Evaluation of Wind Turbine Noise in Japan

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ABSTRACT

In order to tackle with wind turbine noise (WTN) related complaints, Ministry of the Environment of Japan (MOEJ) set up an expert committee in 2013. In November 2016, the committee published a report on investigation, prediction and evaluation methods of WTN. The report compiles recent scientific findings on WTN, including the results of nationwide field measurements in Japan and the results of review of the scientific literature related to health effects of WTN. The report sets out methodology for investigation, prediction and evaluation as well as case examples of countermeasures. A noise guideline for wind turbine, which suggests WTN should not be more than 5dB above the residual noise where residual noise levels are above 35-40dB, is also presented in the report. MOEJ is developing a WTN noise guideline and a technical manual for WTN investigation based on the report. Both documents will be finalized in the fast half of 2017.

INTRODUCTION

Among renewable energy sources, wind power generation is an important energy sources that emits neither air-polluting substances nor greenhouse gases and can also contribute to energy security because the power can be generated by a natural resource readily available in Japan. The Basic Energy Plan of Japan (Cabinet decision in April, 2014) regards wind power generation as an energy source that can be made economically viable because its generation cost could be as low as that for thermal power generation if it could be developed on a large scale.

The number of wind power facilities installed in Japan started to increase around 2001, and 2,034 units were installed by 2014 (as of the end of March, 2015) [1]. According to the Supplementary Materials for the Long-term Energy Supply and Demand Outlook issued by the Agency for Natural Resources and Energy in July, 2015, approximately 10 million kW of wind power is expected to be installed by 2030, which represents a nearly four-fold increase from the existing installed wind power capacity of approximately 2.7 million kW [2].

