Health effects of low frequency noise and infrasound from wind farms: results from an independent collective expertise in France

Philippe Lepoutre[1], Paul Avan[2], Anthony Cadene[3], David Ecotière[4], Anne-Sophie Evrard[5], Frédérique Moati[6], Esko Topilla[7].

[1] ACNUSA, 244 Bd Saint Germain 75007 PARIS, France
[2] INSERM, UMR Inserm 1107 - Equipe Biophysique Neurosensorielle, France
Facultés de Médecine et de Pharmacie, 28 place Henri Dunant, 63001 Clermont-Ferrand, France
[3] ANSES, 14 rue Pierre et Marie Curie 94701 Maisons-Alfort, France
[4] Cerema, EPR AE, 11 rue Jean Mentelin, 67000 Strasbourg, France (corresponding author)
[5] Ifsttar, Univ Lyon, Université Claude Bernard Lyon1, IFSTTAR, UMRESTTE, UMR T_9405, 25, avenue François Mitterrand, Case24 F-69675 Bron, France
[6] Université Paris Sud XI, Faculté de médecine, Orsay, France
[7] Finnish Institute of Occupational Health, Topeliuksenkatu 41,00250 Helsinki, Finland

Corresponding author's e-mail address: david.ecotiere@cerema.fr

ABSTRACT

Several complaints were expressed by some residents of French wind farms, putting forward infrasound and low frequency noise (ILFN) as a potential source of annoyance. Since available information on this subject are multiple and often contradictory, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) was mandated by the French Ministry of Environment to conduct an independent collective expertise on the evaluation of the health effects related to ILFN from wind farms. The objective was first to produce a complete review on auditory and non auditory health effects due to WTN, focusing on ILFN ; then, to collect experimental ILFN data from some wind farms in order to compare with data from the literature ; and finally to propose some improvements in the process of wind farm assessment or of impact studies, concerning ILFN. This paper presents the main results and conclusions of this expertise.

BACKGROUND

Several complaints were expressed by some residents of French wind farms, putting forward infrasound and low frequency noise (ILFN) as a potential source of annoyance. Since available information on this subject are multiple and often contradictory, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) was mandated by the French Ministry of Environment to conduct an independent collective expertise on the evaluation of the health effects related to ILFN from wind farms [1]. The objective was first to produce a complete review on auditory and non-auditory health effects due to WTN, focusing on ILFN; then, to collect experimental ILFN data from some wind farms in order to compare with data from the literature; and finally to propose some improvements in the process of wind farm assessment or of impact studies, concerning ILFN.

EXPERIMENTAL ASSESMENT OF ILFN EXPOSURE OF PEOPLE LIVING NEAR WIND FARMS

In order to supplement the data from the scientific literature on exposure to ILFN from wind farms, ANSES has conducted noise measurements near 3 wind farms. Cerema carried out these acoustic measurements.

On each site, the noise was recorded outside at 500m and 900m from the wind farm. The noise was also recorded inside a house located at 900m. A point located close to the nearest wind turbine (150m) was used for the estimation of the wind turbine sound emission, following the IEC procedure [2]. A meteorological mast equipped with a 3D sonic anemometer gave access to wind conditions, and also to sound propagation conditions thanks to a specific procedure [3]. The duration of each campaign was one week.

Main tendencies encountered in literature [4,5] are confirmed by experimental results: the noise emission spectrum of wind turbines has a quasi linear shape, decreasing along with the log frequency (figure 1). Spectra also exhibit some ILFN discrete components that can be attributed to mechanical noise from the hub. As expected, the ILFN emission increases with the wind speed, up to a theoretical step that have not been observed due to experimental conditions (figure 2). Noise level spectra observed at 500m and 900m exhibit a strong dispersion along with time (figure 3), due to fluctuation of meteorological fluctuations or non-controlled parameters (turbulence, temperature influence…).

