Do demand-based obstruction lights on wind turbines increase community annoyance? Evidence from a Danish case

Aaen, Sara Bjørn; Lyhne, Ivar; Rudolph, David Philipp; Nielsen, Helle Nedergaard; Clausen, Laura Tolnov; Kirkegaard, Julia Kirch

Published in:
Renewable Energy

DOI (link to publication from Publisher):
10.1016/j.renene.2022.04.127

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Aaen, S. B., Lyhne, I., Rudolph, D. P., Nielsen, H. N., Clausen, L. T., & Kirkegaard, J. K. (2022). Do demand-based obstruction lights on wind turbines increase community annoyance? Evidence from a Danish case. *Renewable Energy*, *192*, 164-173. https://doi.org/10.1016/j.renene.2022.04.127

Renewable Energy 192 (2022) 164–173

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Do demand-based obstruction lights on wind turbines increase community annoyance? Evidence from a Danish case

Sara Bjørn Aaen [a,*], Ivar Lyhne [a], David Philipp Rudolph [b], Helle Nedergaard Nielsen [c], Laura Tolnov Clausen [b,1], Julia Kirch Kirkegaard [b]

[a] Department of Planning, Aalborg University, Rendsburggade 14, Aalborg, Denmark
[b] Department of Wind Energy, Technical University of Denmark, Frederiksborgvej 399, Roskilde, Denmark
[c] Department of Planning, Aalborg University, A.C. Meyersvænget 15, Copenhagen, Denmark

ARTICLE INFO

Article history:
Received 4 January 2021
Received in revised form
9 April 2022
Accepted 25 April 2022
Available online 28 April 2022

Keywords:
Community annoyance
Wind energy
Obstruction lights
Obstruction light control (OLC)

ABSTRACT

Adverse impacts from wind turbine obstruction lights have received little attention in literature and practice with respect to community annoyance with wind energy and studies on the effects of mitigation measures are absent. Technology development has made demand-based obstruction lights possible, allowing lights to be turned on only when aircrafts are approaching. The aim of this study is to investigate the effects of demand-based obstruction lights on community annoyance while considering the intervening effects from other influential factors. This is done by means of a before-after study of the installment of a demand-based obstruction light technology at a test center for wind turbines with a height up to 330 m in the northern part of Denmark. The results document that a radar-based obstruction light controlling system contributes to the reduction of community annoyance, but that annoyance is also influenced by several factors besides the direct impacts from obstruction lights. The results underscore the importance of communicating the effects of the radar system during the planning phase and when implemented. The findings thus provide important evidence that informs the efforts made by developers and authorities to reduce annoyance and increase community acceptance of wind turbines as part of the green transition of societies.

1. Introduction

Obstruction light control (OLC) systems are installed and tested at an increasing number of locations [e.g. 1,2]. A key motivation is to reduce light pollution and annoyance of residents living nearby [3–7] and thus overcoming community opposition, which constitutes a main barrier to wind energy development [8]. However, scientific investigation and documentation of the effect of OLC-systems on annoyance has so far been limited.

The literature on impacts on communities and community annoyance related to wind turbines has focused primarily on negative physical impacts such as noise [9–12], visual changes to the landscape [3,4] and shadow-flicker [10,5]. An aspect of this discussion that has received relatively little attention is the impact from aviation obstruction lights [6,7,13,14]. Traditionally, impacts from obstruction lights have been regarded as a part of the visual impacts and not a distinct impact from wind turbines [15]. However, as the size of wind turbines has increased significantly over time, from average hub heights between 60 and 70 m in the beginning of the century to an average hub height over 120 m 20 years later [16], turbines more often reach into elevations of interest to aviation. Consequently, there is a growing need for aviation obstruction lights on wind turbines in order to ensure aviation safety [7]. This development has emphasized the relevance of investigating impacts from obstruction lights on local communities separately from other visual impacts, including how to mitigate the impacts effectively.

Research on light pollution has predominantly focused on health impacts or public perception of light pollution in general [17,18]. General light pollution, defined as excess use of artificial light from multiple sources, can consist of different kinds of

* Corresponding author.
E-mail addresses: sara@plan.aau.dk (S.B. Aaen), lyhne@plan.aau.dk (I. Lyhne), dpru@dtu.dk (D.P. Rudolph), helle@plan.aau.dk (H.N. Nielsen), laura.t.clausen@uia.no (L.T. Clausen), jukk@dtu.dk (J.K. Kirkegaard).
[1] Present address: Department of Global Development and Planning, University of Agdar, Universitetsveien 25, Kristiansand, Norway.

https://doi.org/10.1016/j.renene.2022.04.127
0960-1481/

pollution e.g., sky glow (Typically from cities on to the sky), light trespass (From specific light sources on the ground), glare (Light shining horizontally) and over illumination (Excess level of lux) [19]. General light pollution has been linked to cancer [19,20] and disturbances to the circadian clock causing sleep problems and metabolic disorders [21]. Impacts from the specific glare and over illumination pollution from obstruction lights are less described. Pohl et al. [7,14] and Rudolph et al. [6] are a few of the scholars who have discussed the impacts on local communities specifically from obstruction lights installed on wind turbines and connected it to community annoyance caused by wind energy.

Pohl et al. [7,14] in accord with Rudolph et al. [6], found that obstruction lights on wind turbines do cause annoyance among neighbors when referring to annoyance as an evaluation of the perceived WT sound. However, in relation to other impact factors, participants felt comparably strongly annoyed by shadow-casting but more strongly annoyed by landscape changes and WT noise [7]. Particularly, substantial annoyance effects including stress reactions from obstruction lights among neighbors was not observed [7,14]. . Despite individual differences in how neighbors are affected by obstruction lights, Rudolph et al. [6] furthermore find that annoyance caused by obstruction lights is not reduced over time without mitigation measures.

This paper investigates the mitigation effects from a radar-based obstruction light control system (OLC-system), a technology that has only recently become widespread in connection to wind turbines. The system consists of a radar device placed near a wind farm that continuously scans the airspace for objects (planes, birds etc.) and ensures that obstruction lights are activated only when airplanes are sufficiently near the wind farm [18]. The radar system is typically either a single-turbine system where each turbine is equipped with a radar, or a central system, where one central radar detects relevant airplane transponders so that only relevant air traffic activates the obstruction lights [22]. Either way, the result of OLC-systems is that obstruction lights are turned on less frequently thus reducing the light emission from obstruction lights.

Optimally, less light emission means fewer negative impacts on the local community, which could reduce the annoyance of wind turbines. However, community annoyance is a complex phenomenon that is not solely determined by the physical impacts from a project [1,23]. The effect of an OLC-system on community annoyance is therefore still unknown. The aim of this study is to investigate the effects on community annoyance from installing an OLC-system at wind farms, while considering the intervening effects from other influential factors including; attitudes, the planning process and economical compensation schemes. The study is based on a case study of a test center for wind turbines with a height up to 330 m in the northern part of Denmark. The concept of community annoyance is further discussed in the following section in order to provide a framework for evaluating the mitigation effects from the OLC-system.

2. Theoretical background - the concept of community annoyance

In order to assess the mitigation effects of the OLC-system on community annoyance, the concept must be unpacked. Annoyance is related to other concepts in the literature such as perceptions, attitude, acceptance and stress [e.g. 24,25]. In a study of annoyance related to noise, Guski et al. [26] conceptualized annoyance as related to; a) an outcome, b) a multi-faceted psychological concept, c) terms such as “nuisance” and “disturbance” and, d) a concept with different meaning depending on culture. Perception of annoyance has furthermore been conceptualized through the psychometric paradigm [27] as subjective judgements and constructions of impacts, utilising and internalising heuristics and simplified information to frame impacts. In terms of definition, several definitions have been used in empirical research. A study of exposure to environmental factors defined annoyance as “a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them” [27,p.3]. In their study of obstruction lights from wind turbines Rudolph et al. defined annoyance as “a feeling of displeasure directly or indirectly related to an emitting source” [6, p. 82]. In this paper, we use the definition by Rudolph it al [6], but we use the term community annoyance to distinguish from any associations to disturbances on animals.

