The Director General

Maisons-Alfort, 14 February 2017

# OPINION
# of the French Agency for Food, Environmental and Occupational Health & Safety

**regarding the expert appraisal on the "Assessment of the health effects of low-frequency sounds and infrasounds from wind farms"**

*ANSES undertakes independent and pluralistic scientific expert assessments.*
*ANSES primarily ensures environmental, occupational and food safety as well as assessing the potential health risks they may entail.*
*It also contributes to the protection of the health and welfare of animals, the protection of plant health and the evaluation of the nutritional characteristics of food.*

*It provides the competent authorities with all necessary information concerning these risks as well as the requisite expertise and scientific and technical support for drafting legislative and statutory provisions and implementing risk management strategies (Article L.1313-1 of the French Public Health Code).*

*Its opinions are published on its website.*
*This opinion is a translation of the original French version. In the event of any discrepancy or ambiguity the French language text dated 14 February 2017 shall prevail.*

On 4 July 2013, ANSES received a formal request from the Directorate General for Risk Prevention (DGPR) and the Directorate General for Health (DGS) to undertake the following expert appraisal: assessment of the health effects of low-frequency sounds and infrasounds from wind farms.

## 1. BACKGROUND AND PURPOSE OF THE REQUEST

The development of wind turbines as renewable sources of electrical energy has led to questions about their potential to produce low-frequency sounds (20 Hz to 200 Hz) and infrasounds (below 20 Hz), and their possible impact on health.

In March 2006, the French National Academy of Medicine considered, in a report on the impact of the operation of wind turbines on human health, that the noise impact of wind farms is comparable to that of airports, transport infrastructure and factories. This report recommended classifying wind farms as "industrial zones" and keeping a minimum distance of 1,500 metres between wind turbines and residential areas.

Further to a new request from the DGPR and DGS, the French Agency for Environmental Health (AFSSE) concluded, in its report entitled "Health effects of noise from wind turbines" published in March 2008, that the noise emissions of wind turbines have no direct consequences on health, whether in terms of the auditory system or effects related to exposure to low frequencies and infrasounds. This report also considered that setting a systematic minimum distance of 1,500

metres, without taking into account the environment (topographic in particular) of the wind farm, did not seem appropriate.

The French regulations on wind turbines have since been amended, with the introduction of a minimum separation distance of 500 metres from any residential dwelling, and then the classification of wind farms in the regime of Classified Installations for the Protection of the Environment (ICPE, Ministerial Orders of 26 August 2011). These texts consider the octave bands from 125 to 4,000 Hz. Very low frequencies and infrasounds, which are more difficult to measure, are currently not taken into account.

As highlighted in a review of the French and foreign regulations produced in 2014 by the French Information and Documentation Centre on Noise (CIDB), at ANSES's request, there are currently no harmonised regulations in the European Union specific to noise from wind turbines or to infrasounds and low-frequencies from all other noise sources. Only a few national guidelines include specific provisions on wind farms. Most of the complaints filed about low-frequency noises have been related to situations of exposure inside buildings. Some countries[1] have therefore formulated recommendations on exposure to low-frequency noises and infrasounds inside homes, most often located near industrial facilities.

In France, complaints from local residents regarding noise from wind turbines have been reported to the DGPR by Regional Directorates of the Environment, Land-Use Planning and Housing (DREALs).

In this context, on 4 July 2013, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) received a formal request from the Directorate General for Risk Prevention (DGPR) and the Directorate General for Health (DGS) to assess the health effects of low-frequencies and infrasounds from wind farms. The Agency was asked to address the following points in particular:

- conduct a review of the available knowledge of the auditory and extra-auditory health effects of wind farms, in particular in the area of low-frequencies and infrasounds;
- study the regulations implemented in countries, mainly European, faced with the same issues;
- measure the noise impact of wind farms, especially of those where disturbance has been reported by local residents, taking into account the contributions of low-frequencies and infrasounds;
- propose avenues of improvement taking into account possible health effects in the regulations, as well as recommendations to better understand these health effects in impact assessments for wind turbine projects.

## 2. EXPERT APPRAISAL METHOD

## Organisation of the expert appraisal

ANSES entrusted the examination of this formal request to the Working Group on the "Health effects of low frequencies and infrasounds from wind farms", reporting to the Expert Committee (CES) on the "Assessment of risks related to physical agents, new technologies and development areas".

