

Ambient Soundscape Assessment of Wind Parks

Tianhong YU^{1,2}, Holger BEHM¹, Ralf BILL¹, Jian KANG³

¹ Faculty of Agricultural and Environmental Sciences, University of Rostock, Germany

² IFB Ingenieure GmbH, Bad Teinach-Zavelstein

³ Institute for Environmental Design and Engineering, The Bartlett, University College London, UK

ABSTRACT

The potential conflicts between wind parks and the public are enormously enhanced after a rapid increase of wind parks. Assessment and management of environmental noise have played a vital role in the reaction of people concerning wind parks. This study uses an aural-visual preference survey to systematically investigate effects of background soundscapes and non-aural factors on annoyance toward wind parks. Visual and acoustic data were captured from seven German rural wind park sites. Laboratory experiments were then carried out with 40 participants to investigate the perception of the wind parks in rural areas. The tests consisted of three parts: 1) visual-only condition, 2) aural-only condition, and 3) combined aural-visual condition. Participants were immersed through google cardboard in laboratories using virtual reality technology to evaluate properties of sound and visual environment. Results suggest that the annoyance of wind parks strongly correlated with sound level ambient wind parks. However, the visual information did not demonstrate substantial effects on the people's opinions of wind parks. Further results show that the soundscape ambient wind parks associated with factors including "calmness/relaxation", "naturalness/pleasantness" and "diversity." Additionally, "calmness/relaxation" and "naturalness/pleasantness" were found to have a strong impact on the evaluation of wind park landscapes.

Keywords: Soundscape; audio-visual impact assessment; virtual reality; Wind parks

1. INTRODUCTION

The concept of the soundscape, which refers to "acoustic environment as perceived or experienced and/or understood by a person or people, in context" (ISO12913-1, 2014). The soundscape was suggested by numerous researchers as a critical factor for the understanding perception of an acoustic environment (Brambilla et al., 2013; Brown et al., 2011; Kang et al., 2016). The soundscape characteristics and sound level were implied as the prominent aspects of the annoyance evaluation (Szychowska et al., 2018). Moreover, the soundscape may dominate the preference degree to the environment due to its components and places with environmental identity (Carles et al., 1999). The soundscape in a rural area is a complex system. To characterize the soundscape in a rural area and verify its environmental identity, perceptual measure using multidimensional indices (semantical differential technique) was suggested (Galbrun and Calarco, 2014). Previous research has indicated the need for categorization of the soundscape in different levels (Kang and Zhang, 2010; Torija et al., 2013; Viollon et al., 2002). Various investigations have used laboratory protocols to examine the influence of the sound to outdoor settings quality (Jiang and Kang, 2016), indicating the enhancing effect of nature-related sounds on residential setting quality (Anderson et al., 1983). Studies on traffic noise annoyance have widely been investigated, as an example, the influence of the visual aspect of barriers on railway noise annoyance has been examined (Maffei et al., 2013). However, the impact of ambient sound characteristics on the annoyance of wind turbines which are placed mostly in rural or mildly built-up areas was so far not clear (Janssen et al., 2011). Many residents near to wind turbines may spend a higher proportion of their time outdoors, thus considering the influence of the future ambient soundscape on a wind park annoyance will be a supplement for acoustic research. In the context of wind parks, a holistic approach to investigate the soundscape around wind parks and their effects should be conducted to improve environmental quality in rural areas.

The landscape environment is rarely perceived in an isolated but multisensory way. Previous studies have confirmed the importance of the interaction between aural and visual information. The

vision and audition are commonly accepted as the significant modalities to perceive the environment (Hong and Jeon, 2014; Pheasant et al., 2010). Several studies have tested virtual reality (VR) technology for participatory evaluation (Yu et al., 2017), proving the applicability and advantages in scenario control for comparative presentations (Iachini et al., 2012; Jiang et al., 2017; Ruotolo et al., 2013; YU et al., 2018). The public's adverse reaction to new wind park projects, likely due to their noise, may be increased by the insufficient information of the projects. It was also suggested that the social acceptance would be enhanced through the accessible information and participatory of the public from the initial phase of the planning process (Simão et al., 2009; Yeh and Huang, 2014).