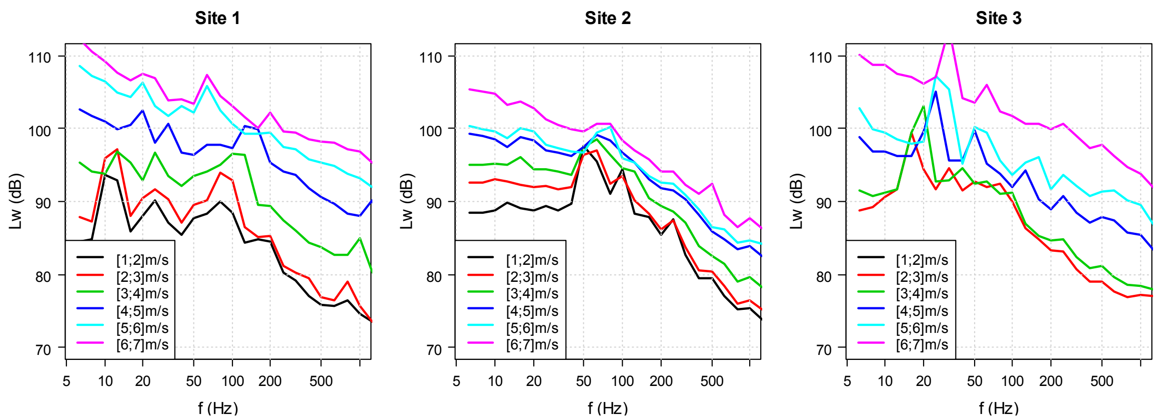

Figure 1: Noise power level spectra and wind speed.

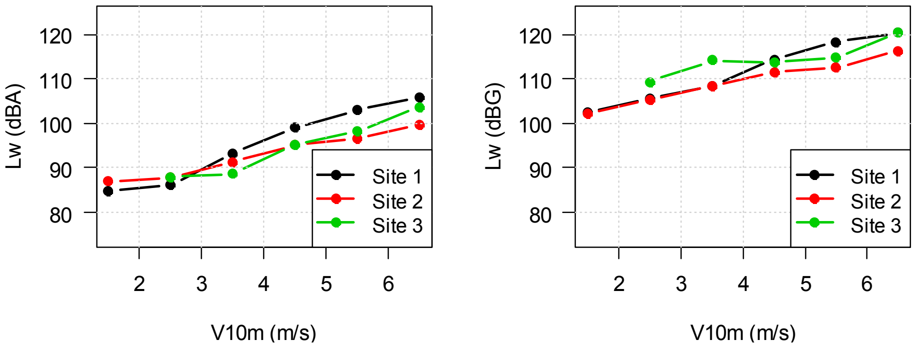

Figure 2: Sound power level along with wind speed at 10m high, expressed in dBA (left) and dBG (right)

Outside, no exceedance of the audibility thresholds was found for ILFN up to 50 Hz, from 500m to 900m from the wind turbines (figure 3). Exceedance of the outer hair cells (OHC) thresholds of Salt et Hullar [6] are seldom exceeded for frequencies lower than 8Hz, but can be exceeded up to 20% of the time for frequencies lower than 20Hz. The ILFN annoyance criterion curve of Moorhouse *et al* [7] is never exceeded. Inside, no exceedance of both audibility and OHC thresholds are observed.

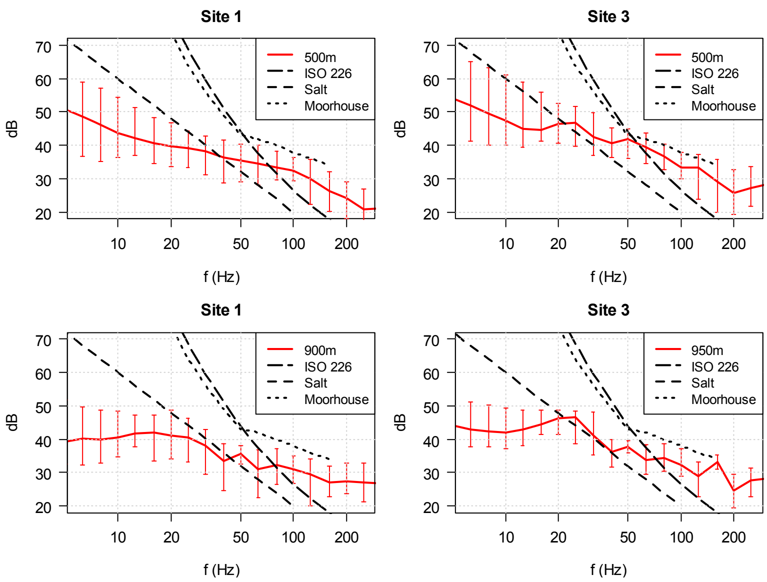

Figure 3: Comparison of noise spectra (red) to audibility thresholds (ISO 226), Salt and Hullar threshold, and Moorhouse *et al.* curve. Red vertical bars include 75% of samples.

