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Correlation between people perception of noise from large wind turbines and measured noise levels

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Summary

ISPRA, in collaboration with the Sapienza University of Rome, have carried out a study on perceptions, opinions and attitudes of citizens in relation to the planning, implementation and working of wind power systems. The study area has involved four municipalities in the South of Italy, including the municipality of Sant'Agata di Puglia (Foggia). The research activities have been divided in two main phases: a first phase of empirical research based on interviews, and the second phase of survey by means questionnaire distribution to a sample citizens in the above mentioned municipalities.

In particular, questionnaires have been distributed to sample citizens of Sant'Agata di Puglia at the aims to acquire piece of information on people perception of noise produced by working wind power systems. Moreover, in order to correlate the qualitative judgments resulting from this survey with the real noise impact in the interested areas, a noise measurement campaign has been carried out at two dwellings considered significant in terms of noise level exposure.

1.Introduction

This study consists in a research related to the perceptions and attitudes of local communities about installation and working of wind power plants.

Nowadays these matters have a particular relevance, especially for the signal of "ambivalence" that emerged in the public opinion against the same technology, considered both as an important contribution against the increase of the greenhouse effect decreasing the production of pollutants, and, conversely, as an additional factor of environmental and social impact or as an element for a economic speculation.

The research has interested some municipalities in the province of Foggia (Italy, Puglia Region) and it was built on two main points: the first one characterized by the use of interviews to local qualified witnesses (key informants); the second one by a survey which has involved a sample of population of the municipalities of Orsara di Puglia and Sant'Agata di Puglia. Both of these points was aimed at identifying and assessing the positive and negative aspects of wind technology considered more relevant by the local communities.

Among the possible factors of annoyance have been considered also the noise associated to the operation of the turbines, a phenomenon which also has a special meaning in relation to the rural context in which the turbines themselves are usually placed. For a deeply discussion of this topic, limited to the municipality of Sant'Agata, an area with high density of wind turbines, a survey was distributed and a noise monitoring campaign has been carried out in some dwelling near wind farms.

2. Sociological survey

2.1. The noise in the interviews As already mentioned, the sociological investigation is divided into two different parts and, at the same time, correlated each other. In fact, the *explorative* phase, mainly based on *qualitative methods* - analysis of documents, especially interviews with qualified local authorities, in reference to four common (besides the two already mentioned, also the municipality of Troìa and Faeto)[1]- in addition to its autonomous significance for the reconstruction stakeholders in the interested areas, the definitions of situations, trends, open issues and possible

[1] N°24 subjects has been interviewed, divided into three categories: a) witnesses of the "civil society", b) witnesses "politico-administrative" and c) experts in the fields and managers/developers of systems.

solutions, has allowed to focus the main concepts and dimensions to be inserted into the questionnaire for the survey; at the same time, the results of this assessment allow an additional and deeply interpretation of the interviews.
Regarding to the issue of noise produced by operational wind farms, basing on the interviews, *it does not emerge as a priority issue*. However, it is *present and highlighted as "real" and not negligible in some of them*. For example, among the witnesses interviewed, a farmer says literally that "*when the wind turbines rotate you cannot sleep and you get nervous, then the animals suffer and they hear that noise ten times more than a human being*"; a former teacher, currently farmer, living at a few hundred meters from the turbines, about the impact of noise, said of "*annoyance produced by a unusual noise*" with "*particular modulations*" that, "*because of its typical characteristic - when the wind is strong - it is not neutralized by the near conifer*"; another farmer highlights that the bigger noise is heard "*by night, just like a plane, because the turbine rotate fast*" and if the new installations are a little bit quiet, given that "*no one makes maintenance ... with the time passing a damage occur and the noise increase*"; whereas a student in electric power engineering that living in country side, near wind farms, confirm that usually "*we are subjected to noise emitted by wind turbines, even if legislation limit values are fulfilled*". All the contacted witnesses are dealing with farms activities and they are living in rural areas near wind power plants. Contrarily, an expert in this field think that "*only the old mono-blade wind turbine are noisy. In fact, with the 2,5 MW wind turbines no noise is heard*".