Annoyance is, furthermore, one of the feelings that can be closely connected to community acceptance [28,29]. and it has been used as a measure for acceptance particularly in connection with community acceptance related to noise and obstruction lights [6,7,13].

In this paper, we follow the efforts of the scholars discussed above when assessing the effects of the OLC-system as a mitigation measure of obstruction light-impacts. Hence, any positive changes to annoyance are considered as a sign of the effectiveness of OLC-system as a mitigation measure. However, acknowledging that the mitigation of impacts from obstruction lights does not take place in a vacuum, the scope of the study is broadened by discussing the effects of influencing factors that are present in a planning process but are outside the direct impacts from the obstruction lights.

2.1. Factors that influence the mitigation effects of the OLC-system — a framework for inquiry

Defined as a feeling of displeasure, the perception of annoyance is highly influenced by people's values and emotions [30,31]. This, in turn, places annoyance in an important context of social, cultural, spatial, and temporal settings, in which people are embedded, since the context influence how people perceive impacts of activities [6,32].

Research on community annoyance related to wind turbines has identified a range of factors that could influence community annoyance. This includes correlations between annoyance and acceptance [13, 33, 34], between annoyance and prior attitudes [32] between annoyance and planning process fairness [13] as well as outcome fairness and economical compensation [32] and between annoyance and visual impacts (e.g., Ref. [35]. Furthermore, studies have documented strong annoyance induced by landscape changes [13,36] and in some cases the direct visibility of turbines has also been found to have an effect [37,38]. Gender has in some cases been found to have a significant influence [32] and finally, a correlation has been found between annoyance and the perceived sensitivity towards impacts from wind turbines e.g. noise [10,39].

Specifically related to impacts from obstruction lights, Pohl et al. [7] find that annoyance is also influenced by a number of factors besides the direct impact from the obstruction lights. Factors such as the time of day and weather conditions are found to be strong predictors of annoyance because, according to Pohl et al. [7], they affect the visibility of the lights. Rudolph et al. [6] support this finding adding that the kinds of activities that the individual undertakes and the micro-geography of the residents’ properties also influence the visibility and thus the annoyance of the turbines.

Inspired by the review of research on community annoyance of wind farms, this study focuses on some of the most commonly found predictive factors to assess the effects of the OLC-system: Personal/socio-demographic factors, factors related to impact on place perception, awareness of light emission, procedural and distributive justice and attitudes towards wind energy and the specific facility. "Awareness of light emission" encompasses the perceived visibility of the obstruction lights and is a factor that attempts to include the findings from Pohl [7] and Rudolph [6] that temporal factors such as weather and time of day influence annoyance due to differences in visibility.

The OLC-system has potential for mitigating the negative impacts from obstruction lights since it has the ability to reduce light emission from obstruction lights considerably, especially in areas with little air traffic. However, the review of factors influencing community annoyance indicates that the mitigation effect might not be so straightforward to assess, since community annoyance depends on many other factors besides the light impacts.

To investigate the mitigation effects from an OLC-system, this study has focused on a critical case. That is, a case that is most likely to reveal the most information related to the problem under investigation [40]. The study thus investigates a Danish case, where an OLC-system has been implemented at a test center for wind turbines in a sparsely populated area with little air traffic. The area is characterized by little light pollution apart from the obstruction lights, meaning that the effects of the OLC-system are presumably more noticeable.

3. The case of the Danish test center

The test of the OLC-system is located at the National Test Center for Large Wind Turbines at Østerild in the north-western part of Denmark. It is operated by the Technical University of Denmark (DTU). The test center holds nine turbine test spots that permit wind turbines with total heights up to 330 m. The test sites are rented out to different wind turbine manufacturers. The current wind turbines have capacity ranging between 3 and 11 MW [41].

The test center is located in a sparsely populated area that mainly consists of pine plantation and smaller towns, which was originally one of the arguments for the siting of the center [42]. The siting process was full of conflict, as a large variety of stakeholders from both the local community and at national level, including press, academia, NGOs and politicians, objected to the project [43]. To some of the local residents, the unjust experience with the process became an integral part of how they perceived and referred to the test center several years after the inauguration in 2012 [6]. One of the main issues that did not gain much attention in the EIA-process but eventually became a main issue for the local community, was the impact from the obstruction lights [6].

In order to comply with aviation safety regulation [44,45], two 250 m pylons (light masts) were placed at each end of the test area with flashing high-intensive white obstruction lights (up to 2000 cd at night) [46]. Initially, the lights were blinking day and night, which produced considerable dissatisfaction among the local residents [6]. As a response to complaints from the local residents, DTU was granted a dispensation in 2017 to alter the light-system, so that the white obstruction lights would only be turned on full-time in the daytime. At night, the obstruction lights would be radar-controlled and only turned on if any planes were within a radius of 5500 m from the test center. The dispensation was given on the condition that in addition to the white high-intensive obstruction lights, red low-intensive lights (10–32 cd at night) [46] would be installed on the light pylons, and turned on at all times [47].

The OLC-system was installed in the summer 2017 but was especially in the following half year prone to malfunction, which entailed increased light intensity at night, asynchronous blinking, and lights that in certain periods were constantly turned on instead of only in case of approaching airplanes. This produced some dissatisfaction in the local area as the residents were expecting the obstruction lights to be completely shut off during the night.

In addition to the implementation of the OLC-system, the Danish Government decided in the spring 2017 to further expand the test center [47], thereby making it possible to test two additional turbines. This meant establishing an additional pylon with high-intensive white light marking in the middle of the test center and moving one of the existing pylons further south. Furthermore, the expansion entailed cutting additional 63 acres of forest in the area, and the increased noise impact caused a local camping ground to be closed and the acquisition of a single estate because noise levels were expected to exceeded threshold values for these specific locations. Given the size and impact of the expansion, as well as the previous highly conflictual planning process connected to the test center, an Environmental Impact Assessment was carried out in the autumn 2017, and public meetings were held in April 2017 and January 2018 [48].

4. Materials and methods

This longitudinal study is a follow up of a study conducted in September–November 2015 where the local residents' perceptions of Østerild test center were investigated prior to the implementation of the OLC-system [See 11]. The aim has been to examine the impacts from the OLC-system on the local residents. Hence, it was imperative to evaluate the same residents in the before- and after-study to investigate the development in their perception of the impacts. In addition to the data from the 2015 pre-OLC survey, the data collection consisted of six semi-structured interviews and a post-OLC survey conducted in April–May 2018 of the same local community.

4.1. Semi-structured interviews

In order to investigate some of the possible interference between the expansion process, the red lights that were introduced together with the OLC-system and the effects from the OLC-system itself, the team conducted six interviews with respondents in the area. Interviewees were chosen among local residents who had participated in the pre-OLC study or among the respondents who provided their contact information in the pre-OLC survey. The interviews covered questions regarding their perception of the changes to the area and test center during the past 2 years, how the obstruction lights affected them at the moment, and how the imminent plans for expanding the test center affected them. Based on the interviews, questions concerning the red obstruction lights and the expansion were included in the post-OLC survey. Furthermore, questions that allowed the respondents to self-evaluate the effect of the OLC-system were included.

4.2. Survey methodology

The post-OLC survey consisted of 40 questions and was to a large extent similar to the pre-OLC survey in order to ensure comparability. The questions covered subjects such as: Perception of the local area, the extent to which respondents noticed the obstruction lights and were influenced and annoyed by them, as well as their general attitudes to wind energy, the test center and the planning process connected to the test center.