A comparison between A-weighted noise levels and G-weighted noise levels shows a significant correlation between the dBA and dBG (figure 4). This can be explained by the specific linear shape of the noise spectrum of wind turbine noise that induces that ILFN part is proportional to audible part of the spectrum. This has a very interesting practical interest because, provided that the noise is wind turbine noise, it shows that it is possible to get informations on ILFN from data expressed in dBA. This result is very similar to what Michaud found for the correlation between dBA and dBC [8,9], and who concludes that no additional benefit would be gained by assessing outcomes in relation to dBC.

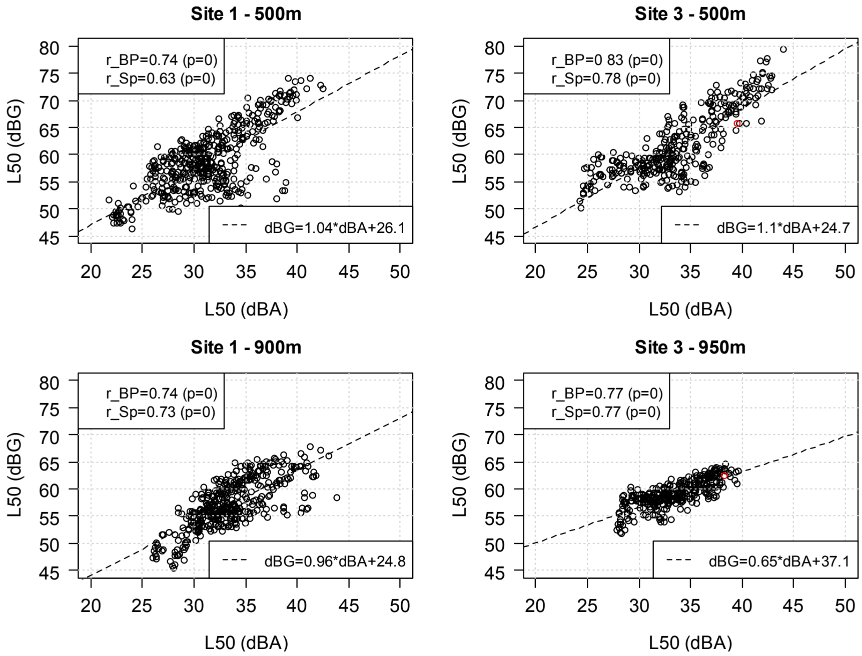

Figure 4: correlations between noise levels expressed in dBG and expressed in dBA. R_BP is the Bravais-Pearson correlation coefficient, R_Sp is the Spearman coefficient.

LITERATURE REVIEW

A review of the available data on the health effects of infrasound reveals a strong imbalance between primary bibliographic sources (documents relating to original scientific experiments and studies) and secondary sources (scientific literature reviews or opinion articles). Indeed, the secondary sources are numerous whereas the number of primary sources that they are supposed to synthesize is limited. This peculiarity, combined with the marked divergence of the conclusions of these reviews, clearly shows the existence of a strong public controversy on this issue.

Review of health concerns expressed by people living near wind farms

The symptoms described by some residents of wind farms, which they associate with their exposure to noise emissions from wind turbines, are extremely diverse. They have been gathered in the literature into two categories: those associated with vibroacoustic disease (VAD), and those constituting the wind turbine syndrome (WTS).

The VAD was defined by a unique research team [9] and refers to a particular biological mechanism linked to exposure to infrasound and low sound frequencies (growth in extracellular matrices of collagen and elastin fibers in the absence of any inflammatory process). According to these authors, this mechanism could ultimately lead to the emergence of a wide range of health effects (fibroses, immune system damage, respiratory effects, genotoxic effects, organ morphological changes, etc.).

The authors of the current paper attributed a very low level of evidence to this hypothesis of a mechanism of health effects because of its weak scientific basis and the significant biases in the studies published by this team in journals often not peer-reviewed, and because the results have not been reproduced by other research teams. Therefore, the working group did not retain the VAD as part of the assessment of the potential health risks associated with noise emissions from wind turbines.

The wind syndrome (WTS) has been described in the literature by Pierpont [10] as a set of symptoms reported by local residents of wind farms and which they attribute to wind turbines. These symptoms (sleep disorders, headaches, tinnitus, disturbances of balance, etc.) are not specific to a pathology. They are notably found in syndromes of idiopathic environmental intolerance. They are, however, a set of manifestations that can be caused by stress, loss of sleep, which can become disabling for the subject who feels them.

