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Infrasound with large peak to trough blade pass harmonics in two houses between three large wind turbine farms - WTFs on the northwest coast of Norway and two single health cases and a health survey near the WTF in Tysvær, Norway

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Summary

The handling of sound pollution was to be transferred from the county governors in Norway to the municipalities in 2020. As chief medical officer on the small island of Frøya, pop. 5.500, that was to become my responsibility. The decision was made in late 2018 to complete the planned WTF with 14 Vestas V136 turbines on Frøya. This brought on many local protests, one being the claim that infrasound from WTFs cause health problems. This seemed somewhat absurd to me, how could any low frequency, non-audible air pressure waves cause havoc on humans and animals?
I decided to look into the available information on any health issues around WTFs. A steep learning curve ensued and resulted in the procurement of the Atkinson & Rapley SAM Scribe II [1] equipment for making null point recordings in homes near the planned WTF on Frøya, before it came into commission in 2021.

In late 2019 I was contacted by concerned citizens on the neighbouring island of Hitra, where Norway's first full scale WTF Hitra 1 with 24 Siemens SWT 2.3 CS turbines with 5.800m² sweep areas had been in commission since 2004. [2] It wasn't until the Hitra 2 WTF, with 26 Vestas V117 turbines with twice the sweep area 10.745m², started their production in the autumn of 2019 that health issues arose. [3]
Simultaneous 2 channel sound recordings were made in the bedrooms and outside of two houses on Hitra in December 2019 and in February 2021. Both houses are located ten kilometres to the northwest and to the north, northwest of Hitra 1&2 WTFs.
Sound measurements and the health issues of the residents are presented.
Norway's second health survey of residents near Tysvær WTF performed in 2023 is touched.
Public health's approach to infrasound from WTFs, a coda on infrasound effects in human and animal physiology at a cellular level and a short discussion on infrasound monitoring and setting limits in homes.

1. Introduction

Proceedings from the Conference on Low Frequency Noise and Hearing, Aalborg, Denmark, May 7-9, 1980: *"The first international colloquium concerned only with infrasound was held in Paris 1973. At this colloquium several effects of infrasound on human beings were presented and reviewed. An effort was also made to suggest some very preliminary criteria for infrasonic exposure. In the following years a number of new results were published, and several of them indicated that the limits for acceptable infrasonic exposure should be lowered considerably, if psychological effects were to be taken into account. Several countries have started more systematically to investigate infrasonic sources and to registrate complaints from people being disturbed by infrasound."* [4]

Dr. Neil Kelley's work from 1982: *"A Methodology for Assessment of Wind Turbine Noise Generation"* [5] and the 1987 presentation: *"A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions"* [6] set me on a quest to find out more.

The Danish Environmental Protection Agency - DEPA proposed limits on infrasound emissions from WTFs into residential homes in 2011.
Vestas, a large wind turbine company and economic provider in Denmark, had made it very clear that the distances required to comply with the set limits would seriously compromise their business model both nationally and internationally. DEPA reneged on their proposed infrasound limits. [7]

2. Recordings

The recordings on Hitra were supplemented with recordings four hours later in a house on the neighbouring island of Frøya for comparison. The Frøya house is located sixteen kilometres from the Hitra house and twenty kilometres from Hitra1&2 WTFs. The outdoor microphone for channel wav-1 was placed two metres above the ground and two metres from the house facing Hitra 1&2. The indoor microphone for channel wav-2 was placed 15 centimetres above the pillow in the bedroom, also facing Hitra 1&2. Calibration tone 1 kHz, 94 dB.Ten minutes recordings with 16bit resolution and 11.025 kHz sampling rate. The sound files are 25 MB and are time, date and GPS location tamper-proof embedded. Weather conditions: Cloud overcast 7/8 with no precipitation. Wind 6-7 m/s with gusts up to 10m/s from E-N-E 60° Temperature between 0° and +1°C with temperature inversion over a large body of water. Air pressure 1003 hPa and humidity 99 percent. The meteorological conditions were similar at the Hitra and Frøya houses 16 kilometres and 4 hours apart. Analysis Signal Lab e.K Sigview 7.1 program. [8]

