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Noise impact assessment on the basis of onsite acoustic noise immission measurements for a representative wind farm

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ABSTRACT

Wind energy, comprising a techno-economically mature and clean technology, is not entirely free of impacts on the environment and human health. In this context, noise still comprises a major siting criterion, even hindering the approval for the installation of new wind power projects. The present study evaluates the noise level immission using real acoustic measurements of a representative wind farm, while these measurements are also compared with simulation results of two well-known noise immission prediction models. Emphasis is firstly given on the development of a reliable experimental process and secondly on the estimation of the real noise impact of the existing wind turbines dissociated by the background noise for several wind speed values and distances from the wind farm. According to the results obtained, validation of the prediction models is provided by observing a fairly good agreement between experimental and simulated results. Furthermore, wind farms may be characterized as relatively low noise emission sources, compared to other industrial units or conventional power plants, as the sound pressure level (SPL) at a distance of 300 m away is almost 45 dB(A), i.e. not a prohibitive value for human activities in the wind farm's broader area.

1. Introduction

In recent years, there has been a spectacular increase in wind power installations worldwide. However, despite the fact that wind energy comprises a technologically mature, economically competitive and environmentally friendly energy source, it is often accompanied, inevitably, by concerns related with the noise impact (immission), usually encountered in the direct vicinity of wind farms [1,2]. In this context, noise still remains a major issue for the local communities and statutory authorities [3,4], even hindering the approval for the installation of new wind power projects [5]. Actually, wind farm developers may face strong resistance from people who reside in the close proximity of new projects, owed to concerns that the noise from wind turbines (WTs) is a very distracting nuisance and will disrupt their lives [6,7]. As a result, the noise produced by WTs is considered one of the main limitations for the extensive development of wind energy during the last years [8,9].

Despite the remarkable efforts of the WT manufacturing industry to reduce the noise emission of contemporary commercial machines, noise from WTs still comprises an important siting criterion. Wind turbines generate two types of noise, i.e. mechanical and aerodynamic. Thus, a turbine's noise emission is a combination of both. In general, mechanical noise (generated by the turbine's mechanical and electrical parts) is no more considered as important as the aerodynamic noise is (generated by the interaction of blades with the air [10]), especially for utility scale WTs [11], as it has been reduced efficiently during the last years by advanced mechanical design (e.g. proper insulation to prevent mechanical noise from proliferating outside the nacelle or tower, vibration damping etc.).

Realizing the severity of the noise impact, the up to now rule of thumb dictates that a modern WT should be placed at a distance of at least 300–400 m away -and quite often even further- from the receptor in order for the sound pressure level (SPL) (i.e. perceived sound at a specific point) not to roughly exceed 45–50 dB(A) in daytime (depending on each country's legislation), while at night the level should be lower. In other words, the SPL should at the nearest inhabited areas of wind farms be almost equivalent to the noise inside an unoccupied, almost quiet, air-conditioned office (see also Table 1).

Generally, as it should be expected, the local topography and the unique meteorological conditions of every site largely influence the levels of noise and its diffusion and thus determine the advisable distance between the wind farm and the nearby habitation as

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Table 1
Sound levels of different sources/activities.

Source/Activity	Noise level dB(A)
Threshold of hearing	0
Whisper	30
Rural night-time background	20–40
Quiet bedroom	35
Unoccupied air-conditioned office	45–50
Busy general office	60
City traffic	90
Jet aircraft at 250 m	105
Threshold of pain	140

the case may be. Of course, similar to other impacts of wind energy, perception of the noise also depends on additional features [12,13] such as the area type (i.e. rural or urban), the number of residents and their distance from the wind farm site and finally the type of the community affected (residential, industrial, tourist). The interaction of these factors can either reduce or enhance the perception of sound produced from WTs.

Under the Greek legislation, particularly Article 2 of Decree 1180/81 (although the acoustic protection of noise emission from WTs is not the case), in industrial areas the maximum permissible noise emission level of various mechanical activities is considered equal to 70 dB(A) and for urban areas 50 dB(A), while for a residential building, the legal limit for the SPL (measured inside with open doors and windows) has been set equal to 45 dB(A) regardless of the type of the area where the specific building exists [14].