[1] For example, Denmark officially included low-frequency sound in its regulations on the noise impact of wind farms. But the insulation values used to calculate levels of exposure to low-frequency sounds in homes are controversial.

This Working Group, set up following a public call for applications, brought together experts selected for their competence and independence in complementary scientific and technical fields. It held 27 plenary meetings (at ANSES) between April 2013 and October 2016.

Several hearings with stakeholders and eminent scientists were held during these meetings, to enable the Working Group to have all useful and necessary information to undertake the expert appraisal.

Lastly, two additional studies were requested, as part of the research and development agreements financed by ANSES:

- a review, by the CIDB, of the current regulations on low-frequency noise, applying to wind turbines in France and abroad;
- an analysis of the socio-economic context surrounding the construction of wind farms, by the International Environment and Development Research Centre (CIRED)[2].

The methodological and scientific aspects of this expert appraisal work were regularly submitted to the CES. The produced report and collective expert appraisal summary take into account the comments and additional information provided by the members of the CES.

The expert appraisal was carried out in accordance with French Standard NF X 50-110 "Quality in Expert Appraisals – General Requirements of Competence for Expert Appraisals".

ANSES analyses interests declared by experts before they are appointed and throughout their work in order to prevent risks of conflicts of interest in relation to the points addressed in expert appraisals.

The experts' declarations of interests are made public *via* the ANSES website (www.anses.fr).

## Description of the expert appraisal method

### Measurement campaigns on exposure to noise from wind turbines

In order to supplement the data from the scientific literature on exposure to infrasounds and low frequencies from wind farms, ANSES commissioned noise measurement campaigns (including low frequencies and infrasounds) in the vicinity of several wind farms. These acoustic measurements were taken by the National Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning (CEREMA[3]).

For the selection of sites (wind farms) for the measurement campaigns, a compromise was made between the number of sites to be included in the study and the desired level of analysis for each of these sites.

The measurement campaign protocol was designed so as to have, for each studied wind farm:

- all possible classes of wind (wind speed and direction categories);
- access to four simultaneous measurement points:
    - at the regulatory minimum separation distance (500 m);

[2] Joint research unit no. 8568 of the French National Centre for Scientific Research (CNRS).

[3] CEREMA is a public agency created in 2014 to provide enhanced scientific and technical support for the development, implementation and evaluation of public policies for development and land planning. It comprises the eight former Technical Centres for Public Works (CETEs), the former Centre for Studies on Networks, Transport, Urban Planning and Public Construction (CERTU), the former Centre for Technical Maritime and River Studies (CETMEF), and the former Technical Agency for Transport, Roads and Planning (SETRA).

- at the façade and inside a home (preferably as close as possible to a wind turbine);
- and close to the source, in order to characterise the noise emissions of wind turbines.

Following an analysis comparing several criteria of interest listed by the Working Group's experts and the known characteristics of wind farms in France, three sites were selected, with the following characteristics:

- site 1: farm with the largest (blade diameter) and most powerful wind turbines in operation in France on the dates of this analysis period. These wind turbines are theoretically those emitting the most infrasounds and low frequencies, due to their large dimensions, and prefigure future wind turbines of over 3 MW (measurement period: from 12/10/2015 to 19/10/2015; 1,000 usable 10-minute samples);
- site 2: farm with a "conventional" configuration against which complaints had been filed (measurement period: from 30/06/2015 to 06/07/2015; 887 usable 10-minute samples);
- site 3: farm with a "conventional" configuration against which no complaints had been filed (measurement period: from 23/03/2015 to 27/03/2015; 541 usable 10-minute samples).

- **Review of knowledge related to the health effects of infrasounds and low-frequency noise emitted by wind farms**

A systematic literature search[4] by keywords was undertaken for the period up to 1 December 2015; the corpus of documents was regularly updated during the expert appraisal.

In addition to this search, other documents were found *via* the references in the key reports and documents previously identified.

Lastly, the body of literature was supplement *via* hearings[5], in which the various invited stakeholders informed the Working Group of the references they considered relevant on the topic.

These various documents were sorted, analysed and summarised.

Given the controversies associated with "environmental diseases" such as vibroacoustic disease (VAD) and wind turbine syndrome (WTS), the analyses of articles relating to them were compiled in a specific summary.

