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Case study application of the Italian decree of 1 June 2022 for the measurement of wind noise by switching off the plant

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ABSTRACT

Ministerial decree of 1 June 2022 was issued in order to assess wind turbine noise. It is based on two possibilities: shutting down (Annex 2) or not (Annex 3) the wind farm for collecting residual noise data. To solve the well-known issues associated with WTN measurements and generation, the decree establishes measurement criteria suitable for characterizing the measurement source in its multiple variability over time linked to different weather conditions such as wind speed, direction and gusts, etc. Furthermore, certain weather conditions must be respected at the receiver and the most severe wind conditions must be evaluated. While Annex 3 method has been thoroughly studied and validated in the past, the same cannot be said for Annex 2. For this reason, the present work describes the measurement campaign carried out in an Italian wind farm, which took place with the plant being switched off for at least 24 hours in order to measure the residual noise. To analyze the noise phenomenon of the plant in operation at different wind conditions, this part of the decree requires a monitoring duration of no less than 7 days. Problems, observations and results of the measurement campaign are described in this work.

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1. INTRODUCTION

Wind energy is among the greenest energy solutions, with its low CO_2 emissions during its entire lifespan that has made wind farms a very reliable and diffused choice in windy sites. Besides the visual aspects, the noise impact is representing a major hindrance to both new and old wind farms, especially for those installed in hilly areas, where amenity and quietness are the main attractiveness and characteristics.
The most common location, especially in Italy, is in country areas, sufficiently far from agglomerations and, then, not potentially impacting a high number of citizens. However, small villages or isolated receivers, even very far from a wind turbine, become exposed and disturbed by wind turbine noise [1, 2], which has been shown to be a very intrusive and annoying sound [3-6] due to its peculiarity in the generation mechanism and wind dependency [7-9].
Thus, wind turbine noise requires a careful assessment procedure that includes the measurement of low noise levels and a correct determination of the relationships between wind profiles and noise propagation in the prevailing atmospheric conditions. In those scenarios, the influence of wind profiles on noise generation and propagation is very complex due to the sites topography, making it tricky and weighty the evaluation of landscape and environmental impact of a wind farm. The proper determination of sound propagation path and wind induced residual noise is a complex issue in very irregular terrains

(hills, valleys, thick tree coverage) and for far receivers [10]. The knowledge of relationships between wind speed and direction at hub height and wind speed at receivers' height are of paramount interest. An important aspect is also played by the differences of wind speed and direction between each turbine of the wind farm caused by the complexity of the terrain profile. All these aspects made only few countries to have a proper method to evaluate the noise impact of a wind farm.

For this reason, the Ministerial decree of 1 June 2022 [11] was issued in Italy, whose development started from a preliminary analysis of the limits in the literature [12] without, however, going so far as to issue them. For this issue, future interventions and studies are expected to be proposed as soon as possible [13, 14].

The current decree provides for the application of two methodologies: the one described in Annex 3 obtains the residual values without requiring the plant to be shut down through a procedure based on numerous scientific studies [15-19]. The procedure of Annex 3, although it requires acquisitions lasting for at least 3 weeks, allows the plant manager to save costs by not causing him to interrupt productivity. The one in Annex 2, on the other hand, requires the system to be switched off to measure the periods in which the system does not emit noise.

Although they are both part of the same decree, the procedures followed by the two annexes lead to similar outputs. However, a true comparison between the results obtained with the two methods under the same conditions has not yet been carried out. The present study would be part of a larger comparison of these two methodologies, but in this preliminary phase the results of the measurements analyzed with Annex 2 are described.

The present work is aimed at highlighting the problems, reporting observations and showing the results of a measurement campaign carried out in south Italy as a case study.

2. SUMMARY OF ANNEX 2

A brief summary of the Annex 2 method is given in this section, from the procedural and analysis point of view.