This study, therefore, uses an aural-visual survey to investigate how soundscapes ambient wind parks affect the perception of wind parks and verify some non-aural factors might be considered as statistically significant among them. With the aim of characterizing the soundscapes ambient wind parks, various noise level indices and multidimensional scaling based on the semantic differential technique, which were previously used in the landscape studies, were adopted. As a result of this survey three questions will be answered:

- (1) Effects of sound level on wind parks;
- (2) Effects of visual information related to wind parks;
- (3) Perception of wind parks in terms of multidimensional indices.

2. METHODOLOGY

2.1. Site Selection

Rural landscapes are complex and frequently characterized by various anthropic artificial processing, thus generating a broad diversity of soundscapes with profoundly different characteristics. With the aim of assessing the ambient soundscape of wind parks, a preliminary study with individual sound walks was performed around wind parks in Rostock, which is located in the north-east of Germany and a popular area for wind parks. According to the typologies of soundscapes around wind turbines in the previous studies (Pedersen et al., 2009; Torija et al., 2013), seven locations were selected:

site 01: located within the main avenue with high road traffic flow with a large number of vehicles;

site 02: located in a natural environment isolated from sounds of human activity, this site is dominated by bird sounds;

site 03: situated next to a motorway;

site 04: located in a residential area, including the sounds of people talking;

site 05: located near a residential area, including sounds of outdoor activities;

site 06 located in a residential area with a medium road traffic flow;

site 07 situated in a natural environment with water sounds.

As listed in Table I, these locations possess main features of a rural landscape, including central features of (high traffic flow, birds sound, motorway, human sounds, leisure activities, medium traffic flow, and water sound). For a better understanding of these sites, further related physical data will be described in the coming section.

TABLE I Physical characteristics at each site. L_{Aeq} : A-weighted sound pressure level; N: loudness; S: sharpness; Fls.: fluctuating strength; R: roughness.

Site	Sound feature	Category	L_{Aeq} [dB]	N[soneGF]	S[acum]	Fls.[vacil]	R[asper]	Number of WT
01	High traffic flow	Technological sound	65.3	46.06	3.21	0.017	3.24	4
02	Birds	Natural sound	39.0	1.06	1.93	0.006	0.03	4
03	Motorway	Technological sound	52.5	10.67	1.79	0.005	1.44	10
04	Human sounds	Human speeches	50.2	2.85	1.46	0.005	0.24	10
05	Leisure activities	Human speech	53.6	11.39	1.87	0.011	1.57	10
06	Medium traffic flow	Technological sound	41.2	9.7	1.8	0.010	1.2	5
07	Water	Natural sound	43.7	9.7	1.8	0.010	1.2	10

2.2. Aural Stimuli

Binaural recordings were made with clear weather from 11:00 am to 3.00 pm using a dummy head with a height of 1.6 m and a recorder (DAT 208Ax, Sony) in the selected locations. Wind turbines should be placed at a distance of 800 to 1000 meter away from the residential house according to the local regulations (Plehn, 2012). Jallouli et al. also indicated that wind parks dominate noise perception if wind turbines were located within 1 km distance (Jallouli and Moreau, 2009). In our study, positions for recordings were placed more than 1000 m to the wind park, the noise of wind turbines was thus irrelevant here. The wind speed during recordings was 7.2 ms^{-1} . Our recorder was mounted with a windshield to block wind noise. A-weighted sound pressure level (L_{Aeq}) were recorded in 3 min. For laboratory experiments, the recordings were edited in Audacity and then a 32-s aural recording sample of sounds was excerpted from the aural recording. The analysis of four psychoacoustic metrics including loudness (N), sharpness (S), fluctuation strength (Fls.), and roughness (R) was performed through Artemis (Head Acoustics) Software to identify sounds at each site. The characteristics of each site are presented in Table 1.

2.3. Visual Stimuli

Visual stimuli of wind parks based on the selected sites were created using Unity 3D, which is a cross-platform game engine and can build virtual scenarios for mobile devices. The model of the area and the wind turbines (height: 103m, the diameter of rotor: 105m) were modeled and textured using the 3ds Max modeling software. Both the auditory and visual components of the scenarios were uploaded to make the virtual environment as realistic as possible. The duration and loudness of sounds were normalized before being imported into Unity 3D. This simulation considers visualization of the built environment and the ground of the area and allows head tracking with the aid of a smartphone and a Google Cardboard headset. Sounds and scene view move in an immersive 360-degree as the head moves. This VR technology ensures participants experience a high realistic simulated environment (Rafiee et al., 2018).