Moreover, the analyses of articles were grouped together by study type:

- experimental data;
- epidemiological data.

- **Assessment of health risks related to exposure to infrasounds and low-frequency sounds emitted by wind farms**

The conclusions of the expert appraisal thus rely on a comparison of data on exposure to the infrasounds and low frequencies measured near wind farms, and the levels of evidence provided by the review of knowledge on the potential health effects related to exposure to infrasounds and low-frequency sounds.

[4] The following search engines were used: PubMed, Science Direct and Google Scholar.

[5] In particular the French Renewable Energies Union (SER), Électricité de France (EdF) / Électricité de France – Énergies Nouvelles, France Énergie Éolienne (FEE), Vent de Colère, the Sustainable Environment Federation (FED) and several residents living near wind farms.

## 3. ANALYSIS AND CONCLUSIONS OF THE CES

# Results and conclusions of the collective expert appraisal

The CES on "Physical agents, new technologies and development areas" adopted the collective expert appraisal work and its conclusions and recommendations as described in this summary at its meeting of 5 December 2016 and informed the ANSES General Directorate accordingly.

- **Exposure of local residents to infrasounds and low frequencies emitted by wind turbines**

The measurement of exposure to infrasounds and low frequencies in residents living near wind farms involves several complexities:

- of a metrological nature: the calibration of measurement instruments is complicated and unsatisfactory for very low frequencies, as instrumental background noise is higher at low frequencies;
- of an organisational nature: the current lack of published technical standards limits the relevance of comparisons between measurements taken by various teams, and does not guarantee the quality of practices. For example, the choice of the apparatus used and frequency bands studied heavily influences the results. However, a draft standard on the measurement of infrasounds for all noise sources is about to be published by AFNOR;
- related to the particularities of the noise source and its environment: the sound signal fluctuates over time depending on various factors, some of which are clearly identified (wind speed, topography, etc.) while others remain undetermined or cannot be verified (wind turbulence on the blades or in the propagation medium, local temperature gradients, etc.);

Inside homes, there are also difficulties measuring weak signals, and problems of sound wave reverberation.

These metrological challenges were taken into account in the measurement campaign undertaken near the three wind farms. This work, supplemented by the data from the literature, led to the following findings:

- wind turbines are sources of noise whose spectrum of sound emission mainly contains infrasounds and low-frequency sounds. According to the scientific literature, the sound level of these spectral components increases with the size of the wind turbine's rotor;
- the measurement results on the noise emissions of the wind turbines confirmed the trends described in the scientific literature:
    - the general profile of the spectrum of noise emissions from wind farms (near-linear decrease in the sound level with the logarithm of the frequency) was found on all the sites, with few major differences. A few frequency peaks, probably attributable to mechanical noise in the nacelle, were found in the infrasound and low-frequency part of the spectrum;
    - the greater the increase in wind speed, the greater the increase in noise emissions of infrasounds and low frequencies, up to a theoretical maximum;

- the measurement results for sound levels at 500 m and 900 m (at the façades of homes) from the wind farms confirmed the trends observed in the scientific literature for two of the three explored sites[6]:
    - a wide spread of measurements as a function of time for a given wind farm and wind conditions. Other factors that are difficult to verify (occasional wind turbulence, contamination by other noise sources, etc.) may have had a non-negligible impact on measured noise;
    - the hearing thresholds for infrasounds and low frequencies (< 50 Hz) were not exceeded;
- the infrasound and low-frequency signals measured inside homes, in conditions where wind turbines were operating with the highest wind speeds (above 6 m/s) encountered when taking the measurements, were below the hearing threshold (ISO 226[7]).

The CES points out that noise level measurements expressed in dBA, which are those recommended by the technical standards, are not suited to infrasounds or low-frequency sounds. However, the particular profile of the spectrum of wind turbine noise implies proportionality between the spectral content measured in dBA and the spectral content of infrasounds and low-frequency sounds. Thus, relevant information regarding exposure to infrasounds and low frequencies can be obtained from exposure data measured in dBA. This finding is consistent with those established in recent studies.

Therefore, in light of the emission spectra of current wind turbines, limiting a noise level in dBA also means limiting the noise level of infrasounds and low frequencies.