2.2. The survey First of all, within the considered area in the exploratory phase, we selected two municipalities to carry out the investigation. The choice was on Orsara di Puglia and Sant'Agata di Puglia, municipalities having equivalent dimensions, both with a population between 2,000 and 3,000 inhabitants (Sant'Agata's population size slightly less than the other one but with more land area) and with a direct, although diversified, experience with wind technology. Sant'Agata, starting even before Orsara to install wind farms (the first plant has been connecting to the network since October 1997), is mainly characterized by the improve of wind power installed during the late years and it has reached the 170 MW.
The data collection was carried out through a *semi-structured questionnaire*, used under *self-filled in questionnaire*, with delivery and direct withdrawal by the research staff, addressed to a representative sample of the local population. The reference population for the sampling of the entire selected area have been identified in residents aged between 18 and 81 years and have totaled 3,979 units. For the preliminary determination of sample size, the population size of the two municipalities have indicated the opportunity to adopting a calculation formula, correction factor inclusive, for finite populations (see Corbetta, 1999, p. 323-324). Under the established conditions, the sample size is equal to 350 units.
It has been decided to carry out a random sampling for layers, built on two classification criteria: the living municipality and residence in areas of greater or lesser perceptibility of wind farms. Regarding the stratification criterion, it was decided to identify the areas where a *direct sensorial perception of the presence of wind farms is clear* (proximity, direct visibility, a more or less strong noise). In this way, they become part of the layer "*most exposed*" (defined **layer "VR"** - by "visibility" and "noise") also living in streets that, although located at considerable distances from the wind turbine plants, for their placement, they are exposed undergo a visual and/or noise impact by wind turbines.

The operation of classification has determined the distribution of the layers of the population (N) and the sample (n) represented in the following Table 1.

Table 1. Stratification layer of the population

Layers	N	%	n
Orsara VR	438	11,0	38
Orsara NON_VR	1803	45,3	159
Sant'Agata_VR	532	13,4	47
Sant'Agata_NON_VR	1206	30,3	106
Total	***3.979***	*100,0*	*350*

The above mentioned questionnaire is designed taking care to balancing consider the three categories of factors: “personal”, “psycho-social” and “contextual” - essential in empirical studies on the attitude towards the renewable energy technologies. Following are the schematic sections of the questionnaire:

- *Socio-personal data* (citizenship, birthplace, living place, residence time, sex, age, educational level, marital status, employment status, income);
- *Information and participation* (associations, unions, citizen participation in the life of the municipality, politico-ideological orientation, information channels used);
- *Social and environmental problems* (general problems which affecting the planet and the municipalities);
- *Energy sources* (general and particular knowledge on renewable energy, information channels, judgment on the sources);
- *Opinions on wind power* (attitude towards wind energy problems, judgment about local wind power experience, information on that kind of source, judgment about installation procedures of the wind power plants, citizen participation, positive or negative predicted and founded effects, desirable minimum distances of the plant by the dwellings and the workplace).

The questionnaire was distributed in two steps: between the end of June and the first half of July in Orsara di Puglia and between the 15th of October and the first week of November 2012 in Sant'Agata di Puglia. The sample actually achieved was 332 units, 188 belonging to the sub-sample of Orsara and 144 for Sant’Agata di Puglia.
Here, we will give an account of the results of the investigation limited to the subject of the noise generated by working wind turbine.

In the questionnaire, the noise impact is explicitly present in only two questions:

- in the first, which is part of a attitude scale about positive and negative aspects on wind technology (in general), it is asked if there is an agreement or disagreement regarding to the statement that wind turbines produce an “*insufferable noise*” who is living near the wind farms for;
- in the second, whether, among the negative effects of personal experience with the wind power, the sample has verified the presence of a “*disturbing noise during operating wind turbines*”.

