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Economics on wind farm noise mitigation by power limitation

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ABSTRACT

Noise is the main factor which contributes to environmental pressure produced by wind farms. People living nearby wind farm often complain annoyance which is proven to be given both by noise and visual impact. In the hypothesis that annoyance is tolerable when law limits are respected, noise levels may be kept under such a limits by a changing the configuration of fan parameters with respect to wind velocity and direction. However changing on fan parameters determines a reduction on the produced electrical power. In this paper a wind farm managing plan has been proposed which allows to respect noise limits in any nearby human settlement; the plan has been determined by correlating: wind speed statistics, fan noise emission characteristics and fan configuration parameters. Adoption of the proposed managing plan determines a reduction on the produced electricity and on earnings; thus a comparison between environmental benefits and economical losses is finally proposed.

INTRODUCTION

Well designed wind turbines are generally quiet in operation, and compared to the noise of road traffic, trains, aircraft and construction activities, the noise from wind turbines is very low. Generally outside the houses which are at least 300 metres away the sound of a wind turbine is likely to be about the same level as noise from a flowing stream about 50 - 100 metres away or the noise of leaves rustling in a gentle breeze. Nevertheless fans noise could disturb those who reside in the close proximity with a wind farm. In this paper the case of a rural house surrounded by several fans is analysed. With regard to outside noise, the Italian legislation provides for different noise buffer zones depending on the intended use of the area. For instance, in Mixed Areas[1] such as those in which rural houses are generally located, limits are 60 dB(A) during the daytime and 50 dB(A) during night. The annoyance produced by an external source in the home environment is evaluated by mean of Differential Noise Level[2]. However indoor noise can be considered negligible if the noise measured at the open windows is less than 50 dB(A) during daytime and 40 dB(A) during night [1].

The noise produced by a fan is dependent both on wind speed and on fan configuration parameters. Nowadays fans are equipped with control systems which adjust the pitch angle of blades to the reference value and regulate the electrical power delivered to the grid according to the power reference. By acting on system controls each fan can be configured with different noise settings. In this paper the effectiveness of fan setting on indoor noise reduction is analized. In particular are evaluated costs due to lost production resulting from the configuration of the fans in lower power noise mode.

CONTEXT

The wind farm under study is located in a rural area which is relatively populated. Fans are located either on woodland than on farmland, close to human settlements. A rural house has been chosen that represents the most critical situation as it is surrounded by n. 6 wind turbines; the fans are at a distance of between 180 and 460 meters (see Figure 1).

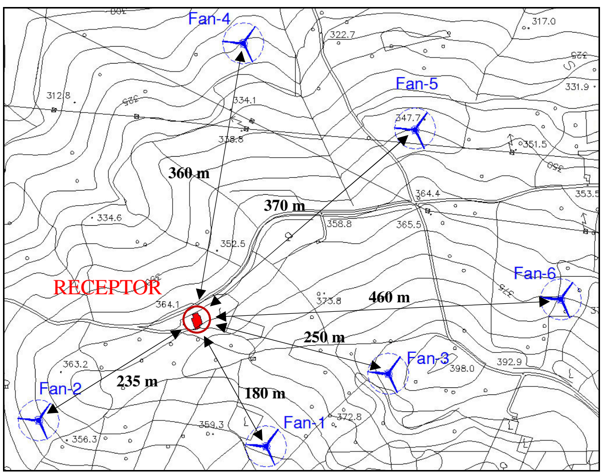

Figure 1. Position of rural house and surrounding fans.

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1 Mixed Areas: urban areas affected by vehicular traffic or local crossing, with average population density, presence of commercial activities, offices, with limited presence in crafts and with no industrial; rural areas affected by activities that use machines.

2 Differential Noise Level: difference between the ambient noise level and the residual noise level.

In addition to the wind turbines, the other noise sources are mainly due to human activities in nature farming and livestock. So the acoustic climate in the surroundings of noise receptor is dominated by wind farm noise.

