marital status			
Married/with partner	83.0%	55.9%	0.182 (small)
Single	17.0%	44.1%	p < .0001
	n = 153	n = 1085	
Years of education (mean, SEM)	13.37 (0.33)	13.21 (0.12)	p = .659
	n = 143	n = 1072	
Job situation			
Employed	65.0%	58.8%	0.134 (small)
Unemployed	0.0%	11.9%	p < .0001
Retired	30.0%	26.7%	
Scholar/student	5.0%	2.6%	
	n = 140	n = 990	
Duration of residency (years, mean, SEM)	25.39 (1.22)	21.450 (0.49)	0.239 (small)
	n = 191	n = 1068	p = .002
Financial participation in wind project			
No	93.2%	97.9%	0.103 (small)
Yes	6.8%	2.1%	p = .003
	n = 146	n = 876	

Table(s)

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Table 4: Perception of impacts from WTs

	DK	**G-S**	**Effect size (w) p-value (Chi^2-test)**
	Percentage (Number)		
Obstruction light inside the house	73.1% n = 128	30.0% n = 467	medium (0.390) p < .0001
Obstruction light outside the house	89.2% n = 157	37.7% n = 176	medium (0.460) p < .0001
Shadow perception outside the house	2.0% (3) n = 153	11.0% (51) n = 462	small (0.138) p = 0.001
Shadow perception inside the house	1.3% (2) n = 153	8.8% (41) n = 465	small (0.127) p = .002
Noise perception outside the house	17.6% (27) n = 153	41.0% (275) n = 671	small (0.188) p < 0.0001
Noise perception inside the house	10.5% (16) n = 153	23.9% (162) n = 678	small (0.127) p < 0.0001

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Table 5: Annoyance induced by WT impacts and other local sources (single item scale 0 to 4; 0='not at all')

	DK	**G-S**	**Effect size (d) p-value (t-test)**
	mean (SEM)		
Annoyed by day obstruction marking (white LED or Xenon or coloured stripes)	0.86 (0.09) n = 169	0.69 (0.04) n = 810	p = .092
Annoyed by day obstruction marking (white LED or Xenon)	0.86 (0.09) n = 169	1.00 (0.07) n = 339	p = 232
Annoyed by night obstruction marking	1.88 (0.13) n = 169	1.14 (0.05) n = 817	small (0.463) p < .0001
Bothered / annoyed by shadow casting	1.33 (0.88) n = 3	1.98 (0.23) n = 152	p = .514
Bothered / annoyed by landscape change	2.11 (0.15) n = 110	1.39 (0.05) n = 1093	small (0.454) p < .0001
Bothered / annoyed by WT noise	2.75 (0.25) n = 24	1.43 (0.08) n = 283	large (1.009) p < .0001
Agricultural machinery noise	2.11 (0.15) n = 110	1.39 (0.05) n = 1093	small (0.454) p < 0.0001

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Table 6: Frequency of annoyance by obstruction lights depending on the time of day and weather conditions

	DK	**G-S**	**Effect size (w)** **p-value (Chi²-Test)**
	Percentage (number)		
Annoyed by obstruction lights during daylight	26.6% (45) n = 169	5.9% (25) n = 423	small (0.289) p < .0001
Annoyed by obstruction lights at night	54.4% (92) n = 169	31.2% (132) n = 423	small (0.216) p < .0001
Annoyed by obstruction lights: clear sky	47.9% (92) n = 169	7.3% (31) n = 423	medium (0.468) p < .0001
Annoyed by obstruction lights: cloudy	43.2% (73) n = 169	8.3% (35) n = 423	medium (0.468) p < .0001
Annoyed by obstruction lights: rainy	37.3% (63) n = 169	8.3% (35) n = 423	medium (0.468) p < .0001
Annoyed by obstruction lights: misty/foggy	32.5% (55) n = 169	10.2% (43) n = 423	small (0.271) p < .0001

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Table 7: Negative impact of obstruction lights on daily activities (scale 0 to 2)

	DK	**G-S**	**Effect size (d)** **p-value (t-test)**
	mean (SEM)		
Garden/fields	0.52 (0.05) n = 168	0.58 (0.04) n = 278	p = .390
In the house	0.41 (0.05) n = 168	0.20 (0.02) n = 411	small (0.374) p < .0001
Taking a walk	0.88 (0.07) n = 168	0.49 (0.04) n = 411	small (0.495) p < .0001
Doing sports	0.42 (0.05) n = 168	0.29 (0.03) n = 354	small (0.206) p = .031
Relaxing	0.69 (0.06) n = 168	0.49 (0.04) n = 410	small (0.263) p = .006
Driving a car	0.72 (0.06) n = 168	0.39 (0.03) n = 399	small (0.453) p < .0001
Watching TV	0.29 (0.05) n = 168	0.23 (0.02) n = 411	p = .252
Reading	0.26 (0.04 n = 168	0.29 (0.03) n = 411	p = .517
During conversations	0.33 (0.05) n = 168	0.22 (0.02) n = 419	small (0.198) p = .042
While hosting guests	0.51 (0.05) n = 168	0.24 (0.03) n = 418	small (0.432) p < .0001