Before taking into account the answers, it is appropriate to set out very briefly what is the attitude towards wind turbines emerging from the survey, both regarding the wind power source in general, and the plants locally installed.

A large majority of the total sample expressed a positive opinion on wind energy technology, with about 60% of the cases (a better judgment is given only to solar, with 75% and hydropower, with more than 61%). The Table 2 shows the consensus percentages attributed to some renewable energy and we can see how the non-renewable sources, instead, the worth of judgments are very low (especially on nuclear and coal).
Regarding the attitude on the local wind farm, as shown in Table 2, there was a similar response between the two sub-samples on negative judgment (for both we are over 39%); they are slightly different about a positive judgment (40% for citizens of Sant'Agatta, about 35% for Orsara).

Table 2. Judgment of installed wind turbines plants (N=295)

Judgment about	Municipalities		
	Orsara di Puglia (%)	Santagata di Puglia (%)	Total (%)
Positive	35,3	40,0	37,3
Negative	39,4	39,2	39,3
Neither positive nor negative	25,3	20,8	23,4
Total	*100,0*	*100,0*	*100,0*

The two questions specifically dedicated to noise inserted into the questionnaire, are as following:
The first - as already mentioned, is part of a scale of attitude. it is intended to detect the degree of agreement/disagreement with a statement on "*unbearable*" noise produced by wind turbines for those who lives near them. Please note that the question, like the rest of the set ones, is not directly related to a local power plants but it regards the problems of wind energy in general. The Table 3, which aggregates the variable by reducing itself to three (agreement, disagreement, indecision), shows a framework in which prevails the consideration of noise as a serious problem for those who lives near a wind farm: only 15.4% expressed disagreement (and the two sub-samples in this case is substantially consistent). We have to note, however, the significant difference of the mode "agree", which is chosen by 63.7% of the Orsara citizen sub-sample, while Sant'Agata does not go beyond 43.8 (in this portion of the sample is recorded almost 40% undecided).

Table 3. Agreement/disagreement about statement on unbearable noise for people living near wind farms (N=311).

Wind power plants product a unbearable noise for those who lives near them	**Municipalities**		**Total**
	Orsara di Puglia	**Sant'Agata di Puglia**	
disagreement	14,7%	16,4%	15,4%
Indecision	24,6%	39,8%	30,9%
agreement	60,7%	43,8%	53,7%
Total	*100,0%*	*100,0%*	*100,0%*

P=0,007

The second question is related to the concrete experience of the singles interviewed about the wind power systems installed in their municipality: “the subject was able to verify the presence of an *annoying noise during operational wind turbines*?” Table 4 reveals a significantly different behavior of the two sub-samples. Even noting that a *large majority of both is expressed for the “no”,* regarding the *affirmative* answer, the rate of Sant’Agata is just over 10%, compared to over 28% of Orsara.

Table 4. Annoying noise verification during the operation of the wind turbines (N=327)

Annoying noise verification during the operation	**Municipalities**		**Total**
	Orsara di Puglia	**Sant’Agata di Puglia**	
Yes	28,3%	10,5%	20,5%
No	71,7%	89,5%	79,5%
Total	100,0%	100,0%	100,0%

Following is shown the cross of these two variables relating to noise with the distances from interviewed’s houses, putting the table for the whole sample beside the one referring to the sub-sample Sant'Agata.