2.4. Experimental design

The primary purpose of our laboratory experiments is to investigate the ambient soundscapes on the perception of the wind park environment. The experiments consist of three parts: 1) visual-only condition, 2) aural-only condition, and 3) combined aural-visual condition. In total 21 stimuli (3 conditions* 7 sites) were created.

In the laboratory experiments, a total of 40 university students (Mean age: 26.8 years, standard deviation: 3.4 years) participated in the study of the perception of aural-visual stimuli in laboratory experiments. All participants had normal hearing and regular or corrected to normal vision, had no prior experience with wind parks and all were naive as to the purpose of the experiment.

Participants were asked to rate their annoyance scores and acceptance of the wind park on each stimulus using a 7-point Likert scale from “not at all” to “extremely” (1 = “not at all”, 2 = “low”, 3 = “slightly”, 4 = “neutral”, 5 = “moderately”, 6 = “very”, and 7 = “extremely”). The preference test, semantic differential (SD) technique, was suggested by previous studies used as a method for connecting public’s feelings at linguistic and psychophysical levels towards sounds and characterizing the soundscape (Cain et al., 2013; Kang and Zhang, 2010). In order to evaluate SD scales of a soundscape in considering the components found in existing studies, 10 pairs of bipolar adjectives (pleasant/unpleasant, various/monotonous, quiet/loud, smooth/rough, calming/agitating, comfortable/uncomfortable, open/closed, natural/artificial, ordered/disordered, and distinct/ordinary) rated on a 7-point scale were selected (Hong and Jeon, 2013; Nilsson et al., 2012; Torija et al., 2013). Finally, socio-demographic questions were recorded, which includes attributes (“Gender”, “Age”). See also in Table II.

Participants evaluated each stimulus under aural only, visual only, and aural-visual conditions. They were allowed to replay stimuli as many times as wanted to answer the questions. Each stimulus lasted approximately 32 s, and the testing order was randomized under each perceived condition.

Each participant was tested individually. During the experiments, participants sat in a quiet room (< 40 dB) wearing a Google Cardboard headset with an embedded mobile device. The center points of the scenarios were aligned on the mobile device as represented by Unity 3D. Acoustic stimuli were delivered through the headphones (Sennheiser HD 598) plugged into the mobile device. The test sound level and the on-site recorded one were closely identified with each other as determined in Table I before the start of testing. All testing procedures were carried out between 10:00 and 14:00 h in a quiet room, to avoid any effect of circadian rhythm.

3. Results and discussion

The general aim of this study was to investigate the ambient soundscape on the perception of a wind park. An aural-visual preference survey to investigate the effects of background sounds and non-aural factor on the perception of wind parks and their interaction was used. As described before,

the present study examined subjective responses to aural only, visual only, and combined aural-visual stimuli. In the following, the analysis of the subjective responses is conducted. The semantic analysis of the descriptions of the sounds, the correlations between the preferences of wind parks, and sound level characteristics are provided below.

TABLE II Index overview of the evaluated variables, the questions, and their scales

Index	Indicator
Perception Question (P)	
P1	Perceived annoyance in the stimuli (Scale: 1-7, from “not at all” to “extremely”)
P2	Preference score for the aural stimuli (Scale:1-7)
P3	Perceived realism of the stimuli (Scale: 1-7, from “not at all” to “extremely”)
P4	Acceptance with the integration of a wind turbine in the stimuli (Scale: 1-7, from “not at all” to “extremely”)
Semantic Differential Test (SD)	
SD1-SD10	10 pairs of bipolar adjectives: pleasant-unpleasant, various-monotonous, quiet/loud, smooth/rough, calming/agitating, comfortable/uncomfortable, open/closed, natural/artificial, ordered/disordered, distinct/ordinary. (Scale: 1-7, from “not at all” to “extremely”)
Socio-Demographic Questions (D)	
D1-D4	Gender, Age