'Annoyance' is, similar to previous studies on obstruction lights [6,7], measured via a range of questions. We differentiate between 'daily annoyance' - annoyance experienced during different activities during a day and 'general annoyance' - annoyance experienced in different circumstances.

The measure for general annoyance includes annoyance under different circumstances such as;

- … time of day (when it is dark outside in the morning, at daylight, when it is dark outside in the evening, at night), and
- … different weather conditions (when the sky is clear, when it is cloudy, when it rains and when it is foggy),

The measure for daily annoyance includes:

- annoyance during different activities (walking, doing sports, relaxing, driving, watching TV, biking, reading, talking and entertaining guests).

The recruitment of participants to the survey took place from mid-April to late-May 2018. In Denmark, nights are short during the summer, which could cause the effects from the obstruction lights to be reduced. Therefore, the data collection was finalized in the spring. Because the study had the objective to study whether an OLC-system controlling the obstruction lights is capable of mitigating negative impacts, a non-probability sampling strategy was applied that targeted respondents that had participated in the pre-OLC survey. It included two rounds of targeted letters to earlier respondents that had provided contact information followed by recruitment methods such as, posters on gathering places in the local area, Facebook announcements in a group previously used for recruitment of respondents, leaflets, and newspaper articles to create awareness. The survey was distributed both electronically via the software tool SurveyXact and via physical copies.

4.2.1. Participants

101 respondents answered the survey, 82 completed the survey, and 19 partially answered the questionnaire. 52 of the respondents had also answered the pre-OLC survey. These respondents were the relevant sample for the study. Despite the two non-probability sampling methods that were applied, the sample showed a representative distribution compared to the local population in the area around the test center on key theoretical and socio-demographic variables. 46.3 pct. were women, and 53.7 pct. were men. The average age was 55.7 years (SD 13.3). 17.6 pct. held a primary or secondary education, 64.8 pct. a vocational education or a Bachelor's degree and 17.6 pct. a Master or PhD degree. However, regarding one of the two concepts of interest for this study “degree of perceived annoyance”, there is a tendency that the sample is distributed along the more extreme parts of the annoyance scale, showing an overrepresentation of respondents that are either “not annoyed at all” or “very annoyed” by the obstruction lights under different circumstances. This is also supported by standard deviations between 1.18 and 1.64 for a 5-point scale for the general annoyance variable which is rather spread out (See Table 1).

Furthermore, comparing with e.g., Pohl et al.'s [14]. annoyance measure means for Denmark, Germany and Switzerland, the annoyance level for the sample is rather high. Pohl et al. [14] e.g., report for ‘annoyance at night’ a mean of 1.88 and 1.14 for Denmark and Germany/Switzerland respectively compared to 3.31 in this case. Similar, Pohl et al. [14] report means < 1 for all measure of daily annoyance and even <0.5 for a many of the measures compared to means above 1.3 in this sample (See Table 1).

4.3. Analytic strategy

The first analysis investigates how the perceived annoyance has changed in the community after the implementation of the OLC-system. In addition to annoyance level, it is investigated how the OLC-system has influenced other impacts caused by the obstruction lights, such as; the residents' attitudes towards the test center and perceptions of their local area, and the extent to which they notice the obstruction lights. This is done by applying Wilcoxon Signed Rank Test [49], a non-parametric test that compares rank sums of variables at the two points in time; pre-OLC-system and post-OLC-system. Wilcoxon Signed Rank Test was chosen for its ability to handle the fact that differences between pre-OLC-system and post-OLC-system variables were not normally distributed. Which is a precondition for the more powerful paired *t*-test. In addition to the Wilcoxon Signed Rank Test, the effect size is calculated to assess which impacts from the obstruction lights have changed the most due to the implementation of the OLC-system. Hence, in addition to establishing whether the change is statistically significant, which the significance (p) will allow us to do, the effect size (r) will reveal how big the change is compared to other changes in impact [50]. For some of the variables, the respondents themselves have assessed the changes caused by the introduction of the OLC-system e.g., attitudes which means that the Wilcoxon test is not applied on these variables.

The second analysis investigates which factors influence the community annoyance after the introduction of the OLC-system. This is done by applying a multiple linear regression analysis. A multiple linear regression is fitting because it shows the association between several predictive variables with ‘annoyance’ and it is sufficiently robust to handle an Likert-scaled variable such as the ‘annoyance’-variable. The dependent variable - ‘annoyance’ consists of the same items as the ‘general annoyance’-variable applied in the Wilcoxon Signed Rank test. The analysis investigates the β-values and goodness of fit for the model. The β-measure describes the effect of the predictor variable on the dependent variable annoyance. Comparing β-values will thus give an indication of the relative importance of the predictor variables [51]. Significance levels was set at $p < 0.05$ for influential predictors. The goodness of fit is investigated for the model in order to understand how well the model predicts the data. This indicates to what extent all relevant predictive factors have been included in the model.

4.4. Methodological challenges

The data collection took place in the period October 2017–May 2018, starting with interviews, and followed up by the surveys. The timing of the data collection was an issue that required careful consideration because it coincided with the expansion process, which might have affected the local residents' perception of the test center and impacts from the obstruction lights. However, because no actual changes connected to the expansion had been implemented yet in May 2018, the impact on the residents' annoyance is presumably negligible which was supported by the interview results.

Furthermore, the conditions had changed from the pre-OLC survey, because the introduction of the OLC-system prompted the requirement of red low-intensive obstruction on the light pylons in addition to the white high-intensity lights. Consequently, the post-OLC situation was potentially rather different from the pre-OLC situation. The post-OLC survey sought to investigate the potential influence from these changed conditions by formulating questions directly aimed at understanding the effects from the red low-intensity lights on the local community. To the question: ‘How often do you notice the red lights at the test center’, the majority answered that they noticed them less than once a week (61.4 pct. in the summer and 52.5 pct. in the winter). When asked whether they found the red lights more annoying than the white lights, only 3 pct. agreed. From these results, we concluded that the introduction of the red lights had a minor negative impact compared to the impacts from the white obstruction lights. Worst case was that it made the respondents answer more negatively regarding impacts from the lights, which would underestimate the effect of the OLC-system as a mitigation measure for white obstruction lights. The

Table 1
Mean and standard deviation (SD) for 'general'- and 'daily annoyance' in pre- and post-OLC-system surveys. (n = 52).

		Mean (SD)	
		Pre- OLC	Post-OLC
General Annoyance	To what extent do you feel bothered by the WHITE aircraft obstruction lights from test centre Østerild in the following conditions? (1 = Not at all, 5 = Very)		
	When it is dark outside in the evening	3.48 (1.60)	2.96 (1.60)
	At night	3.31 (1.64)	2.87 (1.62)
	When it is dark outside in the morning	2.90 (1.56)	2.65 (1.58)
	At daylight	1.94 (1.18)	2.13 (1.37)
	When it is cloudy	2.65 (1.45)	2.25 (1.43)
	When the sky is clear	2.92 (1.63)	2.58 (1.51)
	When it rains	2.37 (1.25)	2.13 (1.30)
	When it is foggy	2.29 (1.33)	2.00 (1.37)
Daily Annoyance	Do the white obstruction lights bother you in your daily activities? (1 = Not at all, 3 = To a larger degree)		
	When I am taking a walk	2.10 (0.85)	1.94 (0.83)
	When I am relaxing	1.87 (0.82)	1.60 (0.80)
	When I am reading	1.31 (0.61)	1.19 (0.53)
	When I am doing sports	1.38 (0.66)	1.31 (0.67)
	When I am driving	1.83 (0.81)	1.65 (0.79)
	When I am watching TV	1.37 (0.69)	1.23 (0.58)
	When I am biking	1.75 (0.81)	1.63 (0.81)
	When I am talking	1.33 (0.62)	1.21 (0.50)
	When I am entertaining guests	1.62 (0.72)	1.48 (0.70)

awareness of the red lights was included as a predictive factor in the regression analyses to separate the effect on annoyance from the effect from the obstruction lights.