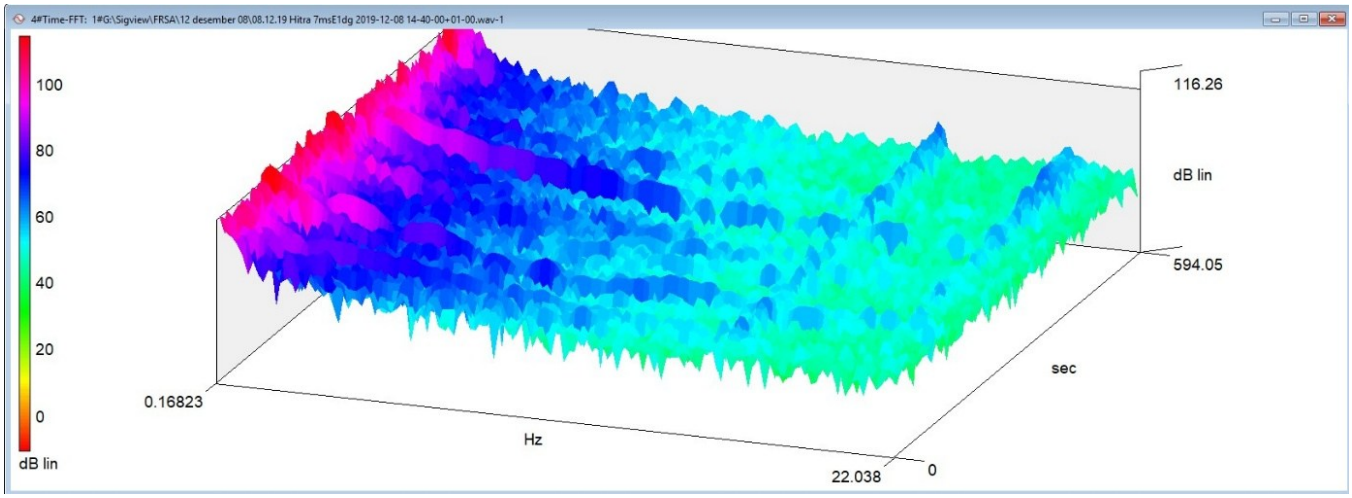

Figure 1 Hitra outdoor X axis 0.17-22 Hz, Y axis 0-596 seconds, Z axis dB lin. 1340-1350 UTC

