Implications of wind power generation: exposure to wind turbine noise

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Abstract

The current study aims at analysing the perception and opinions of people exposed to Wind Turbine (WT) noise. Noise measurements were carried out in a wind farm in the north of Portugal. Data were analysed and crossed with the answers to a survey applied in four nearby villages. Although the noise levels were generally low, it was found that the direct visibility of the WT makes people feel more annoyed and also more sensitive to noise. Finally, it seems that the economic interests that exposed people may have in WT did not significantly affect their annoyance. Noise annoyance perception rather seems to be related to specific aspects, such as the general opinion of people about wind power generation.

1. Introduction

In 2010, Portugal established its national strategy for energy (the so-called ENE 2020), whose main goal was to reinforce the country’s leadership in energy sustainability up to 2020. Accordingly, the National Action Plan for Renewable Energy considers the commissioning up to 2020 of 1,742 MW for all renewable power sources (totalling 8,779 MW)(DGEG, 2012), of which wind power will represent 5,300 MW (circa 60.4%). As by the end of 2011 the existing wind power capacity was 4,351 MW, this means 949 MW will be installed until 2020.

The installation of wind turbines (WT) has consequences in land occupation, as well as at other levels. Amongst these, the effect of noise in human health is paramount. WT noise can be easily perceived (and be a nuisance) even for low sound pressure levels, making it generally incongruous with background noise (Pedersen, 2007).

The effect of WT noise in human health, especially for medium and long periods of exposure has been the object of various studies. Some of these studies highlight the fact that approximately 75% of the people that oppose the installation of WTs consider noise as one of their major worries (Krohn & Damborg, 1999). A recent research by

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Shepherd et al. (2011), in New Zealand, refers that the populations exposed to WT noise reported a lower sleep quality and considered their environment less restful.

Some people that live near wind farms report a variety of negative symptoms that, in certain cases, are sufficiently serious to force them to abandon their residences. Amongst these symptoms, sleep disturbances, headaches, concentration difficulty, irritability, tiredness and auditory system related problems are often mentioned (Salt & Hullar, 2010). However, in the literature there is also evidence that the various nuisances due to perceived noise do not correlate well with its actual level. In fact, those nuisances are often ascribed to other causes, such as a generic negative public opinion towards WTs (Krohn & Damborg, 1999) and their visual impact (Tsoutsos et al., 2009), or to the reflexes caused by the rotor blades or even to their shadows (Pedersen & Waye, 2004). Conversely, the effects can be mitigated if the respondent has an economic interest in the existence of the wind farms (Pedersen et al., 2009).

However, even when the individual perception of noise is determined by extraneous factors, it should not be taken lightly. On the contrary, a wider understanding of the noise impacts occurring in the wind energy sector may help to minimize negative attitudes towards specific wind farm projects (Krohn & Damborg, 1999).

In the present preliminary study we address this problem, by measuring the physical characteristics of the sound generated by the turbines of a wind farm in the north of Portugal and crossing the data with the answers to a questionnaire. Both the measurements and the questionnaire, which contemplates most of the situations mentioned above, were applied in different locations in four chosen villages in the immediate vicinity of the farm.

2. Methodology

2.1. Data collection procedures

Considering the abovementioned factors, the planned research was done according to the following protocol:

1) To characterize the location of wind farms relatively to nearby populations; this characterization should be based on a specific typological classification, considering, amongst other factors, the visibility of the turbines;

2) To make direct sound pressure level (SPL) measurements in the selected areas, with a view to assess the acoustic impact of the wind farms, including the monitoring the sound levels in different periods of the day;

3) To elaborate a questionnaire on noise perception based on those previously developed by Pedersen and Waye (2004), properly adapted to the Portuguese situation and to apply it to the residents of chosen villages.

The case study reported herein was carried out in the Fafe High Land (TerrasAltas de Fafe) wind farm in the north of Portugal. This farm is located in the municipalities of Fafe and Celorico de Basto, in a mountain area, 851 metres height in average. The farm is composed of 53 WTs, corresponding to a 106 MW total installed capacity. The annual production is estimated at circa 210 GWh (for an equivalent of 2,000 hours of full load/year). The turbines are all dimensionally identical, with a 67 metres height tower and a rotor diameter of 87 metres.