Table 5 examines the connection between general judgment of unbearable noise and distance of residence from the wind farms. The hypothesis that a greater proximity to wind turbines could have influenced the overall judgment on the noise does not seem to be confirmed by the data in a unique way: both the table 5.a) and the table 5.b) have the highest proportion of agreement with the statement on noise in the class of intermediate distance, verily with values very similar (although slightly higher) to those of the class between 0 and 1 km; also, while in the whole sample can be seen that the agreement is significantly more pronounced for the first two classes of distance respecting to the group of residents more "distant" (> 5 km), this difference is attenuated in the sub-sample of Sant'Agata (Table 5.b)); by virtue of a lower proportion of agreement of 12-13 percentage points compared to the sample, with a much greater presence of undecided between the first two classes of distance; finally, to confirm at least the non-uniqueness of possible relationship distance/attitude, we can notice a sort of “paradox” regarding the “disagreement”: among who lives less than a kilometer there is the highest percentage of people which they choose this mode and it seems to be an inverse relationship between distance and disagreement. Then, as much as close you are to the wind farm and more there is a *no-sharing* of the “unbearable” noise of the wind turbines (although a minority), whereas we could expect the opposite.

This could be explained by a “familiarization” with the technology, certainly more evident in Sant’Agata.

Table 5. Agreement/disagreement with the *statement* on the unbearable of noise respect the distance from wind turbines.

a) Entire sample (N=310)

Wind power plants product a unbearable noise for those who lives near them	Distance from wind farm			Total
	fino a 1 km	Tra 1 km e 5 km	più di 5 km	
disagreement	21,1%	13,9%	14,7%	15,5%
Indecision	22,8%	27,2%	42,1%	31,0%
agreement	56,1%	58,9%	43,2%	53,5%
Total	100,0%	100,0%	100,0%	100,0%

p=0,041

b)Sant'Agata di Puglia sample (N=128)

Wind power plants product a unbearable noise for those who lives near them	Distance from wind farm			Total
	fino a 1 km	Tra 1 km e 5 km	più di 5 km	
disagreement	20,0%	16,7%	14,5%	16,4%
Indecision	36,0%	37,5%	43,6%	39,8%
agreement	44,0%	45,8%	41,8%	43,8%
Total	100,0%	100,0%	100,0%	100,0%

The distance parameter seems to show a clearer correlation, by the personal experience of the interviewed in wind power, on the presence of a "disturbing noise" during operational wind turbines. Table 6 (both 6.a and 6.b) describes how the distribution of "*Yes*" and "*No*" is significantly influenced by the variable "distance"; it should be added, however, as has already been mentioned in connection with the Table 4, that in both towns there is a significantly different approach - although holding the coherence of the relationship - showen by the rates whom emphasize the recorded "noise annoyance" significantly lower that the sub-sample of Sant'Agata: from 20.1% related of the two municipalities we get to 10.5% of Sant'Agata, as average data, and from 36.1% to 26.7%, in the class of distance 0-1 km.

Table 6. Verification of operational wind farms noise annoyance with the distance of receivers:

a) Entire sample (N=326)

Verification noise annoyance by wind farms	Distance from wind farm			Total
	by 1 km	range 1 km - 5 km	more than 5 km	
Yes	36,1%	18,9%	13,2%	20,2%
No	63,9%	81,1%	86,8%	79,8%
Total	100,0 %	100,0%	100,0 %	100,0 %

p=0,002

b)Sant'Agata sample (N=143)

Verification noise annoyance by wind farms	Distance from wind power plant			Total
	by 1 km	range 1km - 5 km	more than 5 km	
Yes	26,7%	6,3%	6,2%	10,5%
No	73,3%	93,8%	93,8 %	89,5%
Total	100,0 %	100,0%	100,0 %	100,0%

p=0,005

3. Noise monitoring campaign

At aims to support the results of the above mentioned sociological inquiry referred with noise measurements which quantify the population exposure to noise levels, the working group ISPRA has carried out a acoustic monitoring campaign in the period from 15/10/2012 to 15/11/2012, in two receivers near wind farms installed in the territory of Sant'Agata di Puglia.

The measurements have allowed the calculation of significant acoustical parameters in accordance with the methodological criteria laid down by Italian legislation on noise pollution protection.