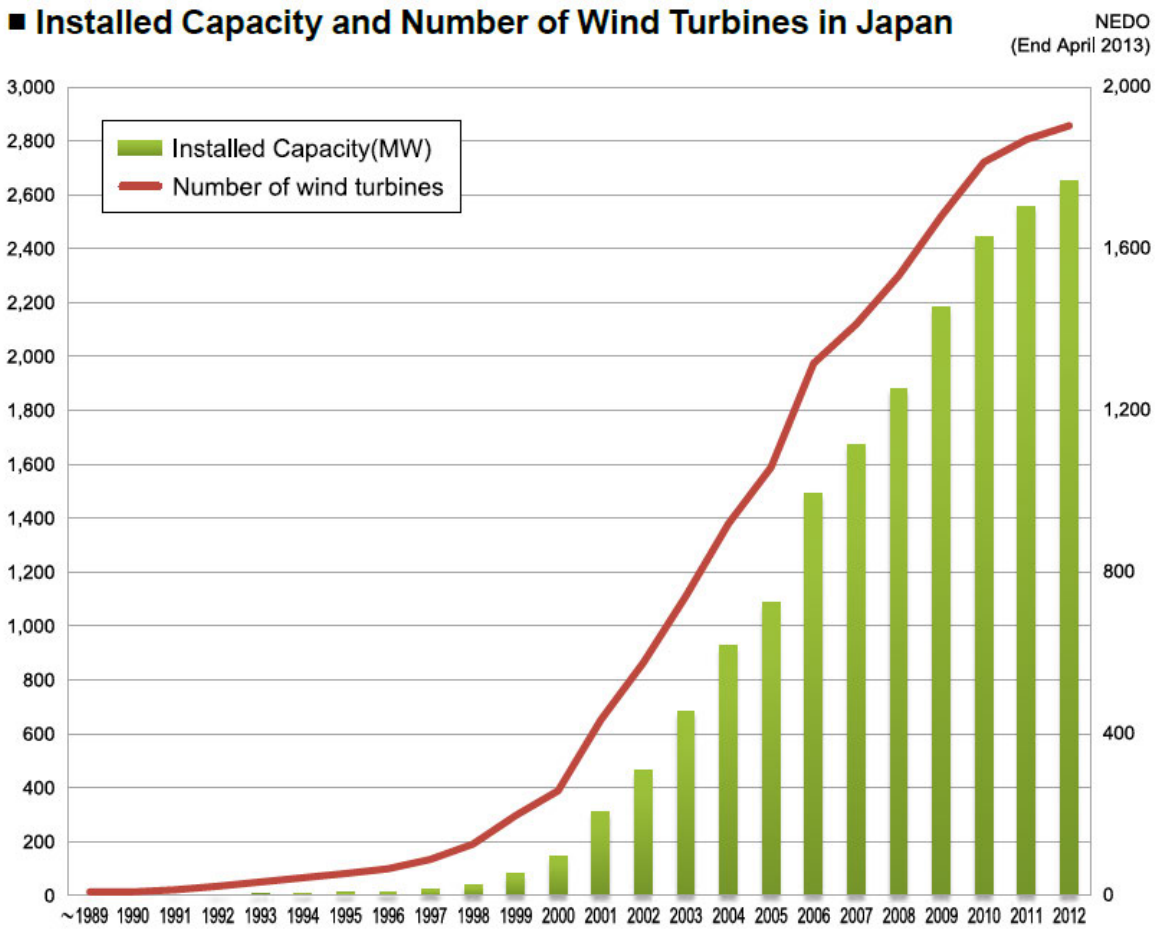

Figure 1: Installed capacity and number of wind turbines in Japan (Source: NEDO)

Wind power facilities emit a certain amount of noise due to their power generation mechanism in which blades rotate by catching wind to generate power. While the noise level is normally not significantly large, there are cases where even a relatively low level of noise causes complaints as wind power facilities are often constructed in agricultural/mountainous areas that have suitable weather conditions including wind direction and velocity that were originally quiet. There have not only been noise complaints but also complaints of inaudible sound of a frequency of 20 Hz or less.

Against such a backdrop, as a result of the amendment of the Order for Enforcement of the Environmental Impact Assessment Act in October, 2012, the establishment of wind power stations came to be classified as relevant projects under the Act and discussions on the environmental impact assessment of wind power facilities have taken place.

In assessing the impact of noise resulting from the installation of a facility, the procedure of environmental impact assessment performed before installation examines "the extent to which such noise can be feasibly avoided or reduced" and, if applicable, "whether it is intended to be consistent with standards or criteria given by the Japanese government or local municipalities from the perspective of environmental protection." For the former examination, the extent to which the impact of noise resulting from the implementation of the relevant project can be feasibly avoided or reduced is assessed by comparing multiple countermeasures in terms of the structure, layout, output, the number of units, and technical noise reduction measures in accordance with the maturity of the project plan. The assessment can also be performed by examining to what extent more feasible technology can be incorporated, etc. Specifically, assessment is made from such viewpoints as whether the local noise level will not be significantly raised, whether the layout plan for the project secures a sufficient distance between the facility and residences, etc.

The Environmental Quality Standards for Noise are generally used for the Environmental Impact Assessment. However, the standards are set based on traditional environmental noise (i.e. traffic noise or noise from factories), not in terms of noise generated from wind power facilities (hereinafter, "wind turbine noise") which has unique acoustical characteristics such as amplitude modulation sound. It is thus necessary to develop methods relevant to the investigation, prediction, and evaluation of wind turbine noise based on the latest scientific findings.

The Ministry of the Environment of Japan (hereinafter, “MOEJ”) has set up an expert committee and examined ideas and issues about methods for investigating, predicting, and assessing wind turbine noise from 2013 to 2016. The expert committee published a report on the investigation, prediction and evaluation methods of wind turbine noise in November 2016. During the development of the report, the MOEJ started a one-month public comment period. All comments were considered, and changes were made to the report where appropriate. The report compiles recent scientific findings on wind turbines in terms of noise, including the results of nationwide field measurements in Japan and the results of review of the scientific literature related to the health effects of wind turbine noise. The report sets out methodology for investigation, prediction and evaluation as well as case examples of countermeasures. Based on the report, MOEJ plans to develop a wind turbine noise guideline and a technical manual for wind turbine noise investigation in the fast half of 2017.

This report introduces the report by the expert committee, the wind turbine noise guideline and the technical manual for wind turbine noise investigation.