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Table 8: Annoyance Stress-Scale (scale 0 to 4)

	DK	**G-S**	**Effect size (d)** **p-value (t-test)**
	mean (SEM)		
Obstruction Lights Annoyance Stress-Level	2.16 (0.09) n = 170	1.27 (0.04) n = 1038	medium (0.777) p < .0001
Shadow Casting Annoyance Stress-Level	0.24 (0.06) n = 153	0.72 (0.03) n = 927	medium (0.648) p < .0001
Landscape Change Annoyance Stress-Level	2.36 (0.08) n = 110	1.42 (0.03) n = 748	large (1.199) p < .0001
Noise Annoyance Stress-Level	0.29 (0.07) n = 130	0.77 (0.04) n = 749	medium (0.544) p < .0001

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Table 9: Percentages of strongly annoyed residents based on the AS-Scale (level 4)

	DK	**G-S**	**Effect size (w)** **p-value (Chi²-test)**
	Percentage (number) of strongly annoyed residents		
Strongly annoyed participants induced by obstruction lights	6.1% (12) n = 153	3.0% (27) n = 890	p = .370
Strongly annoyed participants induced by shadow casting	0.0% (0) n = 197	0.0% (0) n = 467	not calculable
Strongly annoyed participants induced by landscape change	0.5% (1) n = 197	0.4% (2) n = 467	p = 1.00
Strongly annoyed participants induced by WT noise	2.5% (5) n = 197	5.9% (40) n = 679	p = .061
Strongly annoyed participants induced by at least one emission	6.6% (13) n = 197	6.1% (67) n = 1102	p = .780

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Table 10: Percentages of behavioural and cognitive coping to reduce lightning annoyance

	DK	**G-S**	**Effect size (w)** **p-value (Chi²-test)**
	Percentage (number)		
Changing location of outdoor activities (already done)	18.5% (30) n = 162	33.5% (105) n = 313	small (0.158) p = .001
Moving away (already done) or thinking about it	1.9% (3) n = 162	3.6% (15) n = 415	small (0.217) p < .0001
Resigning/getting used to it (already done)	27.8% (45) n = 162	51.7% (213) n = 412	p = .274

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Table 11: Comparison of attitudes and planning process moderator variables

	DK	**G-S**	**Effect size (d) p-value (t-test)**
	mean (SEM)		
Attitudes toward the local wind farm (scale −3 to +3)	1.00 (0.14) n = 158	1.00 (0.05) n = 987	p = .834
Attitudes toward WTs in general (scale −3 to +3)	1.67 (0.12) n = 156	1.62 (0.04) n = 1093	p = .687
Community interests have been heard to a sufficient degree (scale 0 to 4)	1.20 (0.11) n = 160	1.77 (0.06) n = 590	small (0.414) p < .0001
My personal interests have been heard to a sufficient degree (scale 0 to 4)	1.12 (0.11) n = 160	1.38 (0.06) n = 578	not relevant (0.180) p = .035
Stressed during planning and construction process (scale 0 to 4)	1.34 (0.15) n = 111	0.68 (0.04) n = 1071	small (0.480) p < .0001

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Table 12: Sensitivities and general stress (scale 0 to 4)

	DK	G-S	**Effect size (d)** **p-value (t-test)**
	mean (SEM)		
Light sensitivity	1.80 (0.12) n = 111	0.88 (0.03) n = 520	large (0.861) p < .0001
Noise sensitivity	1.68 (0.12) n = 111	1.81 (0.03) n = 672	p = .315
Acute stress	0.63 (0.10) n = 80	1.20 (0.03) n = 1078	medium (0.571) p < .0001
Chronic stress	0.41 (0.08) n = 80	1.08 (0.03) n = 1074	medium (0.696) p < .0001

Table(s) Click here to access/download;Table(s);Table 13.docx

Table 13: Multiple regression prediction of obstruction lights annoyance stress (OLAS-Scale)

	DK **R^2 adjusted = 0.661** **n = 75, all VIF < 5.2**		**G-S** **R^2 adjusted = 0.555** **n = 360, all VIF < 5.7**	
	Beta	**p-value**	**Beta**	**p-value**
Landscape Change Annoyance Stress-Scale	**0.570**	< .0001	0.054	.204
Attitudes towards the local wind farm	–0.002	.984	–0.136	.105
Attitudes toward WTs in general	0.021	.822	–0.115	.174
Community interests have been heard to a sufficient degree	**0.389**	.014	–0.048	.416
My personal interests have been heard to a sufficient degree	**–0.665**	< .0001	–0.076	.180
Stressed during planning and construction process	**0.191**	.047	**0.279**	< .0001
Light sensitivity	0.046	.529	[a]	[a]
Number of WTs visible from home	0.119	.150	**0.291**	< .0001
Duration of residency	0.039	.667	0.052	.208
Age	**0.220**	.010	0.021	.605
Gender	–0.069	.336	0.116	.001
Years of Education	0.045	.553	–0.065	.093
Distance to nearest WT / light mast	–0.025	.728	–0.044	.235

[a] No variable available; the number of respondents is too small.

Note: A VIF below 7 is considered as an indication of low collinearity between predictor variables.