In particular, the analysis of the data has allowed the construction of the daily curves of the A-weighted equivalent sound level (LAeq in dB) divided by periods such as daytime (06:00 a.m.-10: 00 p.m.) and night (10:00 p.m.-06: 00 a.m.) and obtained removing abnormal and exceptional events (eg due to car alarms, rain), for the measurement period October-November 2012.

3.1 Individuation of the measurement points and noise parameters At aims to carry out the acoustic monitoring have been chosen two sites inside the municipality boundary of Sant'Agata di Puglia, which were considered to be significant in terms of proximity and visibility of the wind farm, wind speed profile and for exposure levels expected at the receiver. In particular, the measuring **point n.1** is located at a residential receiver near a wind farm installed in the place of *Cesine*, whereas the **point n.2** is located in the place of *Ciommarino*.

Here following the dislocation of the instrumentation at the chosen measuring points:

- at the point n.1, the sound level meter was positioned at a height of 1.5 from the floor of a balcony, at a distance of 1 meter from the most exposed façade of the house and about at 1 km from the nearest wind turbine of the frontal wind farm.
- at the point n. 2 the sound level meter was positioned at a height of 1.5 meters from the floor of a balcony, at a distance of 1 meter from the most exposed façade and about 500 meters from the nearest wind turbine of the frontal wind farm.

The used monitoring system belongs to a *stand-alone* type, with a control unit that acquires the sound signal continuously throughout the measurement time period. The instrumentation has been chosen according to the following minimum requirements provided by the regulations of the sector, as following:

- sound meter and acoustic calibrator by class 1, conforming to the specifications of IEC 61672-1:2002;
- windshield;
- control unit with battery backup.

For the meteorological data acquisition, has been used a Weather Station able to measure the following parameters:

- rain (mm);
- wind speed;
- wind direction;
- temperature.

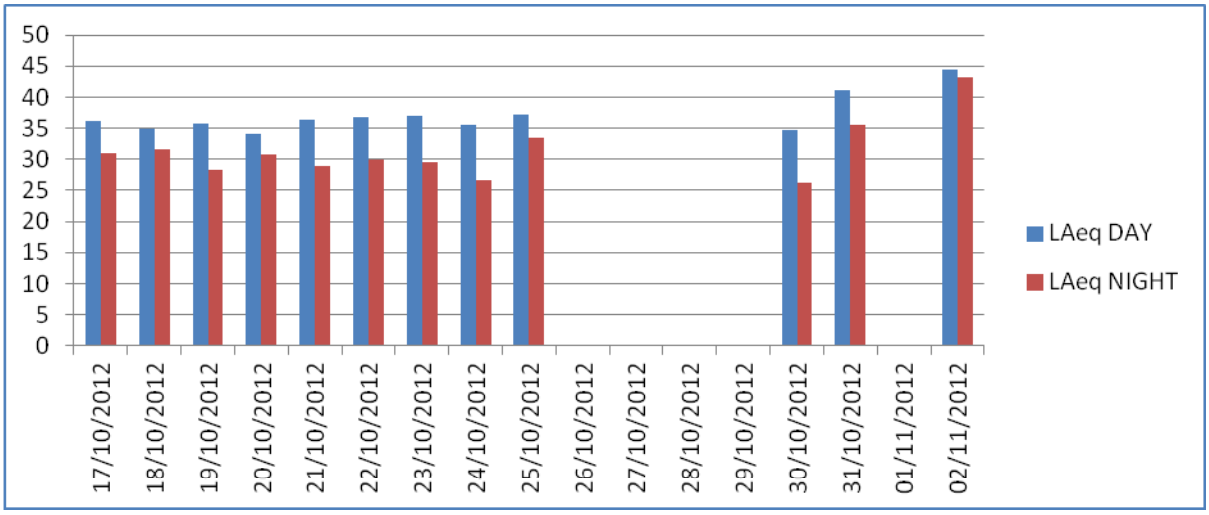
Regarding to the measured acoustic parameters, the time history of LAeq based on a time of 1 second has been recorded.