OUTLINE OF THE REPORT

The report by the expert committee consists of three parts. The first part explains key findings from past researches, namely the field survey measuring wind turbine noise in Japan and a literature review on wind turbine noise and human health. The second part proposes methods for investigating, predicting and evaluating wind turbine noise. A guideline on wind turbine noise is proposed in this part. The third part states the actions recommended by the expert committee. The following chapters summarize those three parts of the report.

KEY FINDINGS

Findings from the field study

Field surveys measuring wind turbine noise conducted in Japan from 2010 to 2012 revealed the following.

In terms of spectral characteristics, wind turbine noise generally has a spectral slope of -4 dB per octave. It has a 1/3 octave band sound pressure level in all parts of the super-low frequency range, which means 20 Hz or lower, is below the ISO threshold of hearing for pure tones and the criterion curve for the evaluation of low frequency noise proposed by Moorhouse et al. (Fig. 2). Super-low frequency range components of wind turbine noise are at imperceptible levels. Therefore, wind turbine noise is not an issue caused by super-low frequency range.

In regard to the audible frequency range, in the range from about 40 Hz and above, the 1/3 octave band sound pressure level is above the said criterion curve and the threshold of hearing defined by ISO 389-7. Therefore, wind turbine noise should be regarded as "audible" sound (noise) in discussing it.All papers must contain an abstract of max. 180 words. A

concise and factual abstract is required. The abstract should state briefly the purpose of the research or project, the principal results and major conclusions. An abstract is often presented separately from the paper, so it must be able to stand alone. For this reason, references should be avoided, but if essential, then cite the author(s) and year(s). Your abstract will be published in the printed and in the online program of the congress.

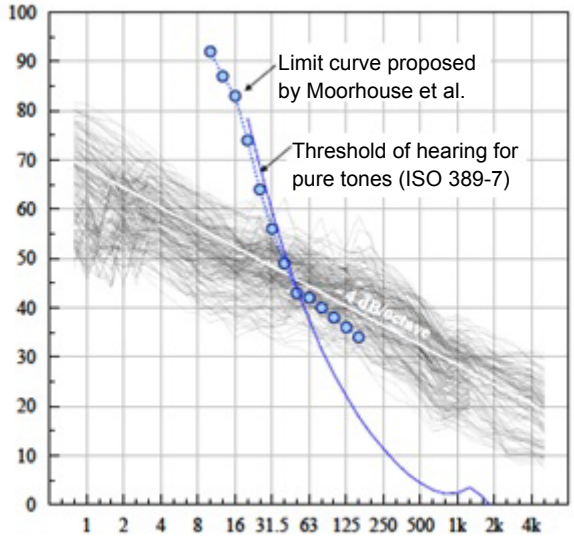

Figure 2: Results of the analysis of frequency characteristics of wind turbine noise (at 164 locations in the vicinity of 29 wind power facilities in Japan)

Noise exposure levels of nearby residents from wind power facilities are distributed in the range of 26–50 dB in time-averaged A-weighted sound pressure levels. While this implies that wind turbine noise is not significantly higher than other types of environmental noise, it can cause serious annoyance to those living residential areas in the vicinity of wind power facilities located in extremely quiet agricultural/mountainous areas.

Low-frequency components of wind turbine noise obtained from field measurements were within the range of those of other environmental sounds.

In Japan, it is known that the following relation holds between LAeq, which properly excludes non-relevant noise, and LA90: LAeq≒LA90+2 dB

It is also generally said that acoustic isolation is not always effective for noise from wind power facilities because it contains more low-frequency components. In a quiet environment with little noise of other types, it is relatively more easily heard than ordinary noise is.

Findings from the literature review on health effects

After careful assessment of the evidence obtained from peer reviewed research results from around the world, it has been concluded that wind turbine noise has likely no negative effects on human health.

However, amplitude modulation and the tonal sounds of wind turbine noise tend to increase annoyance. Existing research results indicate that wind turbine noise over 35 – 40 dB raises annoyance and that the risk of sleep disturbance may increase accordingly.