5. Results

5.1. Changes to annoyance caused by implementation of the OLC-system

The change to the residents' annoyance level was determined by comparing the answers from the pre-OLC survey with the post-OLC survey using the Wilcoxon signed rank test. The test provides an opportunity to generalize the results beyond the sample. Table 2 summarizes the results from the Wilcoxon Signed Rank test.

The results show that the sum of the post-OLC-system rank for the general annoyance caused by the obstruction lights is lower than the pre-OLC-system rank sum, which is also evident from a lower median, a change that is statistically significant. This is the case when it is dark outside in the evening (Pre-OLC MD = 4, post-OLC MD = 3, Z = −3.483, p = 0.000), at night (pre-OLC MD = 4, post-OLC MD = 3, Z = −2.457, p = 0.014) and when it is cloudy (Pre-OLC MD = 2.5, post-OLC MD = 2, Z = −2.287, p = 0.022). This means that the local residents are generally less annoyed by the obstruction lights after the implementation of the OLC-system compared to before the implementation in these specific situations. There are, however, conditions under which no change can be detected. At daylight, and in clear sky, foggy or rainy conditions the lack of effect can be explained by the fact that the obstruction lights are less visible under these conditions, which is supported by the interviews. According to the interviewees, especially cloudy conditions seem to amplify the visibility of the obstruction lights because light is reflected by the clouds. It is perhaps more surprising that no change can be detected when it is dark outside in the morning. This is however, in accordance with results found by Rudolph et al. [6].

The same tendency is visible in the respondents' annoyance level during daily activities. Here the results show that the rank of the pre-OLC annoyance is lower when the residents are taking a walk (Pre-OLC MD = 2, post-OLC MD = 2, Z = −2.000, p = 0.046), relaxing (Pre-OLC MD = 2, post-OLC MD = 2, Z = −2.428, p = 0.015) or reading (Pre-OLC MD = 1, post-OLC MD = 1, Z = −2.121, p = 0.034). The medians for the pre- and post-OLC surveys are evidently the same. This is due to the fact that the ranks of the pre-OLC survey and post-OLC survey can display similar sums even though the rank sums are different. Therefore, the median should always be interpreted together with the standard test statistics (Z-value) and the p-value which, in this case, both confirm that there is in fact a difference between the groups despite the similar medians. Hence, the test shows that there is in fact a mitigation effect from the OLC-system and that the local residents are less annoyed after the installation of the OLC-system compared to before, in instances where they are reading, taking a walk or relaxing. Like the general annoyance measure, there are activities where no change is

Table 2
Results from the Wilcoxon Signed Rank test of differences in rank sums for indicators of annoyance between pre- and post-OLC-system surveys. (n = 52).

		Median (MD)		Std. test statistic (Z)	p-values (p)	Effect size (r)
		Pre-OLC	Post-OLC			
General Annoyance	To what extent do you feel bothered by the WHITE aircraft obstruction lights from test centre Østerild in the following conditions? (1 = Not at all, 5 = Very)					
	When it is dark outside in the evening	4	3	−3.483	0.000	−0.48
	At night	4	3	−2.457	0.014	−0.34
	When it is cloudy	2.5	2	−2.287	0.022	−0.32
	When it is dark outside in the morning	–	–	–	n.s.	–
	At daylight	–	–	–	n.s.	–
	When the sky is clear	–	–	–	n.s.	–
	When it rains	–	–	–	n.s.	–
	When it is foggy	–	–	–	n.s.	–
Daily Annoyance	Do the white obstruction lights bother you in your daily activities? (1 = Not at all, 3 = To a larger degree)					
	When I am taking a walk	2	2	−2.000	0.046	−0.28
	When I am relaxing	2	2	−2.428	0.015	−0.34
	When I am reading	1	1	−2.121	0.034	−0.29
	When I am doing sports	–	–	–	n.s.	–
	When I am driving	–	–	–	n.s.	–
	When I am watching TV	–	–	–	n.s.	–
	When I am biking	–	–	–	n.s.	–
	When I am talking	–	–	–	n.s.	–
	When I am entertaining guests	–	–	–	n.s.	–

detected. For daily annoyance, no effect can be detected from the OLC-system when respondents are; doing sports, driving, biking, talking, entertaining people or watching TV. The common denominator seems to be, that respondents are engaging in an activity. Whereas they might be more aware of the light impacts when they are less engaged in activities e.g., when they are walking, relaxing, or reading and therefore the effect of the OLC-system is greater. This is, however, speculative. Rudolph et al. [6] speculate that differences in annoyance can rather be explained by the time of day when the activities take place. The results from the Wilcoxon Signed Rank test show that the OLC-system has had a mitigation effect on the annoyance level caused by the obstruction lights in the local community. Introducing the OLC-system in Østerild test center had additional effects on several of the common predictors of community annoyance, which is investigated in the following section.

5.2. Changes to predictive factors caused by implementation of the OLC-system

The analysis of the changes caused by the implementation of the OLC-system to the predictive factors of community annoyance showed changes for; the 'attitudes towards the test center', 'awareness of light emission' and factors related to 'place perception'. In addition to these three factors, as an explorative strategy, the Wilcoxon Signed Rank test was also run on the factors general 'attitudes towards wind energy', and 'feeling of attachment to the place' for which there were found no effect.

Residents' attitudes towards the test center appeared to have been influenced by the implementation of the OLC-system. When asked directly about the effects from the implementation of the OLC-system, between 42 pct. and 47 pct. of the respondents report to have a 'more positive' or 'much more positive' attitude towards the test center as a result of implementing the OLC-system (See Fig. 1). The respondents were asked to consider their attitudes; at the time of questioning, when the OLC-system was still challenged by a number of malfunctions and their attitudes towards the test center in the hypothetical situation, when there would be no malfunction. Naturally, hypothetical questions are problematic, but it indicates that a properly working OLC-system would presumably have had an even bigger positive influence on the attitudes of the local community. However, even with the negative bias created by the malfunctions, the mitigation effect of the OLC-system is substantial.

In addition, the implementation of the OLC-system has caused the respondents to notice the white obstruction lights less than before the installation of the radar (See Fig. 2), and they relate this directly to the installation of the OLC-system.

Between 40 and 61 pct. of the respondents report that they notice the white obstruction lights 'less' or 'a lot less' at all times of the day. The change is most significant during winter and at night, where respectively 58 pct. and 61 pct. of the respondents report

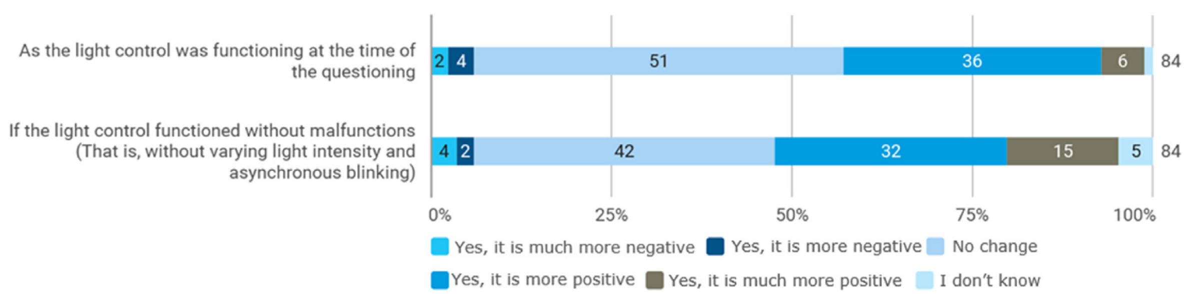

Fig. 1. Answers to the question: 'Did the latest changes to the obstruction lights since 2017 cause your attitude towards the test center to change?'.