3.2 Analisi dei dati acustici e risultati The results of the data analysis for the point n.1 are shown in the following Table n.7 and Figure n.1.

Table n.7 – Site n.1 – L_{Aeq} in the reference time (T_R at daytime and night) from 17/10/2012 to 02/11/2012.

Point n°1 (Cesine) $L_{Aeq,TR}$ **[dB(A)]**		
	Day (6.00 a.m.-10.00 p.m.)	**Night (10.00 p.m.-6.00 a.m.)**
17/10/2012	36,2	30,9
18/10/2012	34,9	31,7
19/10/2012	35,8	28,4
20/10/2012	34,1	30,7
21/10/2012	36,3	28,9
22/10/2012	36,8	29,9
23/10/2012	37,0	29,6
24/10/2012	35,6	26,7
25/10/2012	37,2	33,5
30/10/2012	34,8	26,2
31/10/2012	41,1	35,6
02/11/2012	44,4	43,1

Figure n.1 – Site n.1 – Histogram of L_{Aeq} in the reference time (T_R at daytime and night) from 17/10/2012 to 02/11/2012.

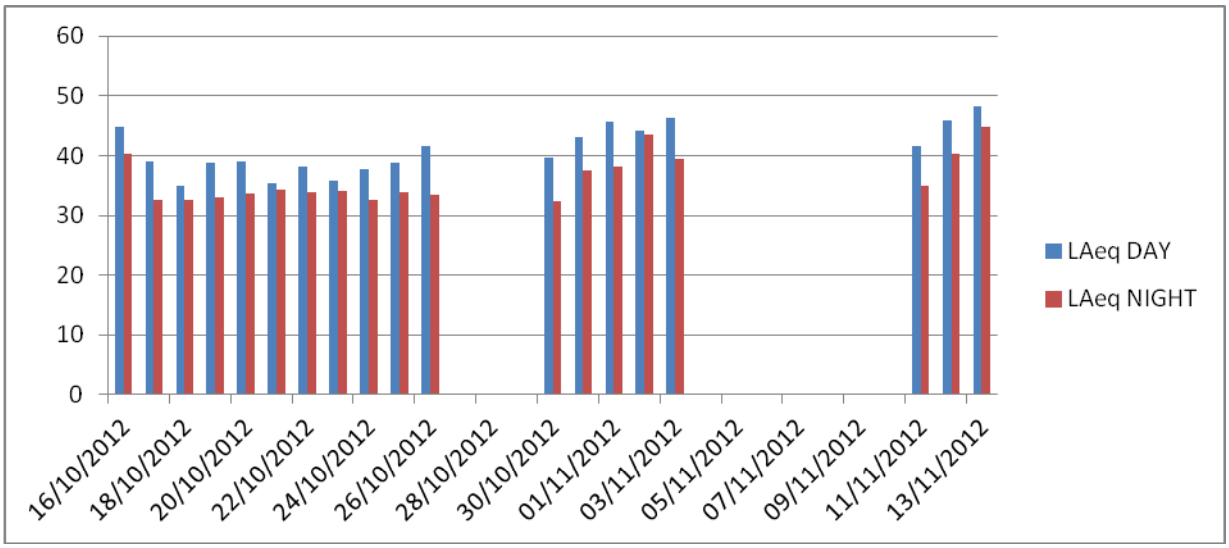


The results of the data analysis for the point n.2 are shown in the following Table n.8 and Figure n.2.

Table n. 8 – Site n.2 – L_{Aeq} in the reference time (T_R at daytime and night) from 16/10/2012 to 11/11/2012.