## ■ Health effects of infrasounds and low-frequency sounds: exploitation of the available scientific knowledge

### An imbalance between primary and secondary sources

An examination of the available data on the health effects of infrasounds shows a strong imbalance between primary (documents on original experiments or scientific studies) and secondary (reviews of the scientific literature and opinion articles) literature sources. Indeed, there are many secondary sources while the number of primary sources they are supposed to summarise is limited. This particularity, combined with the markedly different conclusions of these reviews, clearly shows that there is strong public controversy surrounding this issue.

### Review of the health concerns expressed by residents living near wind farms

The symptoms described by some residents living near wind farms, which they associate with their exposure to noise emissions from wind turbines, are extremely varied. In the literature, they were classified into two categories:

- those associated with vibroacoustic disease (VAD);
- those characteristic of wind turbine syndrome (WTS).

VAD was defined by a single research team[8] and refers to a specific biological mechanism that it links to exposure to infrasounds and low-frequency sounds (growth of collagen and elastin fibres in extracellular matrices, in the absence of any inflammatory process). This mechanism could,

[6] The sound contribution of wind turbines in relation to other noises recorded for local residents at site no. 2 could not be clearly established, causing this site to be excluded from the analyses.

[7] ISO 226:2003: Acoustics - Normal equal-loudness-level contours.

[8] Research team of Alves-Pereira and Castelo-Branco.

according to these authors, ultimately lead to the occurrence of a wide variety of health effects (fibroses, damage to the immune system, respiratory effects, genotoxic effects, morphological changes in organs, etc.).

The Working Group attributed a very low level of evidence to this assumption of a mechanism for health effects, due to its weak scientific bases and major biases in the studies published by this team, often in non-peer-reviewed journals, whose results have not been reproduced by other research teams. Therefore, the Working Group did not take VAD into account in the assessment of the potential health risks related to noise emissions from wind turbines.

Wind turbine syndrome was described in the literature (Pierpont 2009) as a set of symptoms reported by residents living near wind farms which they themselves attribute to wind turbines. These symptoms (sleep disturbance, headaches, tinnitus, balance problems, etc.) are not specific to a disease. They are found in syndromes of idiopathic environmental intolerance in particular. However, they correspond to a set of signs that may occur further to stress or sleep loss, which may become disabling for the subject who experiences them.

**Review of the experimental data**

- ✓ **Potential mechanisms for effects via the cochleovestibular system, which have yet to be confirmed**

Recently acquired knowledge related to the physiology of the cochleovestibular system has highlighted several potential mechanisms for physiological effects that could be activated in response to exposure to infrasounds and low-frequency sounds. This sensory system is indeed particularly susceptible to these frequencies, more so than other parts of the human body.

The current data suggest that sound frequencies that are too low or levels that are too soft to be clearly heard could have effects mediated by receptors of the cochleovestibular system. The possible mechanisms include the following:

- the induction of non-auditory responses by the vestibular cells when a very low-frequency sound reaches the base of the cochlea;
- the "non-conventional" stimulation of the most apical auditory sensory cells activating non-auditory cochlear pathways;
- the induction of ionic and volume imbalances in the fluid of the inner ear, through the prolonged overall generation of vibrations of the basilar membrane by a very low-frequency sound;
- the induction of modulations in the response of auditory sensory cells to ordinary sounds by very low-frequency sounds, which themselves are inaudible but affect the audibility of concomitant audible sounds. Certain characteristics, particularly anatomical, could predispose their carriers to more intense modulations;
- assuming that when certain noise levels are exceeded, it is likely to generate nerve stimulation in the cochleovestibular system (Salt and Hullar 2010), the noise levels occasionally[9] encountered when taking the measurements showed that these levels can be exceeded outside homes, for frequencies below 20 Hz.

The phenomena described above were experimentally observed with intense pure tones (e.g. around a hundred dB SPL at 200 Hz in small laboratory animals, which is not necessarily the equivalent of very low-frequency sound in humans); whether they occur for noise exposure similar

[9] From a few % of the time at 8 Hz to 20% of the time for 20 Hz at a distance of 500 m from the wind turbine. No frequencies below 8 Hz exceeded the various thresholds.

to that caused by wind turbines (prolonged, complex tones of lesser intensity) remains to be demonstrated.

The Working Group underlines that these physiological effects, often described by associations of residents living near wind farms, have an objective signature; for example, if there is a volume imbalance in the fluid of the inner ear, this is manifested as abnormal ENT test results, with higher sensitivity and specificity. And yet this signature has never been tested for in complainants.