Literature review on experimental results about ILFN effects on health

- *Effects mechanisms via the cochleo-vestibular system*

Recent results [6,12] on the physiology of cochleo-vestibular system have revealed several pathways of physiological effects mechanisms that could be activated in response to exposure to ILFN. This sensory system has a particular sensitivity to these frequencies, superior to that of other parts of the human body. Available data suggest the hypothesis that sounds of frequencies too low or levels too low to be clearly audible could have effects mediated by receptors of the cochleo-vestibular system. Possible mechanisms include:

• the induction of non-auditory responses by the vestibular cells when a sound of very low frequency reaches the base of the cochlea;

• "non-classical" stimulation of the most apical auditory sensory cells activating non-auditory cochlear pathways;

• the induction of ionic and volume imbalances in the fluids of the inner ear by placing the basilar membrane in a general and prolonged vibration by a very low frequency sound;

• induction of modulations of the response of auditory sensory cells to ordinary sounds by very low frequency sounds, inaudible by themselves but affecting the hearing of concomitant audible sounds. Certain peculiarities, particularly anatomical, may predispose their carriers to modulations of greater intensity;

• in the case of certain sound levels exceeding certain levels, it is likely that nerve stimulation will occur at the level of the cochleo-vestibular apparatus [6], the noise levels punctually encountered in the measurements These levels could be exceeded outside dwellings, for frequencies below 20 Hz.

These phenomena have been observed experimentally using intense pure tones (for example a hundred dB SPL at 200 Hz in small laboratory animals, which does not necessarily equal a very low frequency sound in humans). Their existence for sound exposures similar to those due to wind turbines (complex sounds, of smaller sonic intensity but of prolonged duration) remains to be demonstrated.

The authors of the present paper stress that these physiological effects, often referred to by the associations of residents of wind farms, have an objective signature. For example, if there is a volume unbalance of the fluids of the inner ear, this results in abnormal results in otolaryngologist tests with high sensitivity and specificity. However, this signature has not yet been sought by complainants. These physiological effects are also reflected in manifestations (vertigo, tinnitus, nausea, etc.) which people can describe but which are rarely mentioned. However, the various testimonies gathered during this expertise more frequently describe other types of effects such as sleep and mood disorders (depression, stress, anxiety, etc.).

- *Effects on health to the exposures to ILFN of high intensities*

Exposures to ILFN of very high intensities (20 to 40 dB higher than those of wind turbines, thus involving energies 100 to 10,000 times higher) are found in the professional environment. However, their effects are controversial (little specific, poorly documented and / or old data, etc.). The scientific issues are therefore not elucidated and the recommendations concerning the limitation of occupational exposures published are in no way transposable to the case of wind turbines.

- *Effects on health to long term exposure to ILFN of low intensities*

There are very few peer-reviewed publications that address the potential effects of infrasound and ILFN of wind turbines. However, some studies have been carried out for other sources of noise, such as ventilation noise, heat pumps or compressors, road traffic noise, etc., for intensities of the same level as those emitted by wind farms. In these studies, self-reported discomfort (questionnaire) is the only health effect observed. No association was found with a physiological marker that could identify an effect on health. These studies have, however, established that a much higher level of sound is required compared to what is known for higher frequencies, to perceive an infrasound and / or to hear a low frequency sound. Extrapolation of the above results to wind turbines should be done with caution.

- *Nocebo effect*

In addition to these controversial results concerning the effects of prolonged exposures to low-level ILFN, several experimental studies of high scientific quality [13-15], carried out in double-blind and repeated experiments, demonstrate the existence of negative effects and feelings in people who think they are exposed to inaudible infrasound when they are not necessarily exposed. These effects or negative feelings would be caused by the only expectations of deleterious effects associated with these exposures. This effect, which can be described as "nocebo", helps to explain the existence of stress-related symptoms in residents of wind farms. It must be all the more important in the wind turbine context, where multiple opposition arguments, not exclusively health (economic, cultural, territorial, political, etc.) circulate, especially those conveyed via the Internet, an anxiety-provoking situation. Nevertheless, the existence of such a nocebo effect does not *de facto* exclude the existence of health effects that it can potentially exacerbate.

Literature review on epidemiological studies about ILFN effects on health

Epidemiological studies should make it possible to compare the pathways of mechanisms of physiological effects with the health conditions observed in the neighboring populations. Unfortunately, these studies are few and they are exclusively interested in the effects of the audible noise of wind turbines on the health of the residents. There is none that has focused on the health effects of ILFN emitted in the environment and more particularly produced by wind turbines.

