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The influence of vision on noise annoyance evaluation of wind farms

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Abstract

The noise impact assessment of new infrastructures is strongly correlated with the environmental context where they are built in. The observers are influenced mainly by two types of stimuli: audio and visual. These stimuli are perceived simultaneously and both contribute to the noise impact annoyance. Different studies have found out that the visual stimuli, such as colour and movement, can influence the auditory perception (e.g. loudness).

Although for wind farms the noise impact evaluation could be not so significant if it is observed only from the acoustic point of view, the vision of the wind farms can modify the global judgement.

The aim of this study is to determine the contribution of some visual factors on wind farm noise perception and annoyance. In a laboratory test four types of visual factors (quantity of turbines, colour difference of rotor blades, rotor speed and wind turbine form) graded at different levels and the wind turbine noise were used as stimuli. They were presented to a sample of people who were then asked to assess the quality of noise through self-report questionnaires. The results of the influence of the visual factors on noise assessment are presented and discussed.

Introduction

In the last decades, concerns about climate change have oriented the worldwide energetic policies toward the installation of a large number of renewable energy power plants. However the construction of wind farms has raised up some environmental impact problems. For wind farms, environmental impact problems are caused, mainly, by the combination of physical (visual and audio) aspects such as the noise, the blinking effect, the movement of shadows and the change of landscape, but also from wildlife preservation aspects.

Regarding environmental noise impact of wind turbine, studies report that wind turbine noise could be more annoying than other types of noise, with equal sound

levels [1-3]. In such cases, noise metrics become more and more inadequate to define noise annoyance which is a psychophysical phenomenon. It requires understanding on the context of the sound source. Contextual approach on noise annoyance lets to reveal the relative contradictions in specific environments, regarding physical and individual factors.

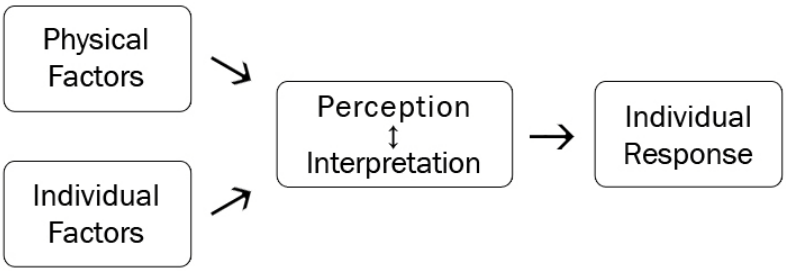

Figure 1. General scheme of environmental perception.

Wind farms are usually built in rural areas where people are more sensitive for new interventions because of the existence of conserved natural values, like calmness, recreational activities, landscape scenery, etc.. For this reason wind turbines generally cause a stronger intrusion on physical environment and a stronger disparity with individual's expectations, which can modify the global judgement of people in terms of noise annoyance [4,5].

The physical factors that contribute on noise annoyance caused by WT include audio and visual variables such as: sound level, timbre, temporal characteristics and visibility, geographical distribution, colour, movement, etc. On the other side individual factors are related to the personal sphere such as the attitude toward green energy, the degree of involvement in the project and the economic benefits from wind turbines [1-7].

These multifaceted factors refer to the multisensory and interdependent nature of human perception. The multisensory integration can determine enhancement or depression of subjective response according to the spatial and temporal relationships of the stimuli as well as their physical parameters [8]. Several studies have investigated the contribution of single visual variables on loudness and noise perception [9-12]. Others use a more realistic laboratory test based on Immersive Virtual Reality systems [13-14].

The aim of this preliminary study is to investigate the contribution of some visual factors on wind farm noise perception and annoyance.

Methodology

In order to determine the contribution of some of the most important visual aspects, on wind farm noise perception and annoyance, a preliminary test was conducted in the Ri.A.S. laboratory of the Second University of Naples. The simulations were prepared by manipulating certain audio and visual variables from an existing situation

taken as reference. The reference situation concerns the wind farm of “S. Giorgio la Molara” in Campania (Italy).