These physiological effects are also reflected in symptoms (dizziness, tinnitus, nausea, etc.) that people know how to describe but are seldom mentioned; however the various testimonials collected during this expert appraisal more commonly described other types of effects, such as sleep and mood disturbances (depression, stress, anxiety, etc.).

- ✓ **Ill-defined effects for exposure to very high-intensity infrasounds and low-frequency sounds**

Exposure to very high-intensity infrasounds and low-frequency sounds (intensities 20 to 40 dB higher than those of wind turbines, thus delivering energy levels 100 to 10,000 times greater) is found in the workplace. However, its effects are controversial (non-specific effects, unsubstantiated and/or old data, etc.). The scientific situation is therefore unclear and the published recommendations on the limitation of occupational exposure can in no circumstances be transposed to this formal request.

- ✓ **Unstable knowledge of the effects of prolonged exposure to lower-intensity infrasounds and low-frequency sounds**

There are very few peer-reviewed publications addressing the issue of the potential effects of infrasounds and low frequencies produced by wind turbines. However, some studies have been undertaken for other noise sources, such as ventilation, heat pumps, compressors, road traffic, etc., for the same intensity levels as those emitted by wind farms. In these studies, self-reported disturbance (questionnaire) was the only observed health effect. No link was found with any physiological marker enabling a health effect to be identified. Nonetheless, these studies helped establish that a much higher sound level than that known for higher frequencies is required to perceive an infrasound and/or hear a low-frequency sound. Caution is required when extrapolating the above results to the situation of wind turbines.

- ✓ **An observed *nocebo* effect**

In parallel with these controversial results regarding the effects of prolonged exposure to low-intensity infrasounds and low-frequency sounds, several repeated double-blind experimental studies of very high scientific quality have shown negative effects and feelings in people who thought they were exposed to inaudible infrasounds when this was not necessarily the case. These negative effects and feelings were thought to be due to mere expectations about the harmful effects associated with this exposure.

This "*nocebo*[10]" effect helps explain why residents living near wind farms report stress-related symptoms. It is likely even greater in a context where there are multiple opposing arguments not only related to health (economic, cultural, regional, political arguments, etc.), conveyed in particular on the Internet, which can contribute to creating an anxiety-inducing situation.

[10] The *nocebo* effect can be defined as a set of symptoms experienced by a subject undergoing something that is "seen as negative"; this may be medication, non-medicated therapy, or exposure to environmental factors. It is the opposite of the *placebo* effect, initially defined in medicine as a *"Substance improving a patient's symptoms whereas its phamacologically predictable efficacy should be nil or negligible".* The effect of the vector varies in both cases depending on the subject's expectations.

However, the occurrence of such a *nocebo* effect does not rule out the actual occurrence of health effects that it may potentially exacerbate.

**Review of the epidemiological data**

✓ **Limited and inconclusive studies**

Epidemiological studies should enable a comparison of the potential mechanisms for physiological effects with the health conditions observed in local populations. Unfortunately, such studies are limited in number and have exclusively dealt with the effects of audible noise from wind turbines on the health of local residents. None have focused on the health effects of infrasounds or low-frequency sounds emitted in the environment and more specifically produced by wind turbines.

All were cross-sectional studies and therefore did not provide grounds to affirm that the cause, i.e. exposure to noise from wind turbines, preceded the effect. The results observed in the majority of these studies were marked by selection biases or confounding factors. Only one of the analysed studies can be considered as of good scientific quality. It was also the only one that included not only subjective measurements but also objective measurements associated with the potential effects it examined. This study did not show any link between the level of audible noise from wind turbines and the health conditions self-reported by the respondents (sleep quality, dizziness, tinnitus, frequent migraines and headaches, chronic diseases such as heart diseases, hypertension and diabetes), stress levels, or perceived quality of life. The objective health measurements (cortisol levels in hair, blood pressure, resting heart rate and measured sleep quality) were consistent with the participants' reports. Again, these measurements were not linked to the level of audible noise from wind turbines. However, this study did show a link between this same level of audible noise and disturbance due to certain wind turbine characteristics (stroboscopic effect, flashing lights, vibrations, visual effect).

Given the small number of studies undertaken on this topic and their methodological shortcomings, it should be considered that no conclusions can currently be drawn as to the health impacts of noise from wind turbines.