2.2. Sound measurements

The sound measurements were carried out in villages the Campo Diantheiro (CD), Lagoa (L), VárzeaCova (VC) and Vila Pouca (VP), all in the immediate vicinity of the wind farm. Measurements were done in two different locations in each village, corresponding to a “higher” and a “lower” point (as most of the villages have a steep topography) using a sound level meter Bruei&Kjaer model 2260 type 1, equipped with a tripod. The equipment was positioned at a 1.2 m of height from the ground and no closer than 4.0 m from any façade, in order to avoid the reflection effect. For each measurement location, the L_Aeq was registered considering a 5 minutes measurement period, during which the background noise was continuously monitored with the aim of avoiding the inclusion of “external” relevant noise events. When one such event occurred, as for example, the sudden barking of a dog or the passing nearby car, the measurement was stopped and the event eliminated. During the noise measurements the wind speed was also assessed and registered and found to be consistently low, i.e., less than 2 m/s. It is also
important to highlight that some sporadic impulsive characteristics were sometimes detected, mainly from the-existent background noise, which seemed not to affect the wind turbines registered overall SPLs.

2.3. Questionnaire

The questionnaire was organized in two sections with distinct types of questions. In Section I they aimed at masking its intentions and at knowing how the respondents reacted to their environment. In section II the questions were directed to the perception of WT noise.

When the questionnaires were presented to the inhabitants of the above localities there were some difficulties. In fact, most of the inhabitants were old people, a few almost illiterate, which had serious difficulties in understanding the questions. As a consequence, only some questionnaires were directly answered. In the majority of the cases it was necessary to read and explain the questions, in a very simple way, so that people could understand it. In other cases, to overcome the initial interaction difficulties, it was even necessary to present the questions in an informal way, similarly to a structured interview.

2.4. Statistical analysis

Data resulting from the questionnaire was analysed statistically using SPSS (Version 19), through which several analyses were made, including the descriptive analysis of the various dependent variables considered (indoor and outdoor nuisance, and sensitivity to noise). It was also applied to test means’ differences between dichotomous categories, using the Levene’s test for the equality of variance. One-way ANOVA was employed to test the effect on variables with multiple categories. Correlations were also analysed using the Spearman’s correlation coefficient. In all tests, the results were considered to be statistically significant at \( p < 0.05 \) level.

3. Results and Discussion

The results of the sound measurements are synthesized in Figure 1. Noise measurements were carried out at eight different locations, designated by the initials of the village name followed by high and low (2 points in each village). According to Figure 1, it is possible to conclude that the sound pressure levels from WTs are relatively low, when compared with those reported in other studies. It should be noted that it is possible that these values were somehow affected by the weather, as most of the measurements were made during summer and, as mentioned above, with low wind speeds. The measurements were also done at different distances from the turbines, depending on the specific location of the village under study.

![Figure 1. Sound measurements data in the different locations.](image)

As mentioned earlier, most of the results of this work were based on a questionnaire. Due to the length limitation imposed on this manuscript, data were only analysed for some variables. The main idea was to examine the relationship between some aspects of the self-reported opinion about WTs and the corresponding noise nuisance, both in outdoor and indoor activities. The first analysis considered the reported nuisance and noise sensitivity and their possible relationship with the direct visibility of the WTs (see Table 1), as previously reported by other authors.
(Pedersen 2007; Waye & Ohrstrom, 2002). Noise nuisance was classified according to a scale in which 5 points corresponded to the less annoying situation (“do not notice”) and 1 point to the other extreme (“very annoyed”). The same codification was applied to the sensitivity scale, with 5 point corresponding to the option “not sensitive at all” and the maximum of 1 point to the “very sensitive” option. Accordingly, low scores on both nuisance and sensitivity mean that a specific person reports a high nuisance by noise, as well as a high sensitivity to noise.

From the data in Table 1 it is possible to verify that, as expected, people whose dwellings have direct visibility of WTs are the ones who reported a higher noise nuisance. The noise sensitivity results were similar. Nevertheless, considering the statistical test for analysing the differences between samples, it is possible to perceive that only the “nuisance when indoor” variable (with p<0.001) is statistically significant for a 0.05 level. Therefore, it can be concluded that direct visibility of WTs only affects reported noise nuisance when people are outdoor.

Another important aspect that may affect the way people report noise nuisance is their opinion about wind turbines. In the questionnaire this was assessed by asking the respondents to state their general opinion on WTs by selecting one the following options: “Very positive” (VP), “Positive” (P), “Neither Positive nor Negative” (NPN), “Negative” (N), “Very negative” (VN). Table 3 presents the corresponding results for noise nuisance in outdoor and indoor activities. In the table, “N” corresponds to the number of respondents, “Mean score” to the average of ascribed nuisance scores and “sd” to the standard deviation. According to the results in Table 2, it is also possible to conclude that, both for indoor and outdoor activities, people who have a favourable opinion about WTs tend to report that they are less annoyed by noise.

