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Understanding stress effects of wind turbine noise – The integrated approach

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ABSTRACT

To better understand causes and effects of wind turbine (WT) noise, this study combined the methodology of stress psychology with noise measurement to an integrated approach. In this longitudinal study, residents of a wind farm in Lower Saxony were interviewed on two occasions (2012, 2014) and given the opportunity to use audio equipment to record annoying noise. On average, both the wind farm and road traffic were somewhat annoying. More residents complained about physical and psychological symptoms due to traffic noise (16%) than to WT noise (10%, two years later 7%). Noise annoyance was minimally correlated with distance to the closest WT and sound pressure level, but moderately correlated with fair planning. The acoustic analysis identified amplitude-modulated noise as a major cause of the complaints. The planning and construction process has proven to be central − it is recommended to make this process as positive as possible. It is promising to develop the research approach in order to study the psychological and acoustic causes of WT noise annoyance even more closely. To further analysis of amplitude modulation we recommend longitudinal measurements in several wind farms to increase the data base — in the sense of "Homo sapiens monitoring".

1. Introduction

Noise problems are one of the most frequently discussed impacts of wind turbines (WT) on residents. Indeed, several studies provide empirical evidence for WT noise to be a potential source of annoyance. However, while about three dozen field studies on the noise effects of large WT (e.g., Health Canada, 2014; Michaud et al., 2016a, 2016b, 2016c, Pawlaczyk-Luszczynska et al., 2014; Pedersen et al., 2009; Pedersen and Persson-Waye, 2004, 2007; Pohl et al., 1999, 2012) and small WT (Taylor et al., 2013) indicate noise annoyance, the reported prevalence of annoyed residents is inconsistent and varies between 4.1% (Pedersen and Persson Waye, 2007) and 21.8% (Pohl and Hübner, 2012). One possible explanation for these different findings is that annoyance is not influenced solely by noise. For example, significant relations between noise levels from < 28 dB(A) to > 45 dB(A) – estimated by diffusion models – and annoyance repeatedly were found. However, the sound level explained only 12–26% of the annoyance variance (Pedersen and Persson-Waye, 2004, 2007; Pedersen et al., 2009), leaving more than 70% to be explained. Consequently, annoyance is influenced by further factors, so-called moderator variables such as visibility and financial participation. However, despite some knowledge on the moderating factors, it remains an open question under what conditions WT noise can lead to strong annoyance. Most of the mentioned studies calculated sound levels and used not local sound measurement at recipient locations, which may contribute to unexplained variance because in diffusion models local acoustical specificities were not considered.

Former studies provided valuable insight into the relation between WT noise and annoyance (e.g., Health Canada, 2014; Pawlaczyk-Luszczynska et al., 2014; Pedersen et al., 2009; Pedersen and Persson-Waye, 2004, 2007). However, they relied on a smaller range of stress indicators and moderators. Additionally, these studies remain descriptive and the indicators are not embedded in a larger stress concept. The benefit of a stress concept is to derive specific strategies for stress reduction on different stages of the stress process. Therefore, we rely on the well-established model of Lazarus (e.g., Lazarus and Cohen, 1977) enlarged by Baum et al. (1984) and Bell et al. (1990). This approach starts with the perception of a possible stressor (e.g., WT noise), followed by evaluation of the stressor (e.g., threatening), psychological and physical reactions (e.g., symptoms) and cognitive, emotional and behavioral coping (e.g., closing the window). Acoustic (e.g., sound pressure level), psychological (e.g., experiences during the planning process) and situational (e.g., distance to the nearest WT) moderators of the stress reaction were also considered.

The present study provides an interdisciplinary approach for a differentiated analysis of WT noise. This approach integrates noise

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measurement, weather and operational information connected with the WT and psychological concepts on social acceptance as well as stress psychology. To develop this integrated approach a field study was conducted involving 212 residents living in the vicinity of a wind farm in Lower Saxony, Germany. Finally, this approach offers a systematic background for recommendations regarding noise mitigation and on how to deal with WT noise.

2. Factors influencing noise annoyance by WT and stress effects

2.1. Influencing factors

Citizens and wind project operators refer to several influencing factors to explain noise annoyance. Some of these lay explanations are not mirrored by empirical evidence such as noise sensitivity, which has a rather weak impact on annoyance (e.g., Hübner and Löffler, 2013; Pedersen and Persson-Waye, 2004; Pohl et al., 2012). Socio-demographic variables such as age, gender and emotional lability, have not been proven to show significant impact (e.g., Pedersen and Larsman, 2008; Pedersen et al., 2010; Pohl et al., 2012).

A well-known moderator of noise annoyance due to WT is the visibility of WT from the property or homes of residents living nearby: on average, residents are significantly more annoyed when the WT are visible from their dwellings (e.g., Arezes et al., 2014; Pedersen et al., 2009, 2010; Pedersen and Persson Waye, 2007). This effect can be explained by the higher salience of the WT in case of visibility. In line with the explanation seems to be the finding that residents in rural and flatland regions reported higher noise annoyance than residents living in a more urban and hilly region (Pedersen and Larsman, 2008; Pedersen and Persson-Waye, 2007, 2008; Pedersen et al., 2009).