■ **Conclusions**

Some residents living near wind turbines state that they feel health effects they attribute to the emitted infrasounds. Some situations of real malaise are encountered in these local residents, sometimes with medically observed health effects for which the causal link to exposure to infrasounds and low-frequency sounds produced by wind turbines cannot however be clearly established.

Exposure to infrasounds and low-frequency sounds from wind turbines is merely one of many assumptions reported (audible noise, visual and stroboscopic effects, electromagnetic fields, etc.) to explain these effects. This situation is not specific to wind turbines. It can be compared to those encountered in other areas such as electromagnetic waves.

It is currently very difficult to isolate the health effects of infrasounds and low-frequency sounds from those of audible noise and other potential causes related to wind turbines.

The measurement campaign undertaken by ANSES:

- confirmed that wind turbines are sources of noise whose spectrum of sound emission mainly contains infrasounds and low-frequency sounds;
- did not show any cases of the hearing thresholds for infrasounds and low frequencies (< 50 Hz) being exceeded.

Furthermore, according to the analysis of the literature:

- infrasounds may be felt by cochleovestibular mechanisms other than hearing at higher frequencies;
- physiological effects have been found in animals (cochleovestibular system) for high levels of infrasounds and low-frequency sounds;
- these effects have yet to be demonstrated in humans for the exposure levels related to wind turbines found in local residents (prolonged exposure to low levels);
- the connection between potential physiological effects and the occurrence of a health effect has not been documented;
- the expected symptoms in the event of cochleovestibular system disruption are not generally those reported by complainants; they seem mainly related to stress and can be found in wind turbine syndrome (WTS);
- a *nocebo* effect can be observed but clearly does not rule out the potential occurrence of other effects;
- due to its weak scientific bases, vibroacoustic disease (VAD) cannot explain the reported symptoms;
- no epidemiological studies to date have examined the health effects of infrasounds and low-frequency sounds produced specifically by wind turbines. At the present time, the only effect observed in epidemiological studies has been disturbance due to audible noise from wind turbines.

## Recommendations of the collective expert appraisal

- **Improving the process for informing local residents during the construction of wind farms**

In general, the health of the population partly depends on its level of information and participation in the implementation of development projects in its immediate surroundings.

When installing a wind farm near homes, the CES recommends:

- providing local residents with relevant information about plans for wind farms as early as possible (before the public inquiry). A guide should be prepared explaining the minimum information to be provided prior to the public inquiry;
- improving the visibility of public inquiries;
- broadening the scope of information and consultation to include all local residents potentially impacted by the project (considering its visual, noise impacts, etc.) without limiting it, as is currently the case, only to the sponsoring municipalities;
- mitigating the current state of access to a wealth of conflicting information, anxiety-inducing or not, available on the Internet, by providing the general public with regularly updated knowledge (dedicated website for example) and making it known to potentially impacted residents, before discussing plans for a wind farm.

Regarding the necessary dialogue between stakeholders concerning wind farms or plans for wind farms, the CES recommends:

- encouraging collaboration prior to plans for wind farms. As it is, project sponsors first request a building permit from the authorities by submitting an impact assessment for a

finalised project, and the public inquiry occurs at the end of the process, thus minimising the weight of this inquiry in the decision-making process;

- better defining local stakeholders and further involving them in the dialogue.

■ **Enhancing knowledge related to the exposure of local residents**

In order to advance knowledge of exposure to infrasounds and low-frequency sounds, and considering how complicated they are to measure, the CES encourages:

- the use of standardised methods for measuring infrasounds and low-frequency sounds from wind turbines. The types of apparatuses used and the protocol or methodology to be followed to take reproducible and comparable measurements should be specified. The CES underlines that, given the high correlation between noise levels expressed in dBA and levels of infrasounds and low-frequency sounds for wind turbines, it could also be relevant to use methods for estimating infrasounds and low-frequency sounds based on measurements in dBA;
- the design of a model for predicting exposure to infrasounds and low-frequency sounds from wind turbines.

In order to improve comparability between data on exposure to noise produced by wind turbines, the CES recommends:

- developing an experimental method for characterising amplitude modulation;
- determining, as is the case for noise from transport[11], a single calculation method for predicting noise from wind turbines. It should take into account the various influencing parameters, to be used when undertaking noise impact assessments for ICPE authorisation requests.