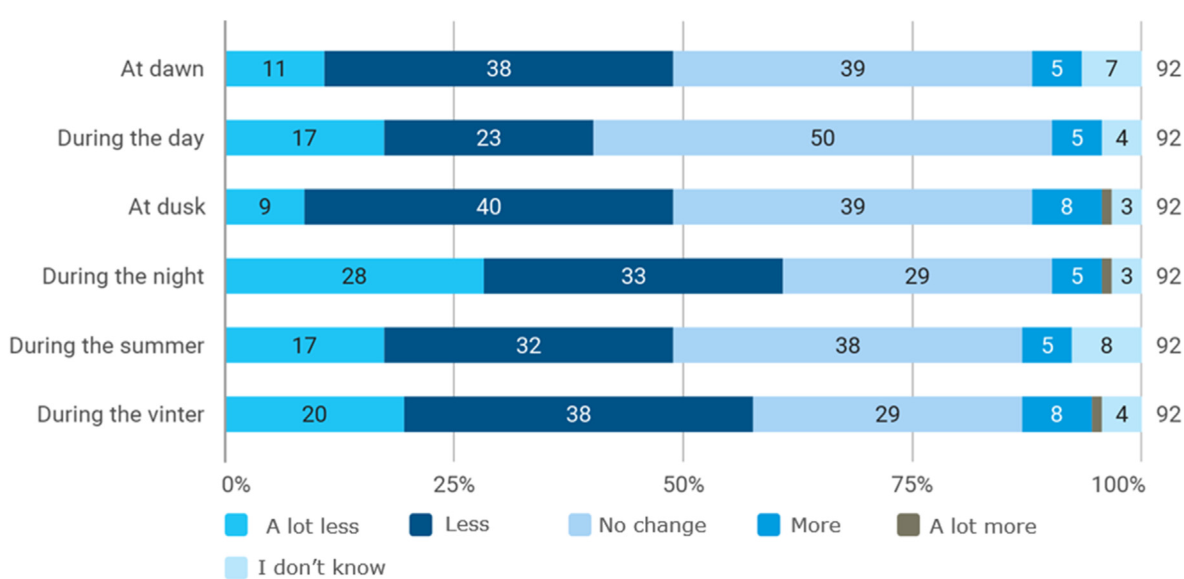

Fig. 2. Answers to the question: 'Did the installation of the radar-controlled light-system (since July 2017) cause you to notice the white lights more or less under the following conditions?'.

Table 3
Results from the Wilcoxon Signed Rank Test of differences in rank sums for predictive factors between pre- and post-OLC surveys. (n = 52).

		Median (MD)		Std. test statistic (Z)	p-values (p)	Effect size (r)
		Pre-OLC	Post-OLC			
Awareness	How often do you notice the WHITE obstruction lights at the test centre Østerild? (1 = Never, 7 = More than 5 times a day)					
	In the summer	5	5	−2.928	0.003	−0.41
	In the winter	5	4	−3.689	0.000	−0.51
Perception of local area	What is your view on the qualities of the area? (1 = Very unattractive, 5 = Very attractive)					
	Scenery	5	5	−2.744	0.006	−0.38
	Nature	5	5	−2.829	0.005	−0.39
	How have the obstruction lights changed your sense of the skyline? (1 = Much worse, 4 = Better)	2	4	5.667	0.000	0.80

that they have noticed the white obstruction lights 'less' or 'a lot less'. This is perhaps not surprising given that these are the periods where the impacts from the white obstruction lights have been strongest due to the darkness.

Besides the self-reported changes, the Wilcoxon Signed Rank Test was also applied to investigate the effects on the predictive factors. Table 3 describes the results from the test.

The Wilcoxon signed rank test supports the results from the self-reported effects on awareness, finding that there has been a statistically significant change in the residents' awareness of the obstruction lights between the pre- and post-OLC survey. The Wilcoxon signed rank test finds that the residents notice the obstruction lights less both in summertime (pre-OLC MD = 5, post-OLC MD = 5, Z = −2.928, p = 0.003) and in wintertime (pre-OLC MD = 5, post-OLC MD = 4, Z = −3.689, p = 0.000). Looking at the effect sizes, it is furthermore evident that the change has been largest in the winter (effect size = −0.51) compared to summer (effect size = −0.41). This, again, is not surprising given that the impacts are presumably larger because of more darkness in the winter, which makes the obstruction lights more visible. In Denmark, the difference between daylight in the darkest winter weeks compared to the brightest summer weeks can be up to 10 h [52].

Furthermore, the test shows that the implementation of the OLC-system has caused the residents' perception of their local area to change. The results from the Wilcoxon signed rank test point in different directions. The residents generally find the quality of the area less attractive at the time of the post-OLC study, measured by scenery (pre-OLC MD = 5, post-OLC MD = 5, Z = −2.744, p = 0.006) and landscape (pre-OLC MD = 5, post-OLC MD = 5, Z = −2.829, p = 0.005). However, when asked about how the obstruction lights have affected their view of the skyline, the tendency is that it has improved after the installation of the OLC-system (pre-OLC MD = 2, post-OLC MD = 4, Z = 5.667, p = 0.000). The somewhat conflicting results can be interpreted as follows: While the OLC-system seems directly linked to the sense of scenery, the perception of landscape involves many other aspects in addition to the changes to the obstruction lights e.g., visual impacts from the turbine structures or the light-pylons.

The effects on the residents' perception of the local area are inconclusive, but the effects on the residents' awareness of the lights as well as the change to their attitudes and annoyance caused by the obstruction lights rather conclusively show a positive effect from the OLC-system. However, it is also evident that even though the annoyance level is improved by the implementation of the OLC-system, the negative impacts from the obstruction lights are not completely gone. For instance, the percentage of respondents who are annoyed 'to some extent' or 'to a great extent' by the obstruction lights is still above 40 pct. when taking a walk (57 pct.), when driving (45 pct.) or when biking (43 pct.). The same is the case at night (50 pct.), when it is dark outside in the morning (44 pct.) or in the evening (55 pct.) and when the sky is clear (42 pct.). These numbers also correspond with the effect size of both the annoyance measures and the awareness measure, which show a medium effect from the introduction of the OLC-system according to the scales introduced by Cohen [50]. The same is the case when measuring the residents' attitudes towards the test center. 27 pct. of the local residents still find that the test center is 'generally unnecessary', and 20 pct. of residents find it to be 'unsafe'.

To understand why the OLC-system has not succeeded in eliminating the annoyance from the obstruction lights completely, we need to better understand what creates annoyance among the local residents and to know which predictive factors are decisive and which are less important to consider. This will help to tailor mitigation measures such as OLC-systems better to the impacts imposed by obstruction lights.

5.3. Predictive factors of annoyance

To understand why the negative impact on annoyance is not fully mitigated by the OLC-system, a multiple linear regression analysis was conducted. It shows which factors can predict local residents' annoyance in addition to the direct impacts from the obstruction lights. A significant regression equation was identified for annoyance ($F(1,42) = 11.791$, $p < 0.0005$ with adj.$R2 = 0.675$). The regression analysis reveals several influential predictors of annoyance caused by obstruction lights (See Table 4).

The regression model contains the predictive factors discussed in section 2.1 with the exception of the factor 'perception of local area' which showed no significant explanatory power in the model. It was thus excluded from the regression model.