All of them are cross-sectional studies [16-27], and therefore do not allow us to assert that the cause, that is to say the noise exposure from wind turbines, preceded the effect well. The results observed in the majority of these studies remain marked by selection or confusion biases. Only one of the studies analyzed can be considered to be of good scientific quality [27]. It is also the only one to have included not only subjective measures but also objective measures associated with the potential effects to which it is interested. This study does not show an association between the level of audible noise caused by wind turbines and the self-reported health status of respondents (sleep quality, dizziness, tinnitus, migraines and frequent headaches, chronic diseases such as heart disease, hypertension and diabetes), the level of stress and perceived quality of life. Objective measurements of health states (cortisol concentration in the hair, blood pressure, heart rate at rest and measured sleep quality) are consistent with the participants' statements. Similarly, these measurements are not associated with the audible noise level due to wind turbines. On the other hand, this study shows an association between the same level of audible noise and the discomfort due to certain characteristics of wind turbines (stroboscopic effect, flashing lights, vibrations, visual effect).

The limited number of studies carried out on this issue and their methodological defects all suggest that it is currently not possible to conclude as to the impact of wind turbine noise on health.

CONCLUSIONS

Some people living near wind farms claim to have health effects that they attribute to the ILFN emitted by wind turbines. Among these residents, situations of real malaise are encountered, and health effects sometimes medically found, but for which the causality with the exposure to the infrasound and low sound frequencies produced by the wind turbines cannot be established in an obvious way.

Exposure to ILFN of wind turbines is only an hypothesis to explain these effects, among the many reported (audible noise, visual, strobe, electromagnetic field, etc.). This situation is not specific to wind turbines. It can be compared to those encountered in other fields, such as electromagnetic waves.

It is very difficult at present to isolate the health effects of ILFN from those of audible noise or other potential causes that may be caused by wind turbines.

The experimental campaign on ILFN exposure of people living near wind farm

- confirms that wind turbines are sources of noise whose ILFN predominates in the sound emission spectrum;
- shows no exceedance of audibility thresholds for ILFN frequencies (>20Hz) outside and inside houses for distances higher than 500m.

Moreover, according to the analysis of the literature:

- infrasound may be felt by different cochleo-vestibular mechanisms of hearing at higher frequencies;
- physiological effects have been demonstrated in animals (cochleo-vestibular system) for high infrasound and low-frequency sound levels;
- these effects have yet to be demonstrated in humans for exposures of the order of those related to wind turbines in local residents (long exposure to low levels of exposure);
- the link between potential physiological effects and the occurrence of a health effect is not documented;
- symptoms expected in case of disturbance of the cochleo-vestibular system are generally not those reported by the complainants; they seem to be related to stress and are found in wind turbine syndrome (WTS);
- a nocebo effect is noticed but of course does not exclude the existence of other effects;
- because of its weak scientific basis, the vibroacoustic disease (VAD) does not explain the symptoms reported;

- to date, no epidemiological studies have focused on the health effects of infrasound and low-frequency sound produced specifically by wind turbines. At present, the only effect observed in epidemiological studies is the annoyance caused by the audible noise of wind turbines.

Acknowledgements

The authors are grateful to the inhabitants of the three sites who hosted the measures.

REFERENCES

[1] *Évaluation des effets sanitaires des basses fréquences sonores et infrasons dus aux parcs éoliens*, ANSES report. (2017). https://www.anses.fr/fr/system/files/AP2013SA0115Ra.pdf

[2] Standard IEC 61400-11:2012, Wind turbines – Part 11: Acoustic noise measurement techniques

[3] Gauvreau, Benoît, David Ecotière, H. Lefevre, et B. Bonhomme. (2009). Propagation acoustique en milieu extérieur complexe: Caractérisation expérimentale in-situ des conditions micrométéorologiques: Eléments méthodologiques et métrologiques..Ed LCPC.

[4] Møller, Henrik, et Christian Sejer Pedersen.(2011). *Low-frequency noise from large wind turbines.* The Journal of the Acoustical Society of America 129 (6):3727-3744.

[5] Bowdler, R., et G. Leventhall. 2012. *Wind Turbine Noise*. Multi-Science Publishing Co Ltd.

[6] Salt, Alec N., et Timothy E. Hullar. (2010). *Responses of the ear to low frequency sounds, infrasound and wind turbines.* Hearing Research 268 (1):12-21.