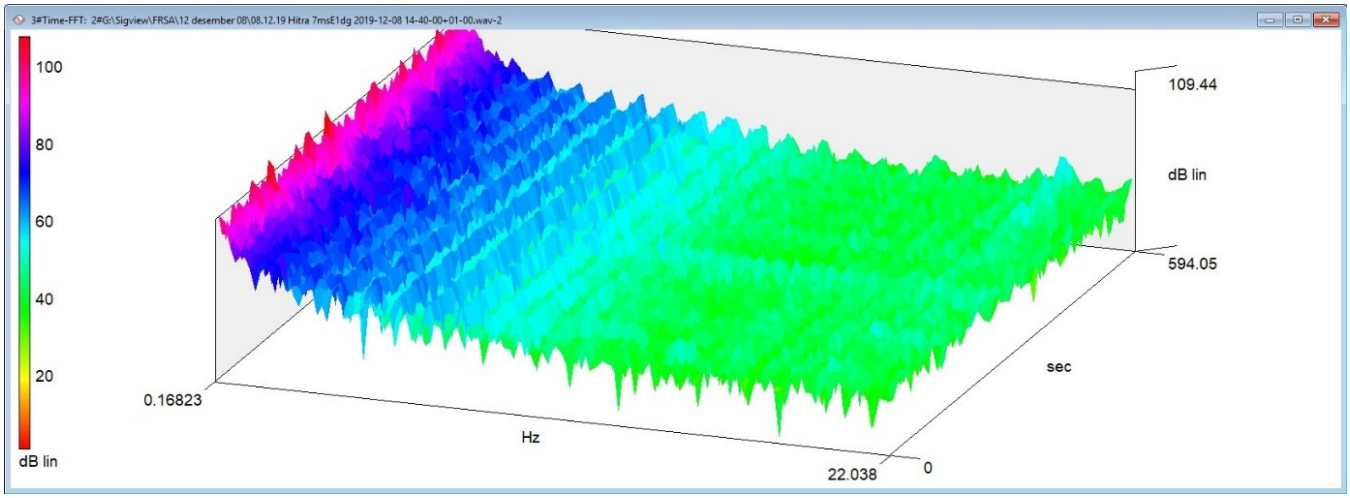

Figure 2 Hitra bedroom X axis 0.17-22 Hz, Y axis 0-596 seconds, Z axis dB lin. 1340-1350 UTC