No clear association is seen between infrasound or the low-frequency noise of wind turbine noise and human health.

Some research results have suggested that wind turbine noise related annoyance is also affected by other issues such as visual aspects or economic benefits.

METHODS FOR INVESTIGATING AND PREDICTING WIND TURBINE NOISE, A PERSPECTIVE FOR ITS EVALUATION, AND RESPONSES AGAINST IT

In light of the findings described in Section 2, the issue of wind turbine noise should be taken not as one of super-low frequency sound below 20 Hz but as one of "audible" sound (noise), and it should be basically measured at the A-weighted sound pressure level. We here summarize matters to be noted in conducting an investigation and/or the prediction of noise before and after installing wind power facilities and a perspective for wind turbine noise evaluation.

Investigation and prediction before installation

Matters to be noted upon an investigation

In selecting a method for investigation, it is necessary to collect various kinds of information in light of business and regional characteristics in order to conduct prediction and evaluation appropriately. Particularly with regard to wind turbine noise, it is important to distinguish and discuss three major issues:

(1) Sound source characteristics

It is necessary to pay attention to:

- information on the wind power facility concerned, including its specifications, manufacturer, model number, hub height, rotor diameter, rated wind velocity, and power generation;
- the sound power level of the generated noise;
- the A-weighted overall value and frequency characteristics (including the 1/3 octave band sound power level) of the sound power level at the rated (maximum) output (to grasp the situation of maximal environmental impact);
- A-weighted overall values and frequency characteristics (including the 1/3 octave band sound power level) of sound power levels under different wind velocities;
- pure tonal frequency components (to be determined in accordance with IEC 61400-11:2012); and
- existing data pertaining to the same model in operation.

(2) Propagation characteristics

In Japan, wind power facilities are often installed in agricultural/mountainous areas. Sound waves emitted from a wind power facility installed in an agricultural/mountainous area are affected by various factors before propagating to a sound receiving point (assessment point), in comparison with one installed on a large, flat piece of land such as a plain or desert. Its noise level and frequency characteristics tend to change due to phenomena including

reflection, absorption, transmission, refraction, and diffraction. It is therefore necessary to pay attention to:

- phenomena such as the reflection, absorption, or diffraction of wind turbine noise due to undulating terrain or ridges,
- the state of the ground surface (including rivers and lakes), and
- meteorological information such as wind conditions including wind direction, velocity, and frequency.

(3) Information on a sound receiving point (assessment location)

With regard to locations where an investigation is conducted, focusing on the daily life and activities of residents in the vicinity of a wind power facility, it is necessary to pay attention to:

- the configuration of establishments particularly requiring consideration for environmental conservation such as schools and hospitals and the outline of housing configuration (including the structure of each house), and
- the state of the acoustic environment (degree of quietness) of the area in question.

(4) The specific method for investigation

In measuring residual noise in a given area, it is necessary to pay attention to the following.

a. Sound to be excluded

Sounds of the types given below should be excluded. Since wind power facilities operate when wind is blowing, noises caused by wind such as the sound of rustling leaves are not excluded. ("Wind noise" generated by wind hitting a sound level meter's microphone is excluded, however.)

i) transitory noise such as the sound of automobiles passing nearby and aircraft noise
ii) artificial sound not occurring regularly such as sound generated by accidents/incidents, vehicles driven by hot-rodders, emergency vehicles, etc.
iii) natural sound not occurring regularly such as sound generated by natural phenomena including rain and defoliation, animals' cries, etc.
iv) sound incidental to measurement such as the voice of a person talking to a measurer, sound of tampering with measuring instruments, etc.

b. Surveying and other equipment

As the wind is generally strong in areas around wind power facilities, it is important to use a windbreak screen in order to avoid the effects of wind noise to the extent possible when measuring residual noise. Several kinds of urethane spherical windbreak screens of different diameters are commercially available. In general, the larger the diameter of such a screen is, the less likely a sound level meter inside the screen will be affected by wind noise. Installing a windbreak screen can reduce the impact of wind noise up to a wind velocity of around 5 m/s.