Audio-visual simulations were presented and assessed by each subjects through self-report questionnaires. The laboratory experiments were carried out on 33 participants (19 males and 14 females, mean age= 22.6 years, S.D.= 5.8) in the anechoic chamber of the Ri.A.S. laboratory. The sample was composed by the 73% of participants who live in urban area, while the 21% in peripheral zones and 6% in rural areas. All the participants reported normal hearing and regular or corrected to normal vision.

Simulations

A recreational area in the wind farm zone of “S. Giorgio la Molara” was chosen and used as starter model for the audio-visual simulations. In this area a representative field of view (FoV) was chosen as landscape of the recreational area. The FoV includes 3 wind turbines with lattice towers (55m hub height and 46m rotor blades diameter). The average wind turbines distance from the point of sight was about 500m (Figure 2, 3).

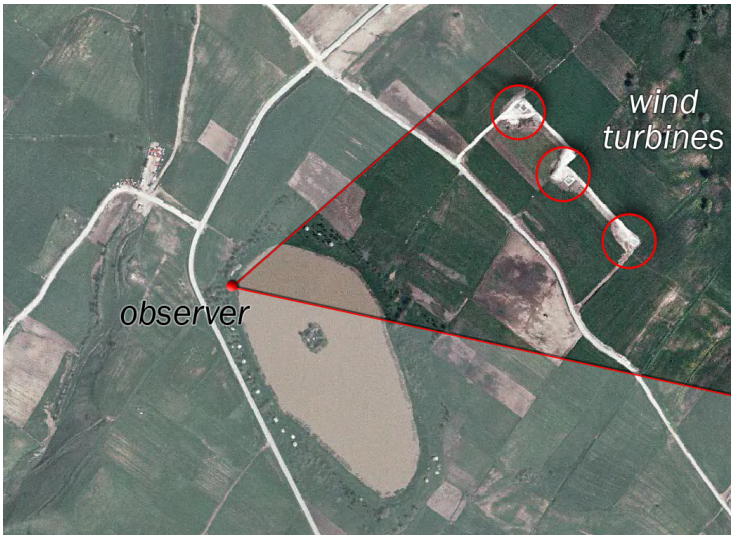

Figure 2. “S. Giorgio la Molara” Wind Farm: field of view chosen for the test.

The mentioned scenery was photographed in autumn on a sunny and almost unclouded day to maximize the visibility of the field. One photo (Figure 3) of the site was chosen as model for the reference scenario (existing situation). This photo was manipulated to have various simulated scenarios with different wind turbine layout and different wind turbine visual characteristics.

The variables of manipulation consist of 4 categories:

- quantity of wind turbines (Q);
- colour of rotor’s blades (C);

- rotor speed (V);
- wind turbine form (F).

Figure 3. Photo used as starter model for the simulation.

Fifteen different scenarios were designed. Each scenario was manipulated by the variation of one variable (Q, C, V or F) respect to the existing scenario. Moreover another scenario representing the non-existence of any wind farm in the area was prepared. The simulations (Figure 4) were prepared with the help of a digital photo editing *software* and afterwards an animation creation tool. The prepared scenarios were exported as a 30 seconds video file (1440 x 1080 pixels resolution and 29 fps frame rate). On the other hand for the audio stimuli of simulations, monoaural audio signals (16 bit/44.1 kHz) were recorded and 3 different tracks were chosen to be coupled with the prepared video simulations.

The table of the simulations is reported in table 1.

Figure 4. Some of the prepared wind farm simulations.