[7] Moorhouse, A., D. Waddington, et M. Adams. (2005). Proposed criteria for the assessment of low frequency noise disturbance

[8] Michaud D (2015), *Wind Turbine Noise and Health Study: Summary of Results*, Wind Turbine Noise conference, Glasgow.

[9] Michaud D, Feder K, Keith S, Voicescu S, Marro L, Than J, Guay M, Denning A, Bower T, Villeneuve P, Russell E, Koren G, van den Berg F (2016), *Self-reported and measured stress related responses associated with exposure to wind turbine noise*, The Journal of the Acoustical Society of America 139(3):1467-1479.

[10] Castelo Branco, Nuno A.A., José Reis Ferreira, et Mariana Alves-Pereira. (2007). *Respiratory pathology in vibroacoustic disease: 25 years of research*. Revista Portuguesa de Pneumologia.

[11] Pierpont, Nina. 2009. *Wind turbine syndrome: A report on a natural experiment*. K-Selected Books

[12] Salt, Alec N. 2004. "Acute endolymphatic hydrops generated by exposure of the ear to nontraumatic lowfrequency tones." Journal of the Association for Research in Otolaryngology 5 (2):203-214.

[13] Crichton, Fiona, et Keith J. Petrie. 2015. "Health complaints and wind turbines: The efficacy of explaining the nocebo response to reduce symptom reporting." *Environmental Research* 140:449–455.

[14] Crichton, Fiona, George Dodd, Gian Schmid, Greg Gamble, et Keith J Petrie. 2014. "Can Expectations Produce Symptoms From Infrasound Associated With Wind Turbines?" *Health Psychology: Official Journal of the Division of Health Psychology, American Psychological Association*.

[15] Tonin, Renzo, James Brett, et Ben Colagiuri. 2016. "The effect of infrasound and negative expectations to adverse pathological symptoms from wind farms." *Journal of Low Frequency Noise, Vibration and Active Control* 35 (1):77-90

[16] Onakpoya IJ, O'Sullivan J, Thompson MJ, Heneghan CJ (2015) The effect of wind turbine noise on sleep and quality of life: A systematic review and meta-analysis of observational studies. Environment International 82, 1-9.

[17] Feder K, Michaud DS, et al. (2015). An assessment of quality of life using the WHOQOLBREF among participants living in the vicinity of wind turbines. Environmental research 142, 227-238.

[18] Pawlaczyk-Łuszczyńska M, Dudarewicz A, Zaborowski K, Zamojska-Daniszewska M, Waszkowska M (2014). Evaluation of annoyance from the wind turbine noise: A pilot study. International Journal of Occupational Medicine and Environmental Health 27, 364-388.

[19] Pedersen E (2011). Health aspects associated with wind turbine noise - Results from three field studies. Noise Control Engineering Journal 59(1), 47-53.

[20] Pedersen E, van den Berg F, Bakker R, Bouma J (2009). Response to noise from modern wind farms in The Netherlands. The Journal of the Acoustical Society of America 126(2), 634-643.

[21] Pedersen E, Persson Waye K (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occupational and Environmental Medicine 64(7), 480-486.

[22] Pedersen E, Persson Waye K (2004). Perception and annoyance due to wind turbine noise—a dose–response relationship. The Journal of the Acoustical Society of America 116(6), 3460- 3470.

[23] Paller C (2014). Exploring the Association between Proximity to Industrial Wind Turbines and Self-Reported Health Outcomes in Ontario, Canada [Master of Science in Health Studies and Gerontology]. University of Waterloo, Canada. Available: https://uwspace.uwaterloo.ca/handle/10012/8268. Accessed 2016 Feb 19. 102 p.

[24] Mroczek B, Kurpas D, Karakiewicz B (2012). Influence of distances between places of residence and wind farms on the quality of life in nearby areas. Annals of agricultural and environmental medicine 19, 692-696.

[25] Nissenbaum MA, Aramini JJ, Hanning CD (2012). Effects of industrial wind turbine noise on sleep and health. Noise & Health 14(60), 237-243.

[26] Shepherd D, McBride D, Welch D, Dirks KN, Hill EM (2011). Evaluating the impact of wind turbine noise on health-related quality of life. Noise & Health 13(54), 333-339.

[27] Magari SR, Smith CE, Schiff M, Rohr AC (2014). Evaluation of community response to wind turbine-related noise in Western New York State. Noise & Health 16, 228-39.

[28] Michaud DS, Feder K, et al. (2016). Effects of Wind Turbine Noise on Self-Reported and Objective Measures of Sleep. Sleep 39(1), 97-109.