c. Survey areas and locations

Considering the propagation characteristics of wind turbine noise, the survey targets areas susceptible to an environmental impact by wind turbine noise, such as residential areas in the vicinity of a wind power facility (generally within a radius of about 1 km from a wind turbine). An area in which a quiet environment should be conserved such as hospital premises may be

included in these target areas. In selecting specific survey locations in the survey areas, in addition to locations where a wind power generation facility is planned to be installed, such locations are to be selected that are immune to local impacts of particular sound sources where the average level of noise in the relevant area can be assessed, including residential areas around the wind power generation facility. Measurement is to be performed at an outdoor location 3.5 m or more distant from a reflective object, excluding the ground.

d. Survey period and hours

In order to grasp conditions throughout the year accurately, a survey is to be conducted in each period of the year for different typical meteorological conditions under which a wind turbine operates (for instance, each season if meteorological conditions vary greatly by seasons).

The period of a single survey should be appropriately determined in consideration of the time variation of noise due to the impact of meteorological conditions and other elements. As measurement values may be unstable depending on wind conditions, a survey should be performed for three or more consecutive days in principle. The survey should be conducted both during the day (6:00–22:00) and at night (22:00–6:00) hours.

Matters to be noted in prediction

As mentioned above, in Japan, wind power facilities are often installed in agricultural/mountainous areas. In comparison with cases where such a facility is installed on a large, flat piece of land such as a plain or desert, sound waves emitted from a wind power facility installed in a mountainous area diffuse in a more complicated manner as they propagate due to the influence of geological states, vegetation, meteorological conditions such as wind conditions, etc. In addition, it should be noted that the propagation of wind turbine noise is extremely complicated as it is subject to attenuation by distance, reflection and absorption by the ground surface, reflection and diffraction by acoustic obstructions, attenuation by atmospheric absorption, etc.

Among the prediction methods used, while "ISO 9613-2：1996" allows incorporation of more detailed conditions, the prediction calculation becomes rather complex. Furthermore, there is the problem of how the reflection rate should be calculated in cases where the effect of reflection by the ground surface becomes an issue, as is the case with a wind turbine installed on a ridge.

The New Energy and Industrial Technology Development Organization (hereinafter, "NEDO") published a prediction method for the environmental impact assessment of wind power generation in July, 2003 (revised as the second version in February, 2006). This models wind power facilities as sound source points and uses sound power levels provided by manufacturers of wind power generators. This method takes into account distance attenuation due to sound diffusion in the propagation process and attenuation by atmospheric absorption. While this method can be used easily, it is difficult to consider meteorological effects, etc.

It is necessary to pay attention to such characteristics of methods in making predictions.

Survey after the installation of a wind turbine

As stated in Section 3.1, predicting wind turbine noise involves elements with large uncertainty such as emission characteristics of noise from the source and effects of meteorological conditions as well as the terrain and structures in the propagation process. Predicted values before the installation of a wind turbine and measured values after installation may sometimes differ greatly.

We here summarize matters to be noted in a survey after the installation of a wind turbine.

(1) Conditions of measurement

It is necessary to grasp the conditions of measurement and other relevant local matters that may impact the propagation of noise. At least, one should grasp the wind direction and velocity at the nacelle height, the variation of power output, and meteorological data required for calculating the attenuation by atmospheric absorption (wind direction and velocity, temperature, and humidity).

(2) Survey method

Wind turbine noise varies greatly according to the wind conditions, and a wind turbine often starts and suspends operation repeatedly. Therefore, measurement should be performed in appropriate hours considering the state of operation of the wind power facility in question. For example, a method is conceivable that measures the average level in a 10-minute period in which wind turbine noise is stable (10-minute equivalent noise level: L_{Aeq}, 10 min) and regards it as the representative value. If the relevant wind power facility operates steadily for many hours, it is effective for obtaining robust data, for instance, to measure noise for 10 minutes every hour on the hour and calculate the average energy over the entire period of time.

For measurement locations, period, etc., refer to what is noted for a survey before the installation.