Table 3 depicts the results of the statistical test ANOVA applied to the above data. According to this test, the variation between different categories of opinion is statistically significant at a p<0.05 levels for noise nuisance, both for outdoor activities (p<0.001) and indoor activities (p=0.001). To contextualise this data, it should be mentioned that during the application of the questionnaire (interview) the researchers had the opportunity to verbally explore and detail some of the opinions of the respondents.

According to these unstructured registries, it was possible to notice two main factors that seemed to affect people’s opinion on WTs and the impact of their noise. The first factor is the feeling that, despite the reported nuisance, wind generated energy is a clean and green option, thus with much more appeal from a societal point of view. Accordingly, they seemed to be “proud” of having such a technological development in their “backyard”. The second factor is related to the belief that WTs brought some economic activity to the region. In fact, they were convinced that, since their construction, the villages were more visited by groups of people somehow interested in them. Local commercial activities were quite stimulated by those visitors, which they consider as a general benefit, even if indirect.

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### Table 1. Noise nuisance and sensitivity as a function of WT visibility

| Variable                        | WT direct visibility | Mean score | Standard deviation | t-test (p value) |
|---------------------------------|----------------------|------------|--------------------|-----------------|
| Noise nuisance when outdoor     | Yes                  | 2.91       | 1.40               | <0.001*         |
|                                 | No                   | 4.33       | 0.98               |                 |
| Noise nuisance when indoor      | Yes                  | 3.40       | 1.42               | 0.823*          |
|                                 | No                   | 3.50       | 1.45               |                 |
| Noise sensitivity                | Yes                  | 2.24       | 1.02               | 0.111*          |
|                                 | No                   | 2.75       | 0.97               |                 |

* Equal variances were not assumed in these cases due to the obtained results in the Levene’s test.
On the other hand, it is possible to hypothesise that people’s opinion might be influenced not only by their attitude regarding WTs but also by the specific concerns about their impact on the landscape, as reported in other studies (Pedersen & Larsman, 2008). Thus, the analysis mentioned above was also applied to verify this hypothesis, using the same scale and codification scheme as before. Table 4 presents the results of this cross-analysis.

From the results in Table 4 it is possible to conclude that, again as expected, the reported noise nuisance correlates inversely with the opinion of the respondent about the WTs landscape impact. For instance, people reporting a very positive opinion about that impact are also those with lower reported noise nuisance and vice-versa. An ANOVA statistical test was also applied to these results, revealing that the abovementioned trend is statistically significant only for the outdoor nuisance (p=0.016) (table 5). This means that, in what regards outdoors activities, people tend to be more annoyed by noise if their opinion about the impact of WT in landscape is also negative.

An additional factor that other authors have suggested may play a significant role on people’s opinion about WTs is the economic relationship with a specific WT farm or with the wind energy sector as a whole (Pedersen et al., 2009). Hence, people were also requested to mention whether they owned any WT or were (are) involved in the WT businesses. The results obtained are presented in Table 6.

| Economic interest in WT? | N | Noise nuisance outdoor | Noise nuisance indoor | Noise sensitivity |
|--------------------------|---|------------------------|-----------------------|------------------|
| No                       | 67 | 3.01                   | 3.37                  | 2.33             |
| Yes                      | 13 | 3.69                   | 3.62                  | 2.23             |
From the results in Table 6, and despite the small sample considered, it is possible to conclude that, as expected, people with economic connections to the WT's tend to feel less annoyed by their noise. In terms of noise sensitivity, the economic interest in the wind energy sector does not seem to affect people’s answers.

Globally, none of the mean differences between the two categories (with or without economic interest) were statistically significant (ranging from p=0.112, for nuisance outdoor, to p=0.738, for noise sensitivity).

Noise nuisance was also tested for the socio-demographic variables of the respondents, namely, gender, age (using age categories), educational background, and employment situation. After testing these variables it was possible to verify that none of their effects were statistically significant for noise nuisance.

4. Conclusions

According to the results obtained, and taking into consideration the limitations of this study, some preliminary conclusions can be drawn, such as the following:
- The registered background and WT sound pressure levels are relatively low, when compared with noise levels reported by other authors, with a maximum registered 5 minute $L_{eq}$ of 48.0 dB(A);
- Direct visibility of WT seems to affect the noise nuisance and sensitivity reported by the respondents;
- People who have a favourable opinion about WT tend to report that they are less annoyed by their noise.
- There is a statistically significant, direct and positive relationship between noise nuisance and the opinion about the impact of WT in landscape;
- Despite the limitation of the small sample analysed, it was verified that people with an economic interest in WT tend to feel less annoyed by noise, even though this relationship is not statistically significant;

Briefly, it should be referred that no WT noise ill health effects were detected herein and that noise annoyance perception rather seems to be related to specific aspects, such as the general opinion on wind power generation.

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