A measurement of both the Ambient (L_A) and Residual (L_R) noise is needed, each evaluated on time intervals, or periods, of 10 minutes. A minimum of 1000 periods are needed for the L_A, corresponding to approximately one week of continuous data, while the L_R must be measured for at least 24 hours. One issue that suddenly arise is the at least 12 hours of this 24 must have a wind condition that grants the correct functioning of the wind turbines, or between their cut-in and cut-off wind speed.

Spurious or unwanted noise source must be excluded from the data, potentially leaving only the wind turbine noise. Single periods can be accepted if masked for less than 5 minutes (50% of their duration). Other discarding criteria are the lack of weather data in the specific period, both for the measuring point and the wind turbine, presence of adverse weather effects such as rain and wind speed at microphone level higher than 5 m/s and finally wind condition at the turbine above cut-off or below cut-in.

L_A and L_R analysis, conducted for every measuring point, is divided for Italian statutory periods Day (6-22) and Night (22-6). Ground wind speed categories are defined by steps of 1 m/s and L_R values are averaged along each individual category: five values or less are then calculated for each statutory period and measuring point.

The specific "immission" level (L_E) can then be calculated as a logarithmic difference between each 10 min L_A value and the corresponding wind class averaged residual noise $\langle L_R \rangle$, given that wind speed values are known during the measurements. The calculation can be performed only if $L_A - \langle L_R \rangle \geq 1$ dB(A).

For each statutory period in each measuring day, a certain number of L_E can be calculated: if this number exceeds 70% of the total allowed (96 for Day and 48 for Night) the period is considered valid.

Finally, for each statutory period the maximum of L_E (max (L_E)) is extracted among the valid periods: this is the actual source specific immission value that should be compared to normative references that, as previously mentioned, are still not defined.

3. MEASUREMENT SETUP

Measurement followed the decree explicit requirements for the instrumentation involved, such as class 1 sound level meter and calibrator, spherical windscreen with a diameter equal or higher than 90 mm, audio recordings for anomalous events and weather stations granting the following

Table 1. Instrumentation requirements.

Rainfall resolution	≤ 0.2 mm
Wind speed resolution	≤ 0.5 m/s
Minimum wind speed range	0 ÷ 20 m/s
Wind direction resolution	≤ 3°
Temperature resolution	≤ 0.2 °C

Those requests were met during the data gathering that took place between the 23/12/2022 and 07/02/2023, for a total of 46 days and for each of six different monitored measuring points, corresponding to different receivers. Measuring points and wind turbines of the area are reported in Figure 1. Blue wind turbines belong to different operators, while a road is also highlighted as possible conflictual sound source.

Figure 1. Sketch of the investigated area. In red are measurement positions.

As a general description of the area, measuring points 1 to 4 were placed WSW (west – southwest) from the turbine, on a descending slope and with decreasing distances: 373 m for point 1, 337 m for point 2, 266 m for point 3 and 143 m for point 4. Measuring point 5 was placed SSE (south - southeast) of the turbine at a distance of 194 m. Measuring point 5 was placed NNE (north - northeast) of the turbine at a distance of 402 m. No significant non-local noise sources were present nearby the measuring points except for point 6, presenting both a high traffic road and another wind turbine, not part of the study, at distances similar to the characterized noise source. Local road traffic and anthropic activity were present and distinguishable in each point.

Both the acoustic (L_{Aeq} and third octave band spectrum on 1 second time basis) and weather data (wind speed and direction, rainfall and temperature on 10 minutes' intervals) were gathered in each of the 6 point, placing microphonic and weather equipment along the same tripod pole when it was possible. Weather and functioning regime data was gathered for the studied wind farm, composed by a single turbine. Wind speed and direction at the hub along with the blade rotation speed were thus acquired in 10 minutes' intervals with the exception of maintenance periods which occurred during the monitoring period, requiring the full stop of the turbine.

4. WIND CHARACTERIZATION

Figure 2 reports the preliminary investigation, in terms of wind rose and speed (w_s) distribution at hub height, over the previous year. While the most frequent occurrence was an East direction wind, also a North North-West direction is clearly recognizable.