The analysis confirms the suspicion that 'awareness of the obstruction lights' – the factor most directly measuring the effects from the OLC-system – is not the most influential predictor of community annoyance. This explains why the residual annoyance towards the test center is high even after the implementation of the OLC-system despite the apparent effectiveness of the OLC-system as a mitigation measure shown by the Wilcoxon-test.

The local residents are predominantly influenced by five factors that are found to be statistically significant predictors of annoyance: Their 'perception of the planning process' ($\beta = -0.348$), their attitudes towards the test center' ($\beta = -0.327$), the 'awareness of the malfunctions in the OLC-system' ($\beta = 0.291$) the 'length of their education' ($\beta = 0.228$) and whether they have received economical compensation in the process of establishing the test center ($\beta = -0.210$). However, all predictors have a low or moderate effect on 'annoyance' according to Cohen's scale [50] and no single predictor is the dominant explanation of 'annoyance'.

The 'awareness of malfunctions' shows a positive, statistically significant relationship with 'annoyance'. Hence, the more the

Table 4
Linear multiple regression predicting 'annoyance' from the factors: 'Awareness of the red lights', 'Awareness of the obstruction lights', 'Awareness of malfunctions' 'Attitudes towards the test center', 'Attitudes towards wind energy', 'Perception of the planning process', 'Economical compensation' and 'Socio-demographic factors'.

	Standardized Coefficients	*P-values*
Constant	27.021	0.014
Age	0.021	0.810
Gender	0.026	0.761
Education	0.228	0.017
Economic compensation	−0.210	0.041
Awareness of obstruction lights	0.063	0.579
Awareness of red lights	0.020	0.823
Awareness of malfunctions	0.291	0.006
Attitudes towards the test center	−0.327	0.018
Attitudes towards wind energy	0.197	0.098
Perception of the planning process	−0.348	0.001
Adjusted R^2	0.675	
P-value model	<0.000	
N	53	

residents notice malfunctions, such as asynchronous blinking, too high intensity of the lights etc., the more annoyed they are with the lights. This means that 'awareness of the red or white obstruction lights' has a comparably lower effect on residents' annoyance compared to the 'awareness of malfunctions'. This is an important result since it indicates that installing an OLC-system involves a risk of residents being even more annoyed if the implementation involves technical problems.

The goodness of fit (R^2) of the regression model is 0.675, and it is evident that the model explains the variation of the dependent variable annoyance quite well. However, there are evidently still important predictors of annoyance missing from the model. Hence, it is prudent to say that the model does not provide us with the complete understanding of what creates annoyance. However, even though large proportions of the annoyance created by the obstruction lights are not mitigated by the introduction of the OLC-system, it does not mean that the OLC-system is not successful. There are just other predicting factors that fuel annoyance that must be dealt with by additional mitigation measures.

6. Discussion

6.1. Effects of the OLC-system on community annoyance

The OLC-system did have an independent influence on the community's annoyance caused by the obstruction lights which is shown by the Wilcoxon signed rank analysis. Furthermore, the residents reported that the implementation of the OLC-system had a direct effect on their attitudes towards the test center as well as their awareness of the obstruction lights. Therefore, it is sound to conclude that the OLC-system has had a mitigation effect on negative impacts from the obstruction lights. However, the analysis covers only the evaluation of perceived emission - termed by Pohl et al. [7,14] and Hübner et al. [13] as possible stressors, and not potential psychological or physical reactions to those stressors. The mitigation effects from the OLC-system on what Pohl et al. [7] term as 'substantial annoyance' is a relevant subject for further research bearing in mind that no long-term substantial annoyance has so far been connected to obstruction lights emissions [7].

The analysis does not allow us to be conclusive regarding why the effect occurred. As evident from the regression analysis, the positive changes to the local residents' annoyance level is not only caused by the introduction of the OLC-system, as annoyance is influenced by a number of factors, including those related to the way the obstruction lights are impacting the local residents' lives at the present.

The findings on predictors are in line with other research concerning the importance of planning processes [e.g. 53, 54, 55], the level of education [13,56], prior attitudes [32,57] and the softening effect of economic benefits [58–60] for residents' annoyance from wind turbines. Evidence does not, however, point in the same direction on all predictive factors. Pohl et al. [14] did not find education or prior attitudes to be a significant predictor in their investigation of obstruction lights annoyance stress. However, contrary to results found in this study, Pohl et al. did find gender to be a significant predictor in one of their cases. Considering the conflicting results, the most robust result of the present study regarding predictive factors of annoyance is the effect from the residents' perception of fairness in the planning process. Which has repeatedly been identified in different contexts [see e.g. 13,14,57]. This consistent result raises the question: When annoyance that is detected six years after the inauguration of the test center is still influenced by events in the past connected to the planning process, can impacts from obstruction lights then ever be fully mitigated by implementing an OLC-system in the present? In the case of Østerild, an OLC-system alone was not an adequate mitigation measure. A relevant question is therefore to discuss how it could be supplemented.

6.2. Ways to improve the mitigation effect of OLC-systems

For mitigation measures to be considered effective, they need to avoid, reduce, or remedy adverse impacts of a development project [61]. This can be done in a number of ways aimed at either: '(…) the proposed development, its processes, the end product of its processes, the byproduct of the process or even the structure or essence of the development' [65 p. 197]. The focus tends to be on physical features and the structure of projects, neglecting possible mitigating opportunities related to the planning process or the operational phase [62]. The case of Østerild is an example where the focus of the mitigation efforts has been on physical features by means of the OLC-system and less on other mitigation measures which, the study shows, could have been effective in complementing the mitigation efforts of the OLC-system. The regression analysis identifies three factors that influence how the residents are affected by the obstruction lights: The residents' perception of fairness in the planning phase, their awareness of the malfunctions in the operational phase, and economical compensation. None of these are mitigated by the OLC-system, which calls for other forms of mitigation measures in order to effectively mitigate the adverse effects from the obstruction lights.

Transparency, procedural justice, and fairness in the process are well-known factors which in other studies have proven to be important for residents' experience of the planning process [13, 53, 57, 63]. Improving on these factors would undoubtedly also contribute to improving residents' perception of the planning process and community acceptance. However, a factor that emerged in this study specifically connected to OLC-systems and which played a role in their perception of the planning process was the presentation of the OLC-system in the planning process. In this case, many of the residents initially got the impression from presentations in the planning phase that the OLC-system would completely eliminate nuisance from the obstruction lights during the night. This was not the case since lights are turned on whenever an aircraft approaches. Parts of the annoyance with the obstruction lights thus arose due to unclear communication of what could be expected from the OLC-system. This should be possible to allay by being clearer regarding the limitations of the OLC-system in the planning phase.

Furthermore, the study shows that a strong contributor to the annoyance related to the obstruction lights was the residents' awareness of the malfunctions of the OLC-system in the operational phase. Being a relatively new technology for wind turbine installations, the OLC-system is vulnerable to malfunctions in the implementation phase. This was also the case at Østerild test center. Residents thus experienced malfunctions, such as increased light intensity at night, asynchronous blinking, and lights that in periods were constantly turned on regardless of approaching airplanes. As shown by the regression analysis, the awareness of the malfunctions contributed to residents' annoyance. Part of it was caused by the impacts of the malfunctions themselves, but part of the annoyance was, according to the interviewees, caused by a lack of information regarding malfunctions and the fact that residents did not know whether the effects they experienced were temporary or permanent conditions of the obstruction lights. During meetings and interviews, the residents therefore expressed a request for better continuous communication between the authorities and the local community specifically related to the malfunctions.