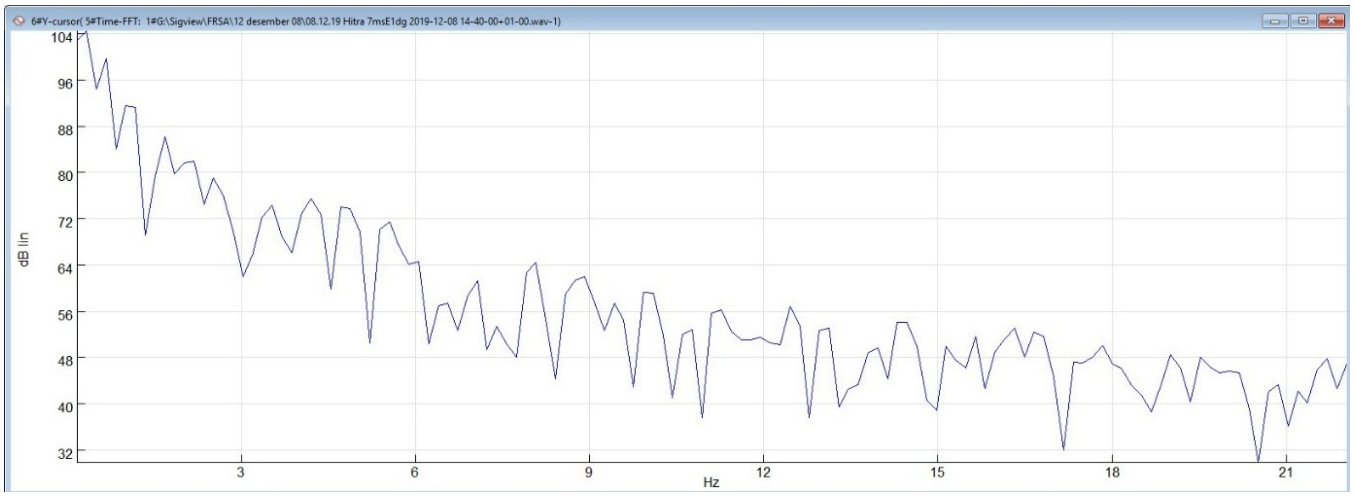

Figure 3 Hitra outdoor X axis 0.17-22Hz, Y axis dB lin. 1340-1350 UTC

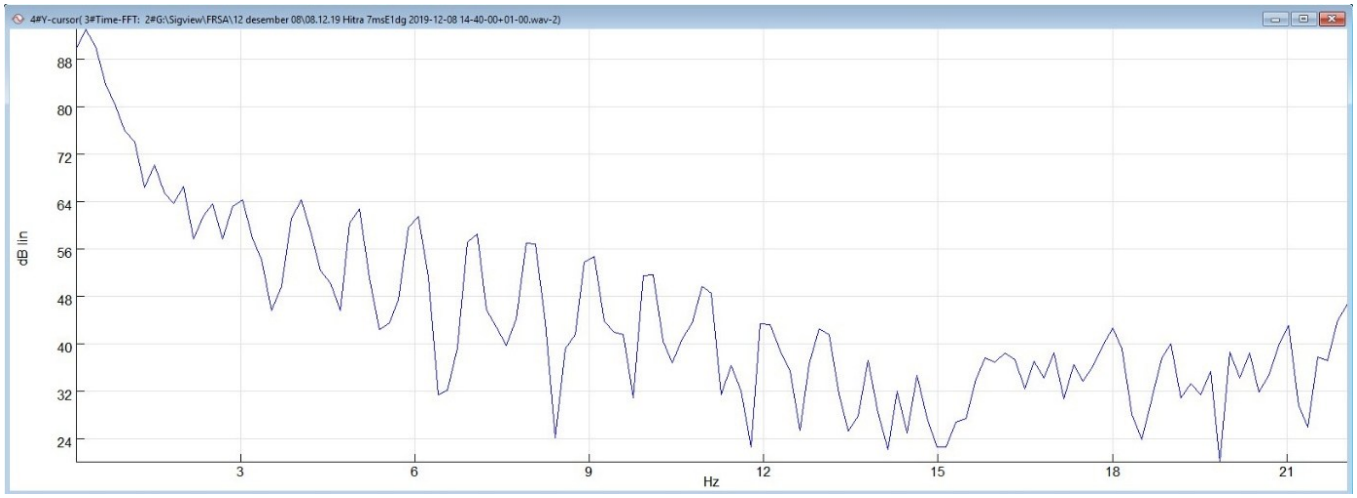

Figure 4 Hitra bedroom X axis 0.17-22Hz, Y axis dB lin. 1340-1350 UTC

Figures 5,6,7 and 8 show the corresponding recordings in the house on Frøya

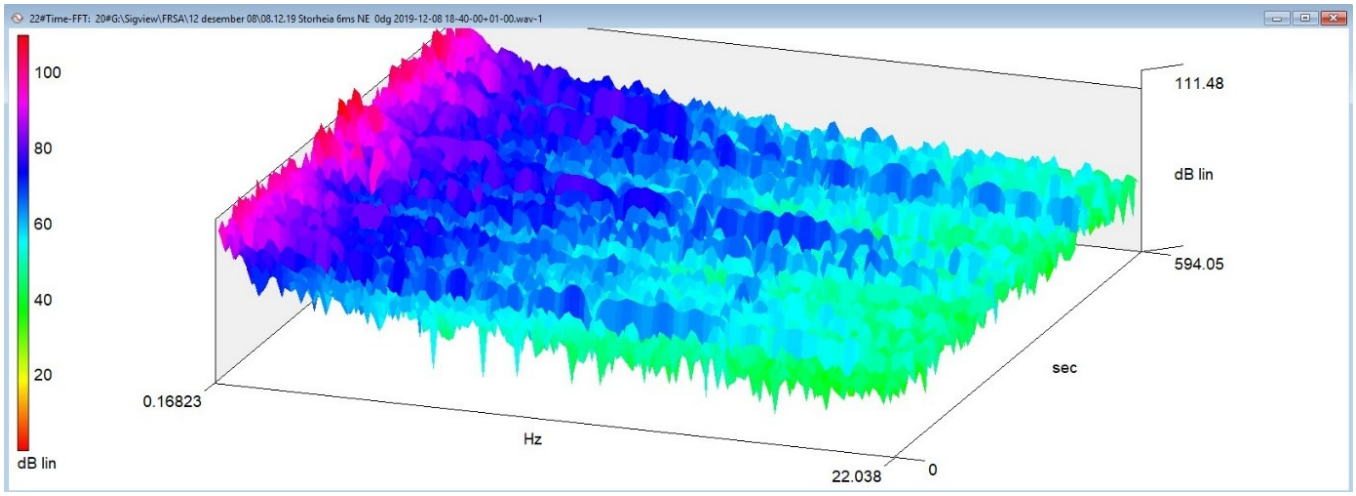

Figure 5 Frøya outdoor X axis 0.17-22 Hz, Y axis 0-596 seconds, Z axis dB lin. 1740-1750 UTC