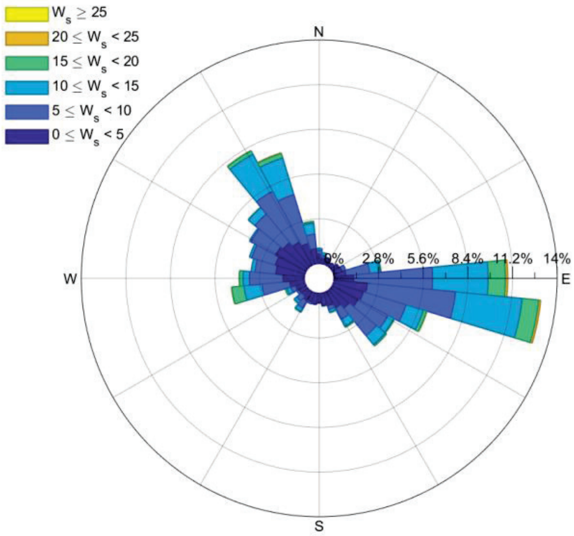

Figure 2. Previous year wind rose and speed distribution.

Similarly, Figures 3 and 4 show respectively the historical data sequence and the data gathered during the measurements, limiting the first dataset to the same days of the measurements but occurring the previous year. A different behaviour is observed in the new wind data, with direction prevalence that were essentially absent the year prior.

The relation between RPM and wind speed at blades' height is reported in Figure 5 for both the historical and measured data. The two dataset show a good agreement, both presenting a sigmoid like shape with two asymptotic regimes of 15 and 18 RPM after a wind speed threshold of approximately 7 m/s. A series of low RPM values even in presence of strong winds depicts the case of turbine's stop. Other points not clearly on the mentioned curves represent acceleration or deceleration regime for the turbine.

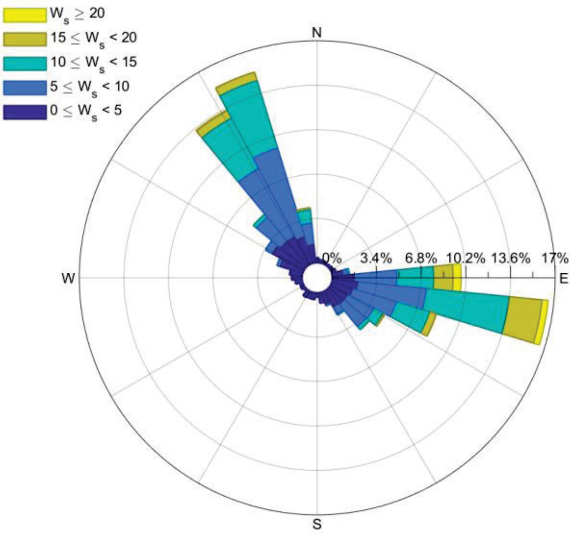

Figure 3. Previous year wind rose and speed distribution, limited over measurement period.

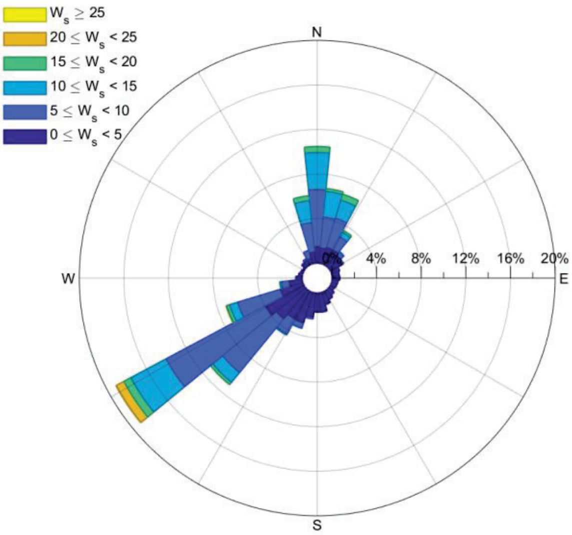

Figure 4. Measured wind rose and speed distribution.