■ **Regulations**

**Systematically measuring the noise emissions of wind farms**

The CES recommends systematically measuring the sound power of wind turbines *in situ*, before they are brought into service, in order to ensure that the sound characteristics of installed wind turbines are consistent with those specified in the impact assessment.

Drawing on practices in the airport sector, the CES also suggests, as soon as the farm is brought into service, setting up the systematic and continuous measurement of noise levels (audible noise and infrasounds and low-frequencies) from the wind farm, at one or more representative points, at the operator's expense. A simplified measurement method should be proposed in order to:

- monitor changes in noise levels in relation to the regulatory limit values and, when necessary, identify potential periods for which the regulatory limit values may be exceeded and determine the frequency;
- have noise measurements for comparison with the disturbance logs kept by local residents and look for possible correspondences between noise and reported disturbances.

If the regulatory limit values are repeatedly and significantly exceeded, the CES recommends defining specific criteria leading to actions that have yet to be determined (fines, forced shutdown, compliance measures, etc.).

[11] NF S 31-133: Acoustics – Outdoor Noise – Calculation of Sound Levels.

The CES also recommends undertaking a campaign to measure the noise impacts of wind turbines using an expert appraisal method as defined by the Pr S 31-114[12] standard under preparation. The Working Group insists on the importance of taking measurements on property lines.

The CES points out that this type of practice has helped reduce tension around airports, since it provides objective data on exposure and helps better meet the expectations of local residents.

The appointment of a main contact person, in charge of monitoring this systematic measurement of exposure and responses to the requests of local residents, should be considered.

**Limit values**

The current regulations require a noise exposure limit on property lines (70 dBA during the day, 60 dBA at night) which in principle is not suited to infrasounds and low-frequency sounds from wind turbines, as it is expressed in dBA.

However, at the minimum distance separating wind turbines from homes (currently 500 m) and considering the particular profile of the spectra of wind turbines currently in operation, which enables a relationship to be established between levels in dBA and dBG for these noise sources, the CES considers that limit values expressed in dBA can already guarantee that exposure to infrasounds and low-frequency sounds in local residents (at the façades of homes) is below the commonly accepted hearing threshold (85 dBG).

Compliance with these limit values should thus protect local residents against any potential nuisance related to the audibility of the low and very low-frequency components of wind turbine noise. However, these limit values do not protect local residents from potential effects related to non-audible infrasounds and low-frequency sounds whose occurrence has yet to be demonstrated.

To reduce noise exposure in residents living near the oldest wind farms, and considering the acoustic performance of the most recent turbines, the CES recommends facilitating the replacement of old wind turbines with new ones by simplifying the related administrative process.

- **Improving knowledge regarding the relationship between health and exposure to infrasounds and low-frequency sounds**

**Experimental studies**

Regarding the possible cochleovestibular mechanisms responsible for effects observed in laboratory animals and recent advances in techniques for non-invasive physiological measurements which can be taken within a few dozen minutes, the CES recommends undertaking additional studies in humans, in homes, using these techniques.

The tests already validated for the detection of abnormal homeostasis of cochlear sensory cells in patients with Meniere's disease could therefore be used (evoked otoacoustic emissions, spontaneous otoacoustic emissions, electrocochleography, videonystagmoscopy). These tests can all be performed in the field and repeated without discomfort. It would therefore be feasible to perform them on subjects, whether complainants (individuals describing symptoms of interest) or not, and whether or not they are exposed to very low-frequency sounds from the wind farm they live close to.

The implementation of a study demonstrating the objective signature of a physiological effect in complainants but not in non-complainants, only when the wind farm was in operation, could answer some major questions. These observations would not only help confirm a possible explanation but

[12] Pr S 31-114: Measurement of outdoor noise before and after wind farm construction.

would also provide an opportunity to identify at-risk individuals and determine the physical threshold above which a specific risk emerges.

### Epidemiological studies

Observing the health of residents living near wind farms, using epidemiological studies in particular, appears to be an obvious approach supplementing the expected advances in knowledge of physiological mechanisms. Requested by associations of local residents, carrying out such epidemiological studies nonetheless entails some methodological challenges, including a problem of statistical power due to the clearly limited number of individuals exposed to audible and inaudible noise from wind turbines, as well as the occurrence of countless biases that are often uncontrolled. Considering the large investment required to undertake such studies, as well as the possible relevance of the data they could generate, the CES supports the implementation of a feasibility study prior to such an epidemiological study.