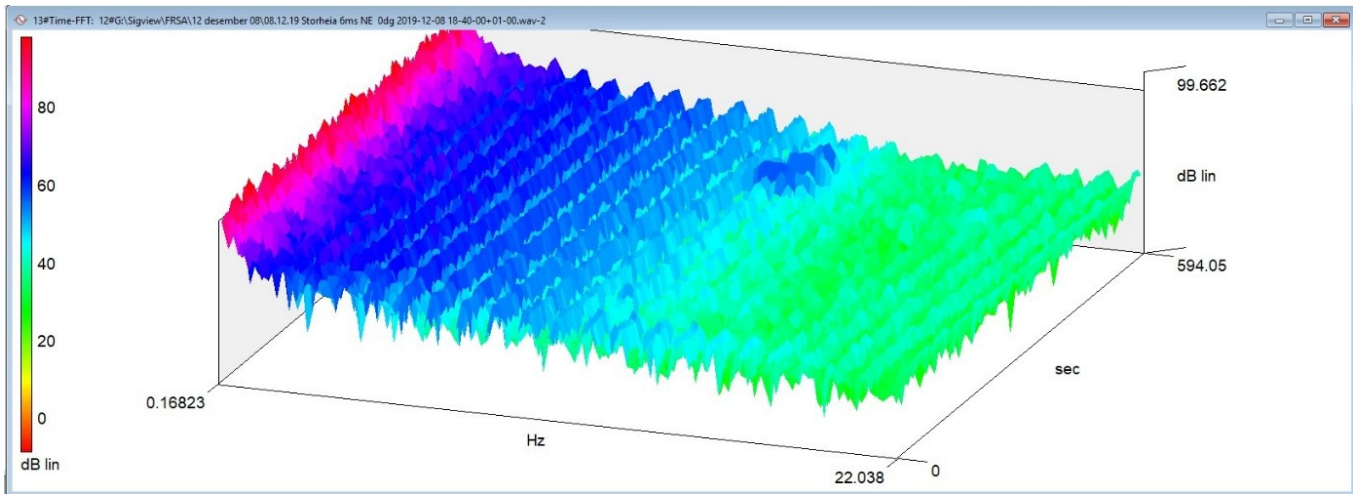

Figure 6 Frøya bedroom X axis 0.17-22 Hz, Y axis 0-596 seconds, Z axis dB lin. 1740-1750 UTC