The frequency distribution of wind in the area has increased in two directions: NE-SW and SW-NE. Analysis of data recorded from the fans during the last year shows that the wind has blown for 59 percent of the time from NE-SW[3] and for 41 percent of the time from SW-NE[4] (see Figure 2).

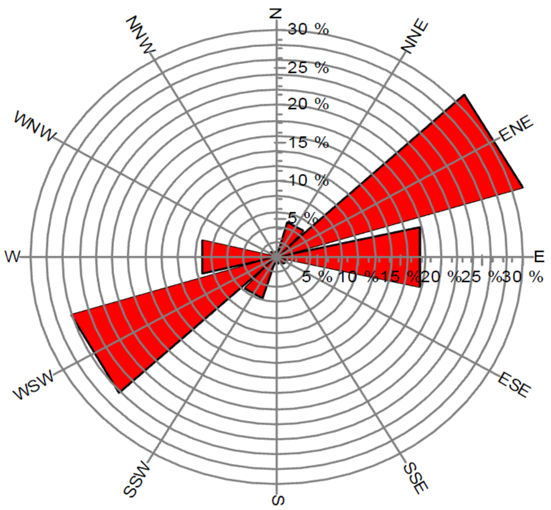


Figure 2. Frequency distribution of wind direction.

Concerning the wind speed, the analysis of measured data at hub height (65 meters) shows that for both directions, the average wind speed is equal to 5.6 m/s.

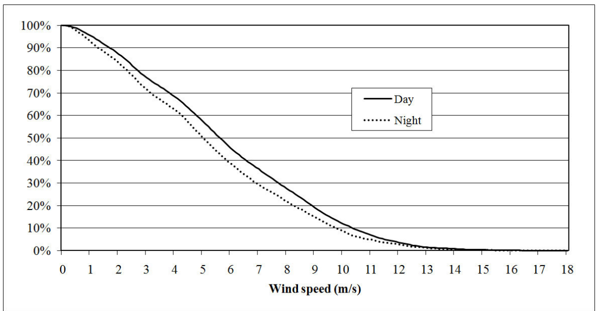


Figure 3. Cumulative distribution of wind speed (NE-SW).

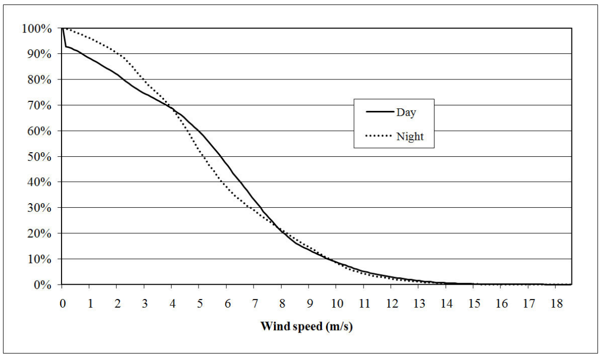


Figure 4. Cumulative distribution of wind speed (SW-NE).

[3] Calculated taking into account the contributions of the directions E and E-NE.
[4] Calculated taking into account the contributions of the directions W, W-SW and S-SW.

In Figure 3 are given cumulative distribution of wind speed during the day and overnight, for the direction from NE-SW. Figure 4 shows the same distribution of wind speed for the direction provenance SW-NE.

The cumulative distribution provides information about the percentage of time that each wind speed is exceeded within 12 months of data acquisition. Such datum can be correlated with noise emitted by wind turbines for different wind speeds to identify the probability that a given level of noise occurs at the receptors.

WIND TURBINE DESCRIPTION

The wind farm is equipped with Vestas V52-850kW wind turbine model. The Vestas V52-850kW is a pitch regulated upwind turbine with active yaw and a three-blade rotor. Wind turbines control system is divided into 3 blocks called main controller, pitch regulator and power controller. The main controller manages the overall control functions, whereas pitch and power controller are subordinate units. The main controller generates reference values for the pitch angle (pitch reference) and for the electrical power to be produced (power reference) dependent on the wind speed and the current noise reduction [1].