3.1. Effects of sound level on wind parks preference

3.1.1.Sound level characteristics

First, a median test was performed to determine the reliability of the differences between the perceived annoyances at each site. The result shows a significant difference for the investigated sites [$\chi^2(6, N = 40) = 41.74; p < 0.001$]. Second, a correlation analysis to determine the background sound characteristics with the perceived aural annoyance was applied under aural-visual condition. According to the results, a strong correlation between the perceived sound, the sound characteristics including the measured sound pressure level ($p < 0.01$), loudness ($p < 0.05$), fluctuation strength ($p < 0.05$), and roughness ($p < 0.01$) were found. Finally, the correlation coefficients with sound characteristics were calculated and presented below (Table III).

This shows that loudness explained the most variance (81%), compared to sharpness (52%), fluctuation strength (60%), roughness (80%), and measured sound pressure level (74%). It was suggested that the aural annoyance was getting worse as the increase of the sound level of ambient sound at wind park sites.

TABLE III The percentage of explained variance calculated using the correlation coefficient between the perceived annoyance and background sound characteristics. N: loudness; S: sharpness; F: fluctuating strength; R: roughness; L_{Aeq} : A-weighted sound pressure level.

Sound characteristics vs. perceived annoyance	Explained variance R^2
N	0.81
S	0.52
FIs.	0.60
R	0.80
L_{Aeq}	0.74

3.1.2.Dominant sound information

In order to further examine how background sound information influences aural-visual wind park environment, overall preference score was compared between the visual only and mixed aural-visual conditions. Average general preference scores under these three stimuli conditions were illustrated as shown in Fig. 1. The ANOVA on annoyance rates were performed for each condition. According

to our analysis, the differences in the mean annoyance rates between the visual only and aural-visual conditions at site 01, site 02, site 05, and site 06 were statistically significant (Fig. 1). There was a significant difference in preference score when aural information was added. The sounds at site 01 and site 02 were considered as least preferred and most preferred one. The annoyance scores for the aural-visual stimuli increased at site 01 and decreased at site 02 regards the visual-only stimuli. At site 01 the dominant mechanical sounds may cause an adverse effect on the preference. On the contrary, at site 02 the dominant natural sounds may decrease the annoyance. At site 05, the aural input of human activities increased the annoyance for participants. The reason was that, where human activities took place nearby, allowance for any wind parks will be decreased. At site 06, the noise of traffic enhances the general annoyance score.

The results indicate that the sounds influence the annoyance a lot. The addition of natural sounds (birds sounds) may increase the preference of the wind parks environment by a score of 0.75, the addition of mechanical sounds (traffic sounds) and anthropogenic sounds (human sound) may decrease the preference of the wind parks environment by a score of 2.73 and 0.65. For preference of wind parks under the aural-visual condition with dominant natural sounds would be the most preferred. For preference of wind parks with dominant mechanical sounds would be the least preferred.

3.1.3.Human sounds

To evaluate the level of acceptance of wind parks with different background sounds, the acceptance level of wind parks with the aid of the aural and visual stimuli was rated. The acceptance scores were illustrated under visual and aural-visual conditions at each site (Fig. 2). All of the investigated sites were considered as a highly accepted area for wind parks except site 04 and site 05 where human sounds and activities happened nearby.

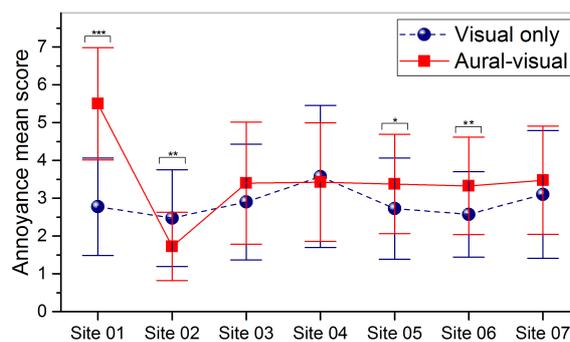


Fig. 1. Annoyance scores under visual only and aural-visual conditions at each site, where site 01 was rated as the most annoyed one and site 02 was rated as the least annoyed one under the aural-visual condition. Error bars depict standard error values (** = $p < 0.01$, ** = $p < 0.01$, = $p < 0.05$).