(3) Survey Results

The representative value of a survey after the installation of a wind power facility should be taken as the A-weighted equivalent sound pressure level measured over a period of time in which the effect of wind turbine noise is at its maximum and in which the effect of background noise is low (e.g. during night time). It is also required to confirm whether there is any pure tonal component.

The equivalent noise level during operation can be estimated by adding around 2 dB to the noise level exceeded for 90% of the measurement period (L_{A90}).

Evaluation of wind turbine noise

With regard to the evaluation of wind turbine noise, the expert committee proposed the development of a new guideline. Detailed proposals on the new guideline are as follows:

- The guideline should be applied when a wind power facility will be newly built or a wind power facility will be retrofitted to add a power generation facility.
- As a guideline value, “residual noise + 5dB” is proposed.
- Residual noise should be measured when wind is steady.
- In low noise environments, a lower limit for wind turbine noise should be set since there is no acoustic benefit. Wind turbine noise should be limited to 35dB in the

areas where background noise is lower than 30 dB and where some noise sensitive locations exist. For other areas, 40 dB should be set as the lower limit of wind turbine noise.

- To apply the guideline, locations where wind turbine noise might affect residents' daily activities (e.g. nearest dwellings) should be selected.
- To conserve the indoor environment, evaluation should be made based on outside noise data (both day and night).