### Psychoacoustic studies

Considering the significance of the effects of audible sounds on disturbance caused by wind turbines, and given current gaps in this area, the CES recommends:

- undertaking additional studies on the loudness of complex low-frequency sounds (not only pure tones);
- developing, to that end, a study protocol for quantifying inter-individual variability in perception by undertaking hearing tests, etc.
- improving the characterisation of disturbance related to temporal variations in non-stationary audible noises and amplitude modulation in addition to other factors (visual, vibrations, etc.).

### Neuroscience studies

Lastly, given the impacts of stress on health and the observed *nocebo* effect, the CES suggests promoting neuroscience research and in particular studies using medical imaging in order to identify the mechanisms involved.

## 4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

The French Agency for Food, Environmental and Occupational Health & Safety endorses the conclusions and recommendations formulated above by the CES on "Physical agents, new technologies and development areas".

ANSES reiterates that wind turbines emit infrasounds (sound below 20 Hz) and low-frequency sounds. There are also other sources of infrasound emissions that can be natural (wind in particular) or anthropogenic (heavy-goods vehicles, heat pumps, etc.). The measurement campaigns undertaken during the expert appraisal enabled these emissions from three wind farms to be characterised.

In general, only very high intensities of infrasound can be heard or perceived by humans. At the minimum distance (of 500 metres) separating homes from wind farm sites set out by the regulations, the infrasounds produced by wind turbines do not exceed hearing thresholds. Therefore, the disturbance related to audible noise potentially felt by people around wind farms mainly relates to frequencies above 50 Hz.

The expert appraisal showed that mechanisms for health effects grouped under the term "vibroacoustic disease", reported in certain publications, have no serious scientific basis.

There have been very few scientific studies on the potential health effects of infrasounds and low-frequencies produced by wind turbines. The review of these experimental and epidemiological data did not find any adequate scientific arguments for the occurrence of health effects related to exposure to noise from wind turbines, other than disturbance related to audible noise and a *nocebo* effect, which can help explain the occurrence of stress-related symptoms experienced by residents living near wind farms.

However, recently acquired knowledge on the physiology of the cochleovestibular system has revealed physiological effects in animals induced by exposure to high-intensity infrasounds. These effects, while plausible in humans, have yet to be demonstrated for exposure to levels comparable to those observed in residents living near wind farms. Moreover, the connection between these physiological effects and the occurrence of a health effect has not been documented.

In this context, ANSES recommends:

Concerning studies and research:

- verifying whether or not there is a possible mechanism modulating the perception of audible sound at intensities of infrasound similar to those measured from local residents;
- studying the effects of the amplitude modulation of the acoustic signal on the noise-related disturbance felt;
- studying the assumption that cochleovestibular effects may be responsible for pathophysiological effects;
- undertaking a survey of residents living near wind farms enabling the identification of an objective signature of a physiological effect.

Concerning information for local residents and the monitoring of noise levels:

- enhancing information for local residents during the construction of wind farms and participation in public inquiries undertaken in rural areas;
- systematically measuring the noise emissions of wind turbines before and after they are brought into service;
- setting up, especially in the event of controversy, continuous noise measurement systems around wind farms (based on experience at airports, for example).

Lastly, the Agency reiterates that the current regulations state that the distance between a wind turbine and the first home should be evaluated on a case-by-case basis, taking the conditions of wind farms into account. This distance, of at least 500 metres[13], may be increased further to the results of an impact assessment, in order to comply with the limit values[14] for noise exposure.

Current knowledge of the potential health effects of exposure to infrasounds and low-frequency noise provides no justification for changing the current limit values or for extending the spectrum of noise currently taken into consideration.

Dr Roger GENET

[13] Regarding minimum separation distances, those already set by the Grenelle 2 Act of 12 July 2010 (Article 90) have been maintained: 500 metres from any building for residential use or area intended for housing, 300 metres from a basic nuclear facility or ICPE.

[14] The noise emissions of a classified installation subject to authorisation must not generate, in noise aggravation zones, aggravation above the acceptable values.

**KEYWORDS**

Wind farm, wind turbine, low frequency noise, infrasound, risk assessment.