7. Conclusions

There is still a lot to learn about the negative impacts from obstruction lights and how they can be mitigated effectively. This study has advanced the discussion on three accounts in particular. First, it has shown that a radar-based obstruction lights controlling system does indeed have a mitigation effect on annoyance levels. Furthermore, it has a positive effect on residents' awareness of the obstruction lights as well as their attitudes towards the test center, and thus can be viewed as an effective mitigation measure of adverse impacts from obstruction lights connected to wind turbines. Second, it has shown that annoyance connected to obstruction lights is influenced by a number of factors besides the direct impacts from obstruction lights, such as the residents' education level, the residents' perception of fairness in the planning phase, their awareness of the malfunctions in the operational phase and economical compensation. Hence, it should not be expected that an OLC-system alone will mitigate all adverse impacts caused by obstruction lights. Third, further measures can be taken that would make an OLC-system a more effective mitigation measure if attention is paid to other factors that influence community annoyance. Based on this study, two additional mitigation measures are proposed to complement the OLC-system. First, special attention should be paid to realistic communication of the performance of the OLC-system and to aligning it with residents' expectations in terms of shutting off lights and second, continuous communication with local communities regarding malfunctions of the system should be prioritized in order to avoid unnecessary frustration.

This study is based on a Danish case study and further studies are therefore needed in order to generalize the findings to an international perspective and to validate proposals for increasing the effectiveness of OLC-systems. However, the study indicates that an OLC-system is a promising mitigation measure that can be an important part of the toolbox to mitigate adverse impacts on community acceptance from obstruction lights and thereby reduce barriers for wind energy development.

CRediT authorship contribution statement

Sara Bjørn Aaen: Conceptualization, Methodology, Investigation, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Ivar Lyhne:** Term, Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Project administration. **David Philipp Rudolph:** Term, Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing, Project administration. **Helle Nedergaard Nielsen:** Investigation, Data curation, Writing – review & editing. **Laura Tolnov Clausen:** Investigation, Data curation, Writing – review & editing. **Julia Kirch Kirkegaard:** Term, Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The empirical data collection in this paper was financially support by EUDP [grant no. 64014–0563], which is greatly acknowledged. The authors furthermore wish to thank Lone Kørnøv and Niels-Erik Clausen for their participation in the project.

References

[1] E. Maris, et al., Noise within the social context: annoyance reduction through fair procedures, J. Acoust. Soc. Am. 121 (4) (2007) 2000–2010, https://doi.org/10.1121/1.2535507.
[2] Terma, First Wind Farm Obstruction Light Control Project from TERMA Approved and Operational, Terma, Århus, 2018.
[3] A. Lothian, Scenic perceptions of the visual effects of wind farms on South Australian landscapes, Geogr. Res. 46 (2) (2008) 196–207, https://doi.org/10.1111/j.1745-5871.2008.00510.x.
[4] D. Kokologos, et al., Visual impact assessment method for wind parks: a case study in Crete, Land Use Pol. 39 (2014) 110–120, https://doi.org/10.1016/j.landusepol.2014.03.014.
[5] R. Saidur, et al., Environmental impact of wind energy, Renew. Sustain. Energy Rev. 15 (5) (2011) 2423–2430, https://doi.org/10.1016/j.rser.2011.02.024.
[6] D. Rudolph, et al., Spoiled darkness? Sense of place and annoyance over obstruction lights from the world's largest wind turbine test centre in Denmark, Energy Res. Social Sci. 25 (2017) 80–90, https://doi.org/10.1016/j.erss.2016.12.024.
[7] J. Pohl, G. Hübner, A. Mohs, Acceptance and stress effects of aircraft obstruction markings of wind turbines, Energy Pol. 50 (2012) 592–600, https://doi.org/10.1016/j.enpol.2012.07.062.
[8] D. Luga, et al., WISE Power Result-Oriented Report, WindEurope, 2016.
[9] A. Botelho, et al., Effect of wind farm noise on local residents' decision to adopt mitigation measures, Int. J. Environ. Res. Publ. Health 14 (7) (2017), https://doi.org/10.3390/ijerph14070753, 753-573.
[10] D.S. Michaud, et al., Exposure to wind turbine noise: perceptual responses and reported health effects, J. Acoust. Soc. Am. 139 (3) (2016) 1443–1454, https://doi.org/10.1121/1.4942391.
[11] E. Pedersen, et al., Response to noise from modern wind farms in The Netherlands, J. Acoust. Soc. Am. 126 (2) (2009) 634–643, https://doi.org/10.1121/1.3160293.
[12] E. Pedersen, Health aspects associated with wind turbine noise: results from three field studies, Noise Control Eng. J. 59 (1) (2011) 47–53, https://doi.org/10.3397/1.3533898.
[13] G. Hübner, et al., Monitoring annoyance and stress effects of wind turbines on nearby residents: a comparison of U.S. and European samples, Environ. Int. 132 (2019), 105090, https://doi.org/10.1016/j.envint.2019.105090.
[14] J. Pohl, et al., Annoyance of residents induced by wind turbine obstruction lights: a cross-country comparison af impact factors, Energy Pol. 156 (2021), 112437, https://doi.org/10.1016/j.enpol.2021.112437.
[15] M. Johansson, T. Laike, Intention to respond to local wind turbines: the role of attitudes and visual perception, Wind Energy 10 (5) (2007) 435–451, https://doi.org/10.1002/we.232.
[16] R. Wiser, et al., Reducing Wind Energy Costs through Increased Turbine Size: Is the Sky the Limit? Berkely National Laboratory, Berkely, 2016.
[17] J. Lyytimäki, J. Rinne, Voices for the darkness: online survey on public perceptions on light pollution as an environmental problem, J. Integr. Environ. Sci. 10 (2) (2013) 1–13, https://doi.org/10.1080/1943815X.2013.824487.
[18] L.D. Jørgensen, T. Tambo, G. Xydis, An efficiency evaluation of radar-based obstruction lights controlling at a wind turbine test site, Wind Energy 22 (4) (2019) 576–586, https://doi.org/10.1002/we.2308.
[19] R. Chepesiuk, Missing the dark: health effects of light pollution.(Focus)(Report), Environ. Health Perspect. 117 (1) (2009) A20–A27, https://doi.org/10.1289/ehp.117-a20.
[20] A. Haim, A.E. Zubidat, Artificial light at night: melatonin as a mediator between the environment and epigenome, Phil. Trans. Roy. Soc. Lond. B Biol. Sci.