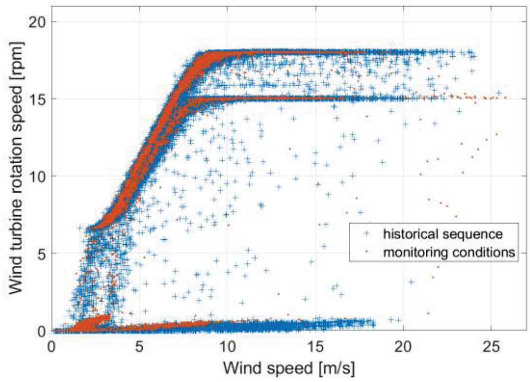

Figure 5. Relation between RPM and wind speed at blades' height for both the historical and measured data.

5. MEASUREMENTS AND RESULTS

Gathered data was cleaned from spurious events both manually and via algorithmic methods [20] and checked against the decree's validity requests previously detailed ($L_{Acut\ in\text{-}cut\ off}$, $L_{Rcut\ in\text{-}cut\ off}$). The total number of accepted 10 min periods is reported in Table 2, confirming that the dataset is compliant to the decree.

The Residual noise is expressed for each Italian statutory period (day 6:00-22:00, night 22:00-6:00) and measuring point as a function of the wind range along which it was averaged, as reported in Table 3.

Table 2. Total valid 10 min periods for each metric and measuring point.

Point	L_A valid periods	$L_{Acut\ in\text{-}cut\ off}$ valid periods	L_R valid periods	$L_{Rcut\ in\text{-}cut\ off}$ valid periods
1	3091	2293	224	204
2	4218	3160	327	291
3	2651	1843	302	266
4	3597	2615	175	160
5	3603	2525	170	158
6	3366	2891	372	339

Table 3. Residual noise level divided for periods and wind range in each measuring point.

Period	Point	Wind range [m/s]				
		0-1	1-2	2-3	3-4	4-5
Day	1	35.3	39.6	45.5	48.8	55.4
	2	36.5	37.4	37.2	41.4	49.0
	3	35.5	36.9	41.3	46.5	48.5
	4	40.2	41.7	42.0	40.6	41.0
	5	39.6	42.3	53.0	48.4	51.3
	6	49.4	49.5	48.4	48.3	50.2
Night	1	34.1	37.7	37.5	--	--
	2	35.9	35.7	35.6	36.2	--
	3	36.2	34.8	39.8	42.2	46.4
	4	39.5	39.7	41.3	40.4	39.2
	5	40.2	40.6	48.1	47.5	49.7
	6	45.3	43.7	44.9	44.7	46.2

The max(L_E) obtained for each measuring point and during each period is reported in Table 4.

Table 4. Max specific immission level obtained in each point and period.

Measuring point	MAX LED [dB(A)]	MAX LEN [dB(A)]
1	53.4	48.2
2	50.5	50.0
3	---	47.2
4	53.0	51.6
5	---	---
6	54.7	52.9

For a deeper analysis, Table 5 shows the final evaluation for a sample measuring point (n.2) and only the first 16 days of the statutory period validity and corresponding to max(L_E), together with an average of blades' rotational speed. The correlation between blades' rotational speed and measured noise level is investigated in Figure 6.

Table 5. Final evaluation in measuring point 2.

Day	Day validity	Night validity	L_E Day [dB(A)]	L_E Night [dB(A)]	Average blades rpm
1	NO	NO	---	---	13.2
2	NO	NO	---	---	13.8
3	NO	NO	---	---	14.4
4	OK	NO	45.7	---	15.5
5	NO	OK	---	41.5	15.3
6	NO	NO	---	---	13.7
7	NO	NO	---	---	13.4
8	NO	NO	---	---	14.5
9	NO	NO	---	---	13.5
10	NO	NO	---	---	11.4
11	NO	NO	---	---	13.7
12	NO	NO	---	---	8.0
13	NO	NO	---	---	9.6
14	OK	NO	43.6	---	14.8
15	NO	NO	---	---	9.1
16	NO	NO	---	---	8.3