Point n°2 (Ciommarino) $L_{Aeq,TR}$ **[dB(A)]**		
	Day (6.00 a.m.-10.00 p.m.)	**Night (22.00 p.m.-6.00 a.m.)**
16/10/2012	44,9	40,3
17/10/2012	39,0	32,6
18/10/2012	34,9	32,5
19/10/2012	38,8	33,1
20/10/2012	39,1	33,6
21/10/2012	35,4	34,3
22/10/2012	38,2	33,8
23/10/2012	35,8	34,0
24/10/2012	37,8	32,6
25/10/2012	38,7	33,9
26/10/2012	41,5	33,4
30/10/2012	39,7	32,4
31/10/2012	43,1	37,5
01/11/2012	45,7	38,1
02/11/2012	44,2	43,5
03/11/2012	46,2	39,5
11/11/2012	41,5	35,0
12/11/2012	45,9	40,3
13/11/2012	48,2	44,9

Figure n. 2 – Site n.2 – Histogram of L_{Aeq} in the reference time (T_R at daytime and night) from 16/10/2012 to 13/11/2012.



It should be noted that all days with unfavorable weather conditions for noise propagation or when abnormal events of exceptional nature happened, as significant

as well frequently throughout the day, have been rejected, to make unusable the data recorded.
From the tables and the trends have been shown in the figures above reported, we can notice, for both measurement sites, quite low levels of environmental noise.
In particular, in the month of October (16/10/2012 - 31/10/2012), we recorded:

- At the point n.1, a LAeq average in daytime of 36.5 dB (A) and 30.2 dB (A) for the night time.
- At the point n.2, a LAeq average in daytime of 38.5 dB (A) and 33.6 dB (A) for the night time.

These values are justifiable because this period has been characterized by weather and anemometer conditions with low wind speed at receiver.
Regarding the month of November, the available data show the highest levels of environmental noise because in this period, the wind speed for the receivers under investigation, has been more significant (wind speed average about 10 m/s).
In particular:

- for point n.1 we have only one data recorded in the day 02/11/2012 which shows a daytime LAeq of 44.4 dB (A) and 43.1 dB (A) at night time.

- At the point n.2 we have an LAeq average in daytime of 45.3 dB (A) and 40.2 dB (A) in the night time.

Moreover to have noise reference levels to compare our measurements, it should be noted that the Italian legislation sets limits for environmental noise as a function of the destination land use. In our case, referring to the land classification provided by the Italian law D.P.C.M. 14/11/1997, which give limit values for different class of land, assuming the measurement sites in question belonging to a class III (of mixed type area), the limits value assigned for this site are 60 dB (A) for daytime and 50 dB (A) for the night time. Therefore, from a comparison, the measured values are conform to the above regulatory limits.
In conditions of *no-winds* (average speed of 0 m/s) and in conditions of wind turbines at rest, the daytime environmental background level L_R has been also measured and the results are: for point n.1 L_R is 31.3 dB (A); whereas for point n.2 L_R is 37.6 dB.
These values appear to be much lower than the calculated environmental daytime LAeq already shown in the previous tables. However, a comparative analysis between the two variables should be carried out with reference to homogeneous classes of wind speed.
Moreover, experiences of previous measurement have shown that the difference between levels of overall environmental noise and the background noise is drastically reduced with increasing wind speed, becoming predominant the contribution of the wind detected at the microphone level.

4.0 Conclusions

The analysis of the data recorded at the two receivers during the monitoring campaign in October-November 2012, has shown an overall environmental noise levels characterized by a low average noise levels, even lower than those provided by environmental legislation.
In the other hand, we have to also consider the comments and the noise perceptual assessment of the population emerged by the ISPRA sociological study.

In fact, this study reports that in cases of stratification of the population particularly exposed to wind farm, in the municipalities of Sant'Agata di Puglia and Orsara, there are cases of complaints and sensitivity to the noise produced by working wind farms that, as said above, probably can be attributed to the annoy relate to the periodical-frequency of the sound signal linked to the rotation of wind turbine blades, rather than the produced environmental overall sound pressure levels.

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