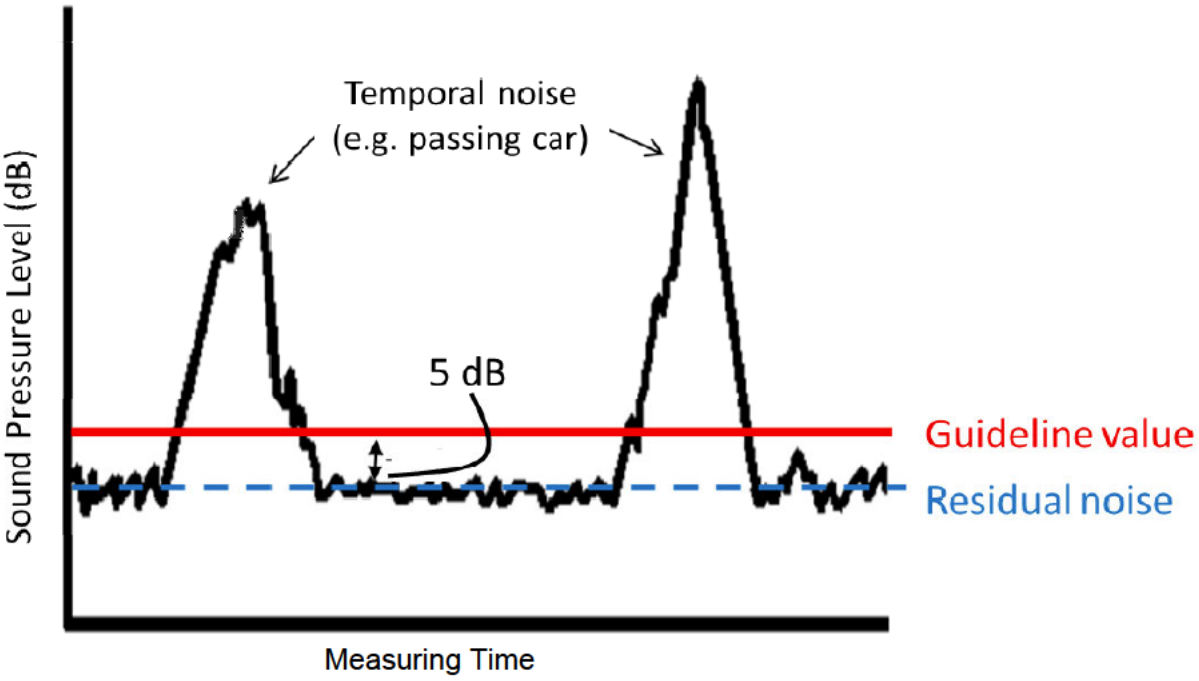

Figure 3: Image of relationship between residual noise and guideline value

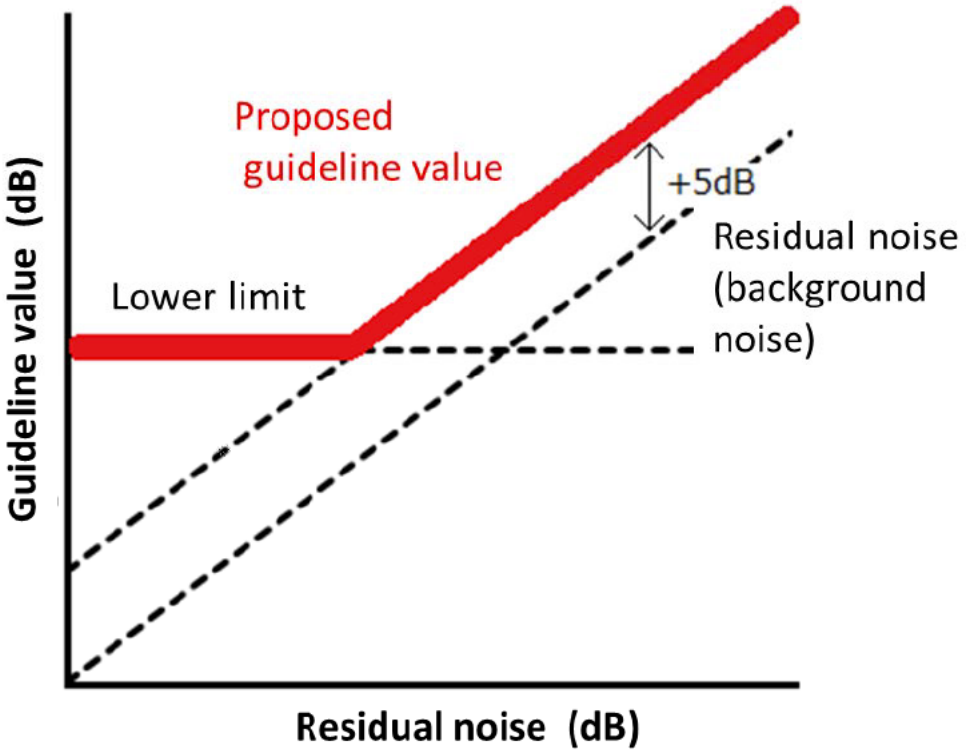

Figure 4: Image of guideline value

RECOMMENDED ACTION

The expert committee recommended actions to be taken by stakeholders.

As for operators and manufacturers of wind power facilities, recommended actions include accumulating survey data after the installation of wind power facilities, promoting R&D for noise abatement technologies such as low noise blades. .

As for administrative agencies (the government of Japan and local municipalities, recommended actions include developing a wind turbine noise guideline and a detailed technical manual for investigation.

As for all parties concerned, recommended actions include facilitating communication among stakeholders.

WIND TUBINE NOISE GUIDELINE AND TECHINICAL MANUAL

On the basis of the report by the expert committee, MOEJ is developing a wind turbine noise guideline and a detailed technical manual for wind turbine noise investigation to be finalized in the fast half of 2017.

The key points of noise guideline are as follows:

- All parties related on wind turbine should consider the social, geographical, or meteorological characteristics of the location of wind power generations and the noise from them.
- The guideline aims to prevent possible noise related effects to protect living environment (indoor environment) of neighborhood residents before installation of a new wind power facility.
- A guideline value of wind turbine noise should be set as “residual noise + 5dB” where residual noise level is above 35-40 dB.
- Evaluation should be made based on outside noise data both day and night.

The technical manual covers following points:

- Methods to investigate wind speed and directions,
- Methods to investigate residual noise including site selection, sampling period, and necessary equipment,
- Methods to investigate wind turbine noise including site selection, sampling period, and necessary equipment
- Methods to process collected data
- Recommended formats to record data

CONCLUSION

This paper summarizes the basic ideas and methods proposed by the report published by the expert committee on wind turbine noise in November 2016, a noise guideline and a technical manual for wind turbine noise investigation which will be finalized in the fast half of 2017.

Acknowledgements

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