Turbines are offered with n. 5 different noise settings (100 dB(A), 101 dB(A), 102 dB(A), 103 dB(A) and 104 dB(A)). The noise setting has an influence on the power curves only in the partial load area (wind speed between cut-in wind speed and rated wind speed). If the turbine is operated with a lower noise demand, the rotor rpm is reduced and the pitch angle is increased. Together with the noise reduction, also the aerodynamic efficiency decreases; this leads to a lower power curve and an increase of the rated wind speed.

Developments of electrical power as a function of wind speed for each of the n. 5 configurations of acoustic power are shown in Figure 5. For example, with a wind speed of 12 m/s, the wind turbine output is equal to 759 kW in 104 dB(A) configuration and equal to 688 kW in 100 dB(A) configuration. The percentage reduction in electric power is thus equal to 9 percent.

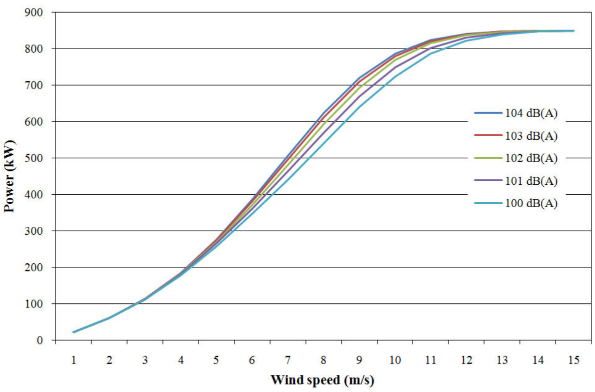
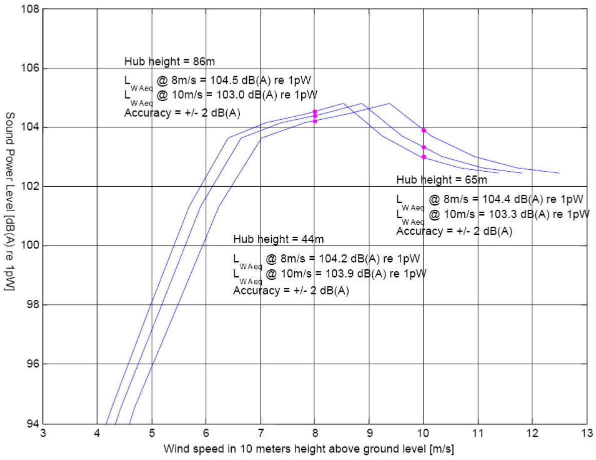


Figure 5. Stationary generator power as a function of the wind speed at different noise levels.

In Figure 6 the V52-850kW Sound Power Level (SPL) as a function of the wind speed at different hub heights is reported. The figure shows how the SPL increases with wind speed up to about 8.5 m/s and decreased after this value. Similar behaviour is also observed for other configurations except the 100 dBA for which the SPL always increases with increasing wind speed.



Source: (Vestas - General specification Vestas V52-850kW, 2006)

Figure 6. Theoretical noise curve for the V52-850kW "104 dB(A)" in roughness class 2 (Hub height = 44/65/86 m).

MEASUREMENT CAMPAIGN

At the noise receptor site were carried out two measurement campaign in living environment for verification of noise level:

- a first measurement campaign in the night period during which the wind, coming from the North-East, has maintained an average speed of about 8 m/s;
- a second measurement campaign in the day period during which the wind, coming from the South-West, has maintained an average speed of about 5 m/s.

All measurements were carried out in a bedroom on the first floor of the building, east side. This room was chosen because it is the living environment more exposed to noise emissions of the wind turbines.

The following table shows the noise levels measured inside bedroom, in opened window conditions, during the shut-down and switch-on of wind turbines in the night period. Inside noise levels measured during day period are reported in Table 2.

Wind turbines were set in 104 dB(A) configuration for all the measurements.

Table 1. Noise levels measured during night period.