Table 1. Tables of the simulated scenarios (*1*: lattice tower-55m hub height-46m rotor diameter, 2*: monopole tower-55m hub height-46m rotor diameter, 3*: monopole tower-105m hub height-72m rotor diameter, 4*: monopole tower-55m hub height-72m rotor diameter).*

Scenario n.	Description	Visual Factors			
		Rotor Speed *V* (rpm)	Quantity of WT *Q* (n.)	Rotor Blade Colour *C*	WT form *F*
1	nonexistence of WF	-	0	-	-
2	existing situation	30	3	white	1*
3	rotor speed variation	0	3	white	1*
4		18	3	white	1*
5		38	3	white	1*
6	quantity of WT variation	30	1	white	1*
7		30	2	white	1*
8		30	4	white	1*
9		30	5	white	1*
10	rotor blade colours variation	30	3	grey	1*
11		30	3	purple	1*
12		30	3	red	1*
13		30	3	yellow	1*
14		30	3	azure	1*
15	WT form variation	30	3	white	2*
16		30	3	white	3*
17		30	3	white	4*

Questionnaire

Individual noise subjective reactions to the audio-visual scenarios were assessed with a questionnaire that consists of three parts: audio related, visual related and global assessment.

In audio part of the questionnaire the degree of loudness and the noise annoyance was evaluated with two continuous rating scales. The subjects were asked to respond also to a 7 point semantic differential scale of 18 bipolar pairs of adjectives and to 2 pairs of positive-negative rating scale.

In visual related part the subjects were asked to indicate the visual elements, that have attracted his/her attention, and the level of pleasantness/unpleasantness of the mentioned elements, to understand the influence of each simulated component in presented scenarios. At the end a complex judgment on the scenario was also asked.

Instrumentation and experimental procedure

For the presentation of video stimuli a 30” TFT LCD monitor (Dell 3007WFP) was employed and concurrently the subjects are asked to listen to audio stimuli with circumaural headphones (Pioneer SE-M290).

Each of the prepared 17 visual scenarios were coupled with each of the three chosen audio tracks (17visual x 3audio = 51audio-visual scenarios).

The “existing situation” and “nonexistence of WT” scenarios were presented to each subject with all 3 sound track (6 audio-visual scenarios) while, in order to have a reasonable experiment duration only 15 random audio-visual scenarios were presented. Then audio-visual test, consisting of a total of 21 scenarios for each subject, lasted about 40 minutes, including the instructions provided by the

experimenter at the beginning. After each scenario, to the subjects was asked to assess the presented audio visual scenario (Figure 5).

Figure 5. Laboratory test

Results and analyses

To assess the role of visual factors (Q, V, C and F) on the noise perception, the subjective scores difference for loudness and noise annoyance between the manipulated scenarios and the existing situation were considered as dependent variable. The differences were indicated as Relative Perceived Loudness and Relative Noise Annoyance. Negative scores point out a more positive assessment of the manipulated scenario, while positive scores point out a more negative assessment respect to the existing situation. Relative Perceived Loudness and Relative Noise Annoyance scores were analyzed by different 3 x n mixed factorial design ANOVAs using as 3-level *between* factor the sound level (Low: 51,8 dBA, Medium: 56,5 dBA and High: 62,4 dBA) while as n-level within factors: Q (n=4), V(n=3), C(n=5) and F (n=3).

Considering the Relative Perceived Loudness the results show the significance of the effect *Sound Level* × *Quantity of WT* ($F[6,90] = 2.777$, $p = .016$), of the effect Sound Level × Rotor Blade Colour ($F[8,120] = 2.030$, $p = .048$) and of the effect *Sound Level* × *Rotor Speed* ($F[4,60] = 10.384$, $p < .001$). No significant effects were observed for the wind turbine form.

Table 2. Average scores of Relative Perceived Loudness between manipulated and existing situation (Q3).

	Quantity of WT			
Sound Level	**Q1**	**Q2**	**Q5**	**Q9**
Low (51.8 dBA)	-10.91^{a}	-11.82^{a}	6.82^{b}	-1.36^{ab}
Mid (56.5 dBA)	2.27^{ab}	6.36^{ab}	-4.55^{a}	10.91^{b}
High (62.4 dBA)	-3.64^{ab}	10.45^{a}	-7.73^{b}	-5.45^{b}

Note: *Equal letters indicate equal means.*

Table 3. Average scores of Relative Perceived Loudness between manipulated and existing situation (white rotor blades).