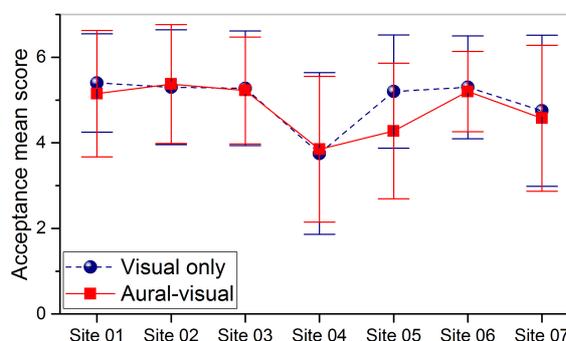


Fig. 2 Acceptance of wind parks under visual only and aural-visual conditions at each site, where site 01 was rated as the most annoyed one and site 02 was rated as the least annoyed one under the aural-visual condition. Error bars depict standard error values.

Wind park projects should be limited to be planned in the leisure sites for human beings.

Although, wind energy was a renewable energy, which can bring the clean energy for human beings. Regards to its intrusion to the landscape and communities, this study suggests that planning of wind parks must be restricted near areas of human activities.

3.2. Effects of visual information on wind parks preference

In order to study the relation between vision and the subjective measures, analysis of aural annoyance between aural-only and aural-visual conditions was performed. The aural annoyance scores at each site averaged across all subjects were illustrated in Fig. 3. The result showed that the most perceived sound was site 02 with birds sound, whereas site 01 with high traffic sound was the least preferred (Fig. 3). Under the aural-visual condition, participants mostly dislike site 01 including the high way sound, with a mean annoyance score of 5.5 (SD of 1.48). Compared to that, the mean annoyance score for site 02 with birds sound was 1.7 (SD of 0.9). The related annoyance scores for site 03, 04, 05, 06, and 07, are 3.4, 3.42, 3.38, 3.33, and 3.48, respectively. Overall, their annoyance scores remained similarly. Finally, it was suggested that there are no significant differences between aural-only and aural-visual conditions at each site ($P > 0.05$).

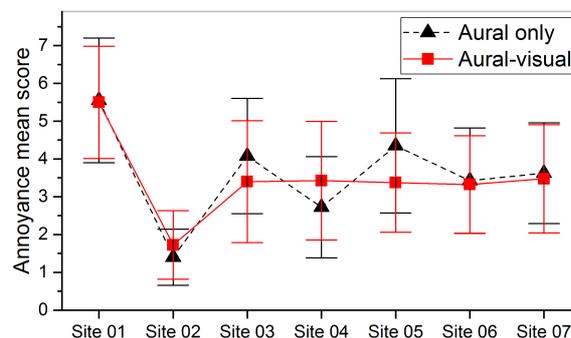


Fig. 3. Average ratings of the aural annoyance at each site under aural only and combined aural-visual conditions, where site 01 was rated as the most annoyed one and site 02 was rated as the least annoyed one. Error bars depict standard error values.

The annoyance of wind parks was mostly on the sound levels of the simulation. The negative impacts of wind parks may depend on either the ambient natural or mechanical elements. Furthermore, according to the ANOVA analysis, no significant effect was observed for the annoyance scores and the number of wind turbines. The number of wind turbines may not affect the preference of wind parks at a distance of more than 1 km.

3.3. Analysis of soundscape on multidimensional scales

For the purpose of evaluating the key factors which characterize the soundscape around wind parks on multidimensional scales, the SD technique was used. Ten semantic descriptors were selected. Factor analysis of overall results under the condition of aural-visual was carried out to classify the ten semantic descriptors. The method of varimax rotation was selected to extract the orthogonal factors. The criterion factor of eigenvalue was set greater than 1. In total, three factors were determined, as shown in (Table IV). Factor 1 (42.4%) is mainly associated with “calmness/relaxation” which was suggested by previous researchers (Sudarsono et al., 2016), including “smooth/rough,” “distinct/ordinary,” “quiet/loud,” “ordered/disordered,” “comfortable/uncomfortable,” and “calming/agitating.” Factor 2 (15.6%) can be associated with “naturalness/pleasantness,” including “open/closed,” “natural/artificial,” and “pleasant/unpleasant.” Factor 3 (11.4%) is associated with “various/monotonous,” composing “various/monotonous.” These three factors cover the main facets of designing the acoustics of a landscape region. The soundscape quality around wind parks correlates well with the attributes.