Additional relevant moderating variables that have the ability to decrease annoyance are financial participation in the wind farm (e.g., Arezes et al., 2014; Health Canada, 2014; Pohl et al., 1999; Pedersen et al., 2010), positive attitudes towards wind energy (e.g., Pawlaczyk-Luszczynska et al., 2014; Pedersen and Persson Waye, 2008; Pohl et al., 1999, 2012), and positive attitudes towards the local wind farm (e.g., Pohl et al., 1999, 2012). On the other hand, annoyance during planning and construction (e.g., Hübner and Löffler, 2013; Pohl et al., 2012) and a negative visual impact of WT on the landscape (e.g., Health Canada, 2014; Pawlaczyk-Luszczynska et al., 2014; Pedersen and Larsman, 2008; Pedersen et al., 2009) increase annoyance.

Additionally, noise annoyance is influenced by situational factors, such as weather conditions and time of day (e.g., Health Canada, 2014; Hübner and Löffler, 2013; Pawlaczyk-Luszczynska et al., 2014; Pedersen and Persson-Waye, 2004; Pedersen et al., 2009). The strongest noise annoyance occurs in the evening and night hours, especially when wind blows constantly from WT towards the dwellings or during periods of strong wind. Furthermore, residents experience higher noise annoyance outside rather than inside the home. Overall, however, the source directivity of wind turbines is still an under-researched topic especially in situations with strong amplitude modulation (AM).

In summary, moderator variables seem to better predict the annoyance caused by WT than, e.g., sound pressure level or distance to the nearest WT (e.g., Pawlaczyk-Luszczynska et al., 2014; Pedersen et al., 2009). Additionally, WT are rated more annoying than other noise sources with a similar sound level (Janssen et al., 2011; Pedersen and Persson-Waye, 2004; Pedersen et al., 2009). This finding also indicates that other factors contribute to the annoyance, such as some factors mentioned so far in combination with e.g., specific noise patterns and qualities. For example, residents felt most strongly annoyed by a noise pattern described as "swishing" (Pedersen and Persson-Waye, 2004, 2008).

2.2. Stress effects of WT noise

Sleep disturbance due to WT noise was reported in some studies (e.g., Bakker et al., 2012; Hübner and Löffler, 2013; Pedersen and Persson-Waye, 2004; Pohl et al., 1999). The proportion ranged from 6% (Bakker et al., 2012) to 11% of the residents (Pohl et al., 1999). Further symptoms caused by WT noise, such as negative mood, nervousness and irritability, occurred only to a small extent (up to 5.8% affected residents) and so far have been demonstrated in two earlier studies (Pohl et al., 1999; Wolsink et al., 1993). Further, there are only a few studies − and with heterogeneous findings − on the relationship between WT noise annoyance and disturbed work, leisure activities and alternating whereabouts (e.g., Hübner and Löffler, 2013; Pohl et al., 1999, 2012). Likewise, cognitive and behavioral coping strategies of annoyed residents have been subject only to a few studies (e.g., Hübner and Löffler, 2013; Pedersen and Persson Waye, 2007; Pohl et al., 1999, 2012). Typical reported measures include closing the windows and turning up the volume of the TV/radio.

While the aforementioned research refers to the health impacts of WT noise, other studies compare residents living near WT ($\leq$ 2 km) with those living further away ($\geq$ 3.3 km) in general (e. g., Nissenbaum et al., 2012; Sheperd et al., 2011). Although deteriorating health characteristics were reported for nearby residents, these studies are to be strongly criticized for their methods. They exclude the impacts of specific emissions, moderator variables or possible previous illness, and they do not control for the possible impact of additional noise sources (Nissenbaum et al., 2012; Sheperd et al., 2011).

2.3. Present research

The present research aims to provide a deeper understanding of the causes and consequences of WT noise stress effects. This knowledge is the base to derive recommendations for noise mitigation.

While existing research provides a basic understanding of the WT noise phenomenon, at least three open questions remain:

First, is there a greater proportion of residents living in the vicinity of a wind farm that is not only annoyed by noise but that also suffers from stress effects or even adverse health effects related to WT noise? To answer this question it is useful to assess possible stress effects by several indicators based on stress psychology concepts (Baum et al., 1984; Bell et al., 1990; Lazarus and Cohen, 1977). Further, it is unclear whether the proportion is stable over the time, since longitudinal studies thus far are missing.

Second, due to the chosen assessment methods, it is still uncertain whether the reported symptoms are directly attributed to WT noise or confounded by others stressors. The link is lacking in most studies. A first attempt to assess and directly link to WT noise was made in the late 1990s (Pohl et al., 1999). This study was mainly directed to analyse the stress impact of periodical shadow-casting but also included several items concerning noise.

Third, we need a deeper understanding of the conditions contributing to substantial annoyance.

Previous research results, illustrated above, suggest that physical factors (e.g., sound pressure level, sound quality, visibility of the wind farm) and psychological factors (e.g., stress during the planning phase, attitude toward wind energy) contribute to this.

Due to our aim to disentangle the responsible factors for WT noise annoyance, we used a case study approach with several psychological stress indicators and physical parameters.

3. Methods

3.1. Design

A longitudinal study design was chosen to test if WT noise annoyance is a stable phenomenon over time or can annoyance be influenced by information about causes and effects of WT noise. The design was based on the methodology of environmental and stress psychology in combination with noise measurement and audio recordings (Baum et al., 1984; Bell et al., 1990; Lazarus and Cohen, 1977). Using a