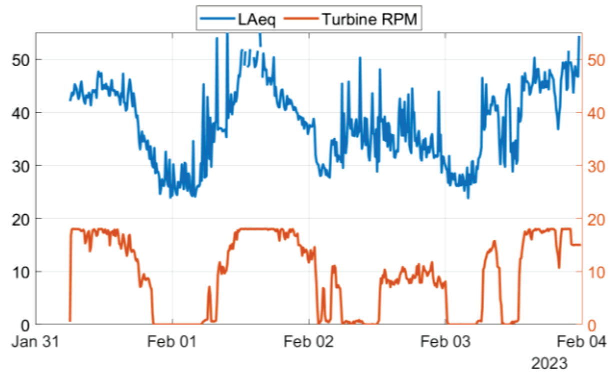

Figure 6. Blades' rotational speed and noise level measured in point 2.

6. RESULTS DISCUSSION

Results presented in Table 5 show that while the procedure can give a quantitative analysis of the impact of the wind turbine, with a good correlation between the blade's behavior and the noise level measured as confirmed in Figure 6, several critical factors must be taken into account.
Among the most important, wind condition resulted to be not clearly predictable. This would be even more true in the present global climate change scenario, were unusual weather would potentially require very long measurements to gather the basic data for the analysis.
A major issue remains in strong and fast wind speed and direction variation that can remain undetected if occurring under the 10min period time frame, which is typically the case for wind gusts. The analysis conducted in this work tried to exclude this behavior in the dataset by evaluating the spectrographic properties of the measured noise, but this should be evaluated at the instrumental level.
Given that the interested noise source increases with higher wind speeds, the most favorable condition for the source

measurement corresponds to the most undesired one in terms of the wind speed at the microphone during measurements. This is especially valid for very exposed measuring points, leading to the exclusion of the data that present the most energetic contribution by the wind turbine.
Due to wind unpredictability, it was not possible to extract residual noise for every wind range: such conditions can be hard to achieve, mainly because the total residual time, corresponding to the turbine's imposed stop, is limited.

The specific "immission" level Le is calculated if the Ambiental noise exceeds the Residual of at least 1 dB, a condition that should grant significant leeway in the parameter calculation. However, it must be pointed out that there were many 10min periods in the dataset with the condition of $L_R \geq L_A$ for the corresponding wind range. This apparently absurd condition can be explained generally by slightly different wind conditions, being each value a 10min average of the actual wind behavior, by undesired but not clearly recognizable noise sources during residual measurements for the lower wind ranges and undetected wind gusts for the higher.

Finally, some noise outliers can arise from the acceleration and deceleration of the wind turbine, occurring whenever the blade rpm as a function of the hub windspeed is lower than the main sigmoid like curve present in Figure 5.

7. CONCLUSIONS

The present work applied the Annex 2 of Ministerial decree of 1 June 2022 methodology for data analysis, requiring wind farm shut down, to a measurement campaign in a wind farm of south Italy in an atypical configuration of a single wind turbine and several receptors, with some significant spurious noise sources nearby. The method, although in principle well defined, presented several criticalities.
In this work, both manual and automatic methods were employed, the latter detailed in further publications. Spurious events and data cleaning can be very time consuming, even assuming an inherent correctness of the process. The whole analysis can be quite robust to this problem, given the various constraints it presents on the acceptability of the results, but it can significantly affect both the accepted data and the statistical significance of the final result.
The required data removal from unwanted noise sources is, at present, a very time intensive procedure. Its difficulty is also high or almost impossible in cases where acquisition points are close to significant noise sources such as major roads. Anthropic and animal activity can also be an important factor in this, but also very high wind gusts can mask the studied noise source without being actually removable from the simple sound measurement. This aspect surely requires further studies and, possibly, exploit the new techniques like machine learning to obtain an automated removal procedure.

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