370 (1667) (2015) 1–7, https://doi.org/10.1098/rstb.2014.0121.
[21] F. Falchi, et al., Limiting the impact of light pollution on human health, environment and stellar visibility, J. Environ. Manag. 92 (10) (2011) 2714–2722, https://doi.org/10.1016/j.jenvman.2011.06.029.
[22] Megavind, Technological Solutions to Reduce the Impacts from Wind-Energy Systems, Megavind, 2016.
[23] E. Pedersen, P. Larsman, The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines, J. Environ. Psychol. 28 (4) (2008) 379–389, https://doi.org/10.1016/j.jenvp.2008.02.009.
[24] Ø. Aas, P. Devine-Wright, T. Tangeland, S. Batel, Public beliefs about high-voltage powerlines in Norway, Sweden and the United Kingdom: acomparative survey, Energy Res. Social Sci. 2 (2014) 30–37, https://doi.org/10.1016/j.erss.2014.04.012.
[25] S. Huber, R. Horbarty, Social acceptance of wind energy, in: State-of-the-Art Report: IEA Wind Task 28, IEA Wind, 2010.
[26] R. Guski, U. Feischer-Suhr, R. Schuemer, The concept of noise annoyance: how international experts see it, J. Sound Vib. 223 (4) (1999) 513–527, https://doi.org/10.1006/jsvi.1998.2173.
[27] T. Lindvall, E. Radford, Measurement of annoyance due to exposure to environmental factors, Environ. Res. 6 (1973) 1–36.
[28] P. Upham, C. Oltra, À. Boso, Towards a cross- paradigmatic framework of the social acceptance of energy systems, Energy Res. Social Sci. 8 (2015) 100–112, https://doi.org/10.1016/j.erss.2015.05.003.
[29] C. D'Souza, E.K. Yiridoe, Social acceptance of wind energy development and planning in rural communities of Australia: a consumer analysis, Energy Pol. 74 (2014) 262–270, https://doi.org/10.1016/j.enpol.2014.08.035.
[30] P. Slovic, The Feeling of Risk. New Perspectives on Risk Perception, Earthscan, London, New York, 2010.
[31] N. Cass, G. Walker, Emotion and rationality: the characterisation and evaluation of opposition to renewable energy projects, Emot. Space Soc. 2 (1) (2009) 62–69, https://doi.org/10.1016/j.emospa.2009.05.006.
[32] T.R. Haac, et al., Wind turbine audibility and noise annoyance in a national U.S. survey: individual perception and influencing factors, J. Acoust. Soc. Am. 146 (2019) 1124, https://doi.org/10.1121/1.5121309.
[33] M. Pawlaczyk-Łuszczynska, et al., Response to noise emitted by wind farms in people living in nearby areas, 2018, Int. J. Environ. Res. Publ. Health 15 (2018) 1575, https://doi.org/10.3390/ijerph15081575.
[34] J. Pohl, J. Gabriel, G. Hübner, Understanding stress effects of wind turbine noise: the integrated approach, Energy Pol. 112 (2018) 119–128, https://doi.org/10.1016/j.enpol.2017.10.007.
[35] J. Meyerhoff, C. Ohl, V. Hartje, Landscape externalities from onshore wind power, Energy Pol. 38 (2010) 82–92, https://doi.org/10.1016/j.enpol.2009.08.055, 2010.
[36] A.M. Maehr, G. R Watts, J. Hanratty, D. Talmi, Emotional response to images of wind turbines: a psychophysiological study of their visual impact on the landscape, Landsc. Urban Plann. 142 (2015) 71–79.
[37] E. Pedersen, L. Pernilla, The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines, J. Environ. Psychol. 28 (2018) 379–389, https://doi.org/10.1016/j.jenvp.2008.02.009 (Google ScholarCrossref).
[38] F. van den Berg, " Criteria for wind farm noise: lmax and Lden, Paris, France (June 29–July 4), Euronoise 2008 (2008) 4043–4048 (Google ScholarScitation).
[39] E. Pedersen, K. Persson Waye, Perception and annoyance due to wind turbine noise—a dose-response relationship, J. Acoust. Soc. Am. 116 (2004) 3460–3470, https://doi.org/10.1121/1.1815091.
[40] R.K. Yin, Case Study Research: Design and Methods, 4 ed., California Sage, Thousand Oaks, 2009.
[41] DTU Wind Energy, Østerild - National Test Center for Large Wind turbines, DTU, 2020.
[42] The Danish Nature Agency, Høringsnotat om VVM redegørelse, Nationalt Testcenter – for Vindmøller Ved Østerild, 2010, The Danish Nature Agency, 2010.
[43] K. Borch, Mapping value perspectives on wind power projects: the case of the Danish test centre for large wind turbines, Energy Pol. 123 (2018) 251–258, https://doi.org/10.1016/j.enpol.2018.08.056.
[44] ICAO, International standards and recommended practices. Annex 14 to the convention on international civil aviation, Aerodromes Aerodrome Des. Oper. 1 (2013).
[45] Transport- Bygnings- og Boligministeriet, Requirements for Aviation Obstacles (Bestemmelser for Luftfartshindringer), BEK Nr 10133 Af 16/12/2009, Transport-, Bygnings- og Boligministeriet, Denmark, 2009.
[46] Danish Transport-, Construction and Housing Authorities, Vejledning Til BL 3-11 Bestemmelser Om Luftfartsafmærkninger Af Vindmøller, 2018.
[47] The Danish Government, 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, 2017.
[48] Danish Business Authority, Miljøkonsekvensrapport: Udvidelse Af Det Nationale Testcenter for Vindmøller I Østerild (EIA: Expansion of the National Test Center for Wind Turbines at Østerild), Danish Business Authority, 2017.
[49] F. Wilcoxon, Individual comparisons by ranking methods, Biometrics Bull. 1 (6) (1945) 80–83, https://doi.org/10.2307/3001968.
[50] J.W. Cohen, in: J.W. Cohen (Ed.), Statistical Power Analysis for the Behavioral Sciences, Erlbaum, Hillsdale, NJ, 1988.
[51] P. Nieminen, H. Lehtiniemi, K. Vähäkangas, A. Huusko, A. Rautio, Standardised regression coefficient as an effect size index in summarizing findings in epidemiological studies, Epidemiol. Biostat. Publ. Health 10 (2013) e8854-1–e8854-15.
[52] Danish Meteorological Institute, Daglængden Dykker under Ti Timer (The Length of the Day Drops under Ten Hours), 2012 [cited 2018 August 27]; Available from: https://www.dmi.dk/nyheder/arkiv/nyheder-2012/daglaengden-dykker-under-ti-timer/.
[53] J. Firestone, et al., Public acceptance of offshore wind power: does perceived fairness of process matter? J. Environ. Plann. Manag. 55 (10) (2012) 1387–1402, https://doi.org/10.1080/09640568.2012.688658.
[54] C. Walker, J. Baxter, Procedural justice in Canadian wind energy development: a comparison of community-based and technocratic siting processes, Energy Res. Social Sci. 29 (2017) 160–169, https://doi.org/10.1016/j.erss.2017.05.016.
[55] C. Gross, Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance, Energy Pol. 35 (5) (2007) 2727–2736, https://doi.org/10.1016/j.enpol.2006.12.013.
[56] E. V Hobman, P. Ashworth, Public support for energy sources and related technologies: the impact of simple information provision, Energy Pol. 63 (2013) 862–869, https://doi.org/10.1016/j.enpol.2013.09.011.
[57] J. Firestone, et al., Reconsidering barriers to wind power projects: community engagement, developer transparency and place, J. Environ. Pol. Plann. 20 (3) (2018) 370–386, https://doi.org/10.1080/1523908X.2017.1418656.
[58] C.R. Jones, J.R. Eiser, Identifying predictors of attitudes towards local onshore wind development with reference to an English case study, Energy Pol. 37 (11) (2009) 4604–4614, https://doi.org/10.1016/j.enpol.2009.06.015.
[59] N. Cass, G. Walker, P. Devine-Wright, Good Neighbours, Public relations and bribes: the politics and perceptions of community benefit provision in renewable energy development in the UK, J. Environ. Pol. Plann. 12 (3) (2010) 255–275, https://doi.org/10.1080/1523908X.2010.509558.
[60] P. M Arezes, et al., Implications of wind power generation: exposure to wind turbine noise, Proc. Soc. Behav. Sci. 109 (C) (2014) 390–395, https://doi.org/10.1016/j.sbspro.2013.12.478.
[61] R. Marshall, Application of mitigation and its resolution within environmental impact assessment: an industrial perspective, Impact Assess. Proj. Apprais. 19 (3) (2001) 195–204, https://doi.org/10.3152/147154601781767050.
[62] D.A. Munro, T.J. Bryant, A. Matte-Baker, Learning from Experience: A State of the Art Review and Evaluation of Environmental Impact Assessment Audits, The Canadian Environmental Assessment Research Council, 1986.
[63] P. Devine-Wright, Public engagement with large-scale renewable energy technologies: breaking the cycle of NIMBYism, Wiley Interdiscip. Rev.: Clim. Change 2 (1) (2011) 19–26, https://doi.org/10.1002/wcc.89.