Wind		*Wind turbines*						L_{eqA}
Speed	*Direction*	1	2	3	4	5	6	*dB(A)*
8,0	44°	ON	ON	ON	ON	ON	ON	43.0
8,1	48°	OFF	ON	ON	ON	ON	ON	41.6
7,7	48°	OFF	OFF	ON	ON	ON	ON	40.6
7,6	50°	OFF	OFF	OFF	ON	ON	ON	38.7
7,6	48°	OFF	OFF	OFF	OFF	ON	ON	36.3
7,5	54°	OFF	OFF	OFF	OFF	OFF	ON	35.3
8,1	51°	OFF	OFF	OFF	OFF	OFF	OFF	34.4

Table 2. Noise levels measured during day period.

Wind		*Wind turbines*						L_{eqA}
Speed	*Direction*	1	2	3	4	5	6	*dB(A)*
5,7	234°	ON	ON	ON	ON	ON	ON	39.5
5,4	238°	OFF	OFF	OFF	OFF	OFF	OFF	31.6

Results show that during the night, for a wind speed of 8 m/s, the noise level produced by all wind turbines exceed the law limit (40 dB(A)) below which the noise can be considered negligible.

During daytime, considering that wind turbines reach maximum Sound Power Level for a wind speed of 8.5m/s (see Figure 6), it is expected that the law limit is never exceeded.

In table 3 is reported the contribution of each wind turbines to the total noise in living environment for a wind speed of 8 m/s.

Table 3. Wind turbines contribution to the indoor noise.

Wind turbine	*Distance* (m)	*LeqA* (dB(A))
Fan 1	180	48.1
Fan 2	235	45.2
Fan 3	250	45.8
Fan 4	360	42.1
Fan 5	370	41.8
Fan 6	460	39.9

WIND TURBINES MANAGING PLAN

Both SPL curves corresponding to each configuration and noise contribution of single fans (see Table 3) have been considered in order to identify the combination of noise settings that provides for each wind speed a total indoor noise level lower than 40 dB(A). In particular, the decrease/increase of sound power level corresponding to wind speed decrease/increase or to configuration change has been calculated. Afterwards the noise contribution of wind turbines has been reduced by the same amount.

In table 4 the proposed managing plan of wind farm is reported. In particular, the plan provides for each wind speed the noise setting of the single wind turbines during the night.

Table 4. Noise settings of wind turbines that provides an indoor noise lower than 40 dB(A).

Wind turbine	*Wind speed* (m/s)								
	5	6	7	8	9	10	11	12	13
Fan 1	104	101	100	100	OFF	OFF	OFF	OFF	OFF
Fan 2	104	103	101	100	101	101	104	104	104
Fan 3	104	101	101	100	100	100	100	104	104
Fan 4	104	104	101	100	101	101	104	104	104
Fan 5	104	104	104	104	104	104	104	104	104
Fan 6	104	104	104	104	104	104	104	104	104

Table 4 shows that for a wind speed of 6 m/s wind turbines 1, 2 and 3 must be set to 101 and 103 dB(A) to meet the indoor noise level of 40 dB(A). For a wind speed of 8 m/s all four closer wind turbines (1, 2, 3 and 4) must be set to 100 dB(A). For a wind speed greater than 8 m/s, the wind turbine 1 must be always turned off in the night period.

ECONOMIC ANALYSIS

The economic loss L_{TOT} due to the managing plan proposed in previous paragraph was estimated taking into account the loss in electricity production consequent to power limitation of wind turbines (see Figure 7). The selling price of electricity P_E has been assumed equal to 0.18 €/kWh. Such price includes both buying price and incentive price (Green Certificates). Wind energy, like other forms of renewable energies, enjoy governmental incentives (Quota System).

The Quota System is a promotion system, dividing the produced electricity into two products, on the one hand the physical power and on the other its *green* quality. The green quality is certified through Green Certificates, which are allocated to the electricity producer by public authorities. Both electricity aspects are traded separately, the electricity on the electricity-market, the certificates on the separated certificate-market. The promotion of power from renewable electricity sources consists of the Certificate price, which is allocated to the producer of renewable energy in addition to the price he realises on the energy market. Quota systems currently exist in Belgium, Italy, Romania, Sweden, Poland and the United Kingdom.