	Rotor Blade Colour				
Sound Level	**Grey**	**Purple**	**Red**	**Yellow**	**Blue**
Low (51.8 dBA)	-6.82[a]	5.00[a]	-5.45[a]	-7.73[a]	2.27[a]
Mid (56.5 dBA)	5.45[a]	-1.82[a]	7.27[a]	2.73[a]	-1.36[a]
High (62.4 dBA)	11.36[a]	11.36[a]	-7.73[b]	8.64[ac]	-5.91[bc]

Note: Equal letters indicate equal means.

Table 4. Average scores of Relative Perceived Loudness between manipulated and existing situation (rotor speed 30 rpm).

	Rotor Speed		
Sound Level	**0 rpm**	**18 rpm**	**38 rpm**
Low (51.8 dBA)	2.73[a]	-34.09[b]	-20.00[ab]
Mid (56.5 dBA)	-47.27[a]	-40.00[a]	-1.82[b]
High (62.4 dBA)	-59.09[a]	2.45[b]	-32.73[c]

Note: *Equal letters indicate equal means.*

Considering the Relative Noise Annoyance the results showed no significant effect for quantity, rotor blades, and colour factors, while a significant effect was observed for *Sound Level* × *Rotor Speed* ($F[4,60] = 7.747$, $p < .001$).

Table 5. Average scores of Relative Noise Annoyance between manipulated and existing situation (rotor speed 30 rpm).

	Rotor Speed		
Sound Level	**0 rpm**	**18 rpm**	**38 rpm**
Low (51.8 dBA)	3.18[a]	-19.55[ab]	-30.00[b]
Mid (56.5 dBA)	-41.36[a]	-48.18[a]	-10.45[b]
High (62.4 dBA)	-43.64[a]	6.36[b]	-34.55[a]

Note*: Equal letters indicate equal means.*

The results showed also a significant main effect of the *WT Form* ($F[2,60] = 4.435$, $p = .016$), while both the *Sound Level* × *WT Form* ($F[4,60] = 0.576$, $p = .681$) and the main effect of *Sound Level* ($F[2,30] = 1.541$, $p = .231$) were not significant.

Table 6. Average scores of Relative Noise Annoyance between manipulated and existing situation (*lattice tower-55m hub height-46m rotor diameter*).

Sound Level	Form		
	Monopole tower 55m hub height 46m rotor diameter	Monopole tower 105m hub height 72m rotor diameter	Monopole tower 55m hub height 72m rotor diameter
Low (51.8 dBA)	-6.18[a]	0.45[b]	-5.91[a]
Mid (56.5 dBA)	-3.64[a]	10.91[b]	-9.55[a]
High (62.4 dBA)	-4.55[a]	2.73[b]	-7.73[a]
Total	-4.24[a]	6.21[b]	-9.24[a]

***Note**: Equal letters indicate equal means.*

Conclusion

Most authors indicate interactions between physicals and individuals factors on noise perception. However the role of some physical aspects on noise perception has to be more investigated. In this preliminary study the effect of some physical factors of Wind Farm's scenarios were investigate. A part of the results of this preliminary study on noise perception was elaborated in terms of subjective score differences respect the existing situation (Relative Perceived Loudness and Relative Noise Annoyance).

The results of ANOVAs, show that the combination of quantity (Q), rotor blades colour (C) and rotor speed (V) with different sound stimuli play a significant role of the Relative Perceived Loudness, while has no effect the form (F). On the other hand the combination of rotor speed with different sound stimuli, as well as the form of rotor, plays a significant role of the Relative Noise Annoyance. No effect results from quantity, rotor blades colour.

Further tests and analyses should be organized for a more deep understanding of the specific contribute of all the factors involved with noise perception.

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