After multiple regression analysis, the results demonstrated the dominant factors which best explain the influence of the perception of wind parks in the landscape with different ambient sounds. Furthermore, through Pearson’s correlation coefficients, the relationships between these factors and sound level characteristics were identified (Table V). Regarding factors obtained under the aural-visual condition, it was indicated that “calmness/relaxation” was related to the acoustic characteristics of the loudness and fluctuation strength, as well as annoyance. Additionally, the “naturalness/pleasantness” was related to the loudness, roughness, and annoyance. Both “calmness/relaxation” and “naturalness/pleasantness” showed a significant correlation with annoyance, which implies the importance of the “calmness/relaxation” and “naturalness/pleasantness” in the perception

of wind parks. Finally, there was no correlation between “diversity”, acoustical metrics and annoyance.

TABLE IV Factor analysis of semantic descriptors under the condition of aural-visual. Kaiser-Meyer-Olkin measure of sampling adequacy: 0.725; cumulative 69.487%. Rotation method: varimax with Kaiser Normalization; N= 40.

Component	Factor 1 (42.4%)	Factor 2 (15.6%)	Factor 3 (11.4%)
Smooth	0.874		
Distinct	0.858		
Quiet	0.841		
Order	0.692		
Comfortable	0.679		0.468
Calming	0.659	0.451	
Open		0.836	
Natural		0.695	
Pleasant	0.458	0.601	
Various			0.919

TABLE V Pearson’s correlation coefficients between the selected sound metrics (** = $p < 0.01$, * = $p < 0.05$).

Factor	Psychoacoustic metrics			L_{Aeq}	Annoyance	Semantical factors		
	Sharpness	Fluctuation strength	Roughness			Calmness/relaxation	Naturality/pleasantness	Various/monotonous
Loudness	0.948**	0.889**	0.946**	0.842*	0.898**	0.841*	0.790*	0.561
Sharpness		0.859*	0.842*	0.693	0.718	0.633	0.577	0.454
Fluctuation strength			0.881**	0.587	0.777*	0.756*	0.672	0.294
Roughness				0.812*	0.896**	0.916	0.843*	0.571
L_{Aeq}					0.859*	0.782*	0.794*	0.431
Annoyance						0.964**	0.971**	0.593
Calmness/relaxation							0.983**	0.644
Naturality/pleasantness								0.622

4. CONCLUSIONS

Investigating how new infrastructure projects, such as wind parks impact the quality of people living, is an essential factor in the landscape planning. Various factors need to be defined and indecently investigated regards the case of wind parks. In this study, the aural-visual simulation was used to evaluate soundscapes ambient wind parks without taking into account the noise of wind turbines. The background sounds and non-aural factor on the perception of wind parks and interaction between the aural and visual information were investigated.

According to the results, the background sound characteristics including sound pressure level, loudness and roughness were strongly correlated with the perceived annoyance of wind parks. The aural information played a significant role in the preference of wind parks. The addition of bird sounds had a positive effect on the preference of wind parks. However, the addition of human sounds, traffic sounds, or water sounds ambient wind parks might decrease preference of the

landscape. Additionally, the ratings of acceptance of wind parks demonstrated a high level of agreement for wind park projects and suggested a limitation of wind parks in the sites where human activities took place nearby. Furthermore, no significant correlation was achieved between visual information and annoyance scores. The visual information may not affect the preference of wind parks at a distance of more than 1 km.

At last, the analysis of the soundscape on multidimensional scales indicated the importance of the “calmness/relaxation”, “naturalness/pleasantness”, and “diversity” on the preference of the environment around wind parks. Among them, factors of “calmness/relaxation” and “naturalness/pleasantness” were strongly correlated with background sound metrics including loudness, fluctuation strength, roughness, sound pressure level, and perceived annoyance. The soundscape has a significant role in the evaluation of wind park landscapes. For a more reasonable acoustic environment within the context of landscape planning, the soundscape should be further considered and studied in future research.

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