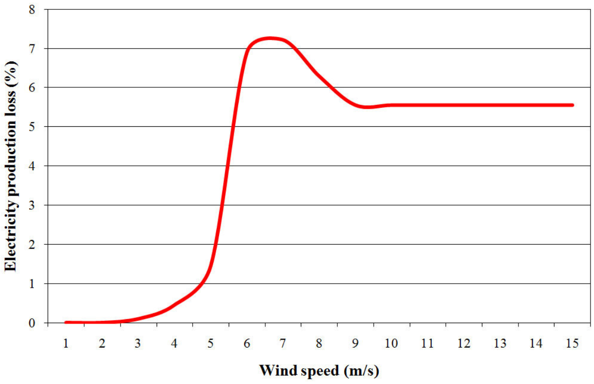


Figure 7. Percent loss in electricity production due to managing plan.

The loss L_i in electricity production of the i-th wind turbine was calculated for each wind speed j, as:

$$L_{i,j} = (H_j - H_{j,D}) \cdot W_j - H_{j,N} \cdot W_{j,k} = H_{j,N} \cdot (W_j - W_{j,k}) \quad (1)$$

where H_j is the number of hours per years that the wind blows at j-th speed, $H_{j,D}$ is the number of hours per years in the day period that the wind blows at j-th speed, $H_{j,N}$ is the number of hours per years during the night that the wind blows at j-th speed, W_j is the maximum power output of wind turbine at j-th wind speed, $W_{j,k}$ is the power output of wind turbine at j-th wind speed and for the noise setting k.

$H_{j,D}$ and $H_{j,N}$ were calculated by cumulative distributions of Figure 3 and 4 as follow:

$$H_{j,D} = \frac{16}{24} \cdot H_{TOT} \cdot [(P_{NE} + P_{SW}) \cdot (P_{j,D} - P_{j-1,D})] \quad (2)$$

$$H_{j,N} = \frac{8}{24} \cdot H_{TOT} \cdot [(P_{NE} + P_{SW}) \cdot (P_{j,N} - P_{j-1,N})] \quad (3)$$

where H_{TOT} is the total number of hours in a year, P_{NE} is the percent of time that the wind blows from North-East direction, P_{SW} is the percent of time that the wind blows from South-West direction, $P_{j,D}$ is the percent of time that the wind exceed the j-th speed in the day period, $P_{j\text{-}1,D}$ is the percent of time that the wind exceed the j-1-th speed in the day period.

The economic loss due to the proposed managing plan is given by:

$$L_{TOT} = \sum_i \sum_j (L_{i,j} \cdot P_E) \quad (4)$$

and results equal to 53 k€/year. The sale of electricity produced by the n. 6 wind turbines at the guaranteed price of 0.18 €/kWh results in an estimated gross profit of 1.4 M€/year. So the loss L_{TOT} represents just the 3.8 percent of the annual gross profit.

The loss in electricity production is mainly due to the settings of wind turbine n. 1, the one nearest to noise receptor. The loss in productivity of such wind turbine is estimated to be 19% with respect to the standard configuration (104 dB(A)). The productivity loss of wind turbines n. 3, 2 and 4 is 2, 1 and 1 percent, respectively.

CONCLUSIONS

In the present paper a wind farm managing plan is proposed which allows to respect noise limits in a rural house located inside the plant area, close to wind turbines.

The plan has been determined by correlating: wind speed statistics, fan noise emission characteristics and results of phonometric measurements carried out inside the house.

The managing plan aims to reduce emitted noise by limiting the power output of wind turbines. For each wind turbines the power limitation has been identified as function of the wind speed and the distance from human settlement.

The reduction on earnings due to the adoption of the proposed managing plan has been evaluated to be about 4 percent of the gross profit produced by the closer wind turbines. The loss in profit is particularly high (about 20 percent) only for the wind turbine closer than 200 meters from the noise receptor.

REFERENCES

1 Vestas Technology Dept., "Vestas V52-850 kW 50/60 Hz OptiSpeed® Wind Turbine - General Specification", Item n. 946506.R9 (2006).