Acknowledging the importance of the noise impact concerning further adoption of wind energy, in the current study the authors present and evaluate a set of real experimental noise measurements, deriving from a small wind farm located at a complex topography Greek area which includes machines of most technologies available. Emphasis is firstly given on the development of an accurate and reliable experimental process and secondly on the estimation of the real noise impact of the existing WTs dissociated from the background noise for several wind speed values. Finally, the availability of experimental measurements allows for comparisons to be made with simulation results deriving by the application of two well-known software tools (i.e. the international standard DIN ISO 9613-2 “Attenuation of sound during propagation outdoors, Part 2. A general method of calculation” and the Danish regulations entitled “Bekendtgørelse om støj fra vindmøller (Statement from the Department of Environment) No. 304 of 14/5/91”) used to predict wind turbine noise immission. Thus, one may get an idea for the accuracy of prediction models (widely used by wind farm developers) by comparing the simulation results with real acoustic noise immission measurements.

2. Position of the problem: assessing the noise immission of WTs

In the design process of a WT model and in the planning stage of a wind farm, semi-empirical prediction models [12,13,15,16] and software tools, such as those found in most commercial packages, are used to predict noise emissions in most practical cases. Through the years, several semi-empirical models have been designed for predicting noise emissions from WTs [17–21]. In this context, the characteristics of airfoil noise have been investigated extensively in both experimental and theoretical studies [22–26]. These studies formed the basis of various semi-empirical wind turbine noise prediction models, which were validated by comparisons with field measurements [27]. However, some of them are rather simplistic, whereas others make use of complex Computational Fluid Dynamics (CFD) solvers and are still rather time-consuming to be applied for computing noise emission for realistic wind turbine applications.

Up to now, there is no specific official legislation for protecting the acoustic environment from the operation of WTs as well as there are not any defined standards for the proper use of a specific commercial software tool used for estimating the generated noise from WTs. As a result, many models are widely used which however cannot be easily adapted for all wind farm projects. Specifically, computer models have different levels of complexity (some dating from the mid-1980), input data and required assumptions, thus making difficult to evaluate their overall results. Furthermore, it is worth mentioning that due to absence of legislation and the diverse nature of the computer models used to assess noise from WTs, it is almost impossible to predict the aggregate effect on the acoustic environment of a region from the simultaneous operation of many wind farms.

On the other hand, investigating wind turbine noise immission on the basis of real noise measurements comprises a difficult, relatively complex and time-consuming acoustic task [28]. Noise immission measurements refer to the assessment of the sound pressure levels emitted by a WT or a wind farm at the area of the receptor. In this context, a set of techniques and methods for measuring and assessing the noise immission of WTs, which is the WT noise at the receptor level location, have been developed in the past [27,28].

Nevertheless, although standards and guidelines concerning the noise measurement from industrial sources have been in force since the early stages of wind energy development, the procedures adopted do not entirely apply to the measurement of noise produced by WTs. The main reason for this shortcoming is the fact that measurements are carried out in windy conditions, i.e. an issue outside the scope of standards dealing with noise measurements from industrial plants.

Generally, from the WT (source of the acoustic noise) to the wind farm’s broader area (receptor of the acoustic signal) there is usually a complex propagation path and additional sources of noise often interfere at the receptor’s point [29]. In this context, one of the main problems when measuring the noise immission of WTs is the influence of the background noise [8], i.e. the wind at the microphone, the wind acting on adjacent trees, shrubs and structures, traffic on nearby roads and rail tracks, aircrafts and industries, animal and human activities, streams or waves on shorelines etc. As a result, in order to evaluate the noise level of WTs and obtain a clear cut picture, sound pressure levels from a wind farm should also be compared with background sound pressure levels produced by other activities within the wind farm broader area. Nevertheless, in many cases, at wind speeds around 8 m/s and above, it becomes a quite a difficult task to measure sound pressure levels from modern WTs. In fact, WT noise is more noticeable at lower wind speeds (e.g. 4-6 m/s) since the wind is strong enough to turn the blades but it cannot create its own noise. On the other hand, at higher speeds the noise from the wind itself or background sounds may generally mask (obscure) the turbine noise completely [8,30] (see for example Fig. 1).

Considering the above, the importance of valid noise measurements concerning operation of WTs is underlined and thus the development of a methodology for the assessment of real noise immission becomes critical. In an attempt to perform valid noise measurements, the present study is first dedicated to the design and implementation of an experimental measurement methodology and accordingly to the evaluation of experimental measurements obtained, using as a case study the operation of a wind farm at a Greek complex terrain.