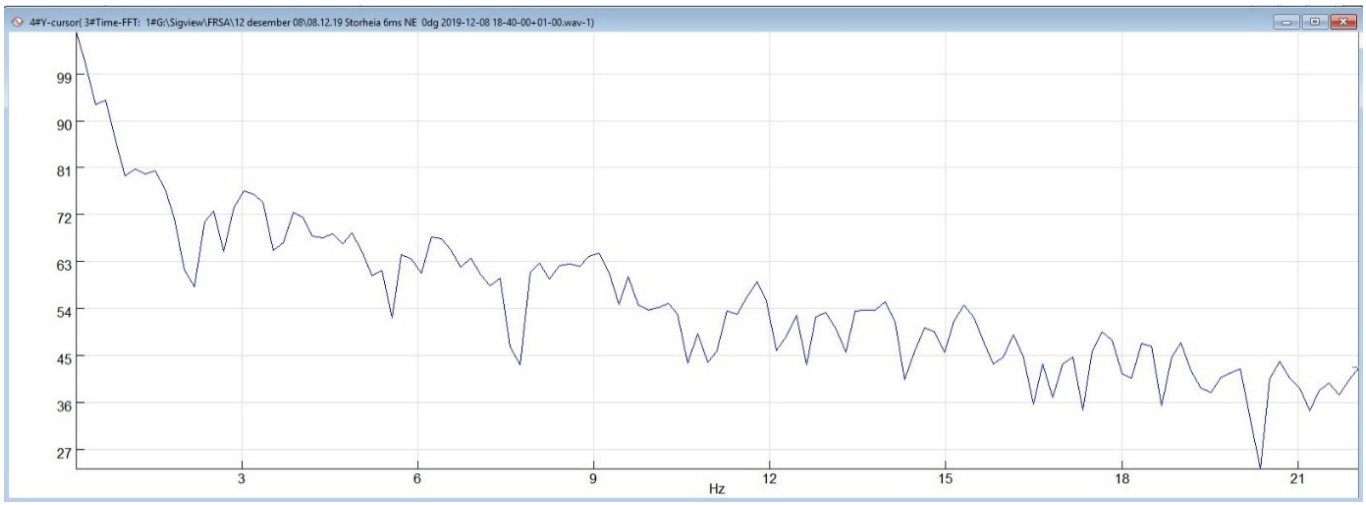

Figure 7 Frøya outdoor X axis 0.17-22Hz, Y axis dB lin. 1740-1750 UTC

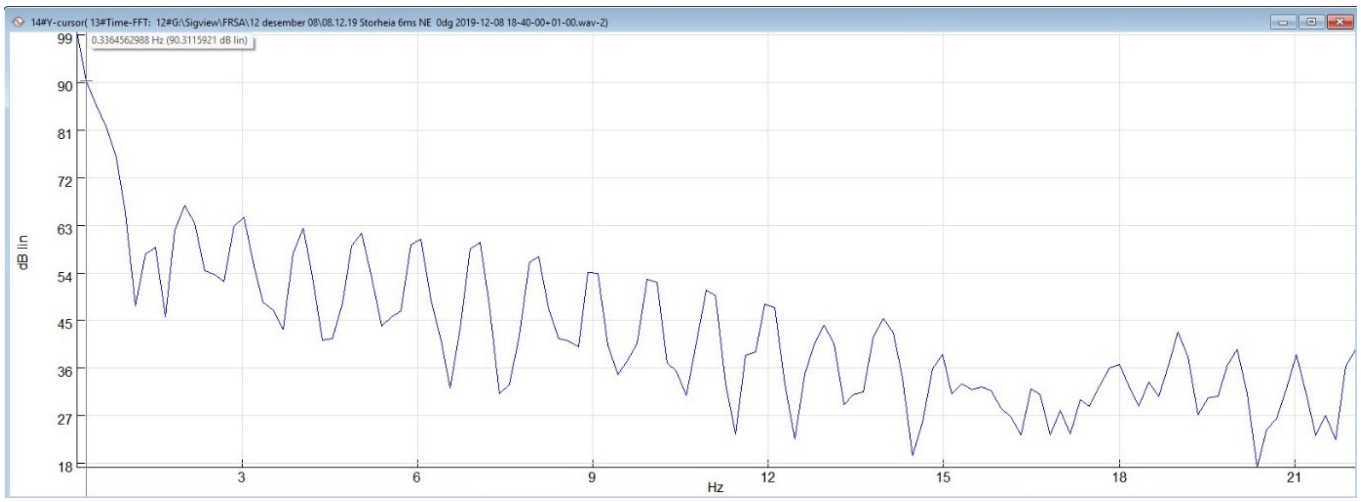

Figure 8 Frøya bedroom X axis 0.17-22Hz, Y axis dB lin. 1740-1750 UTC

Table 1 Outdoor peak to trough values

Outdoor	3 Hz	6 Hz	9 Hz	12 Hz	15 Hz	18 Hz	21 Hz
Hitra	12 dB	14 dB	9 dB	6 dB	11 dB	9 dB	7 dB
Frøya	11 dB	6 dB	10 dB	7 dB	9 dB	9 dB	9 dB

Table 2 Bedroom peak to trough values

Bedroom	3 Hz	6 Hz	9 Hz	12 Hz	15 Hz	18 Hz	21 Hz
Hitra	18 dB	29 dB	23 dB	21 dB	8 dB	19 dB	16 dB
Frøya	20 dB	28 dB	19 dB	25 dB	28 dB	7 dB	20 dB

The indoor harmonic patterns displayed in the spectrum and in the graphs show similar patterns in the Hitra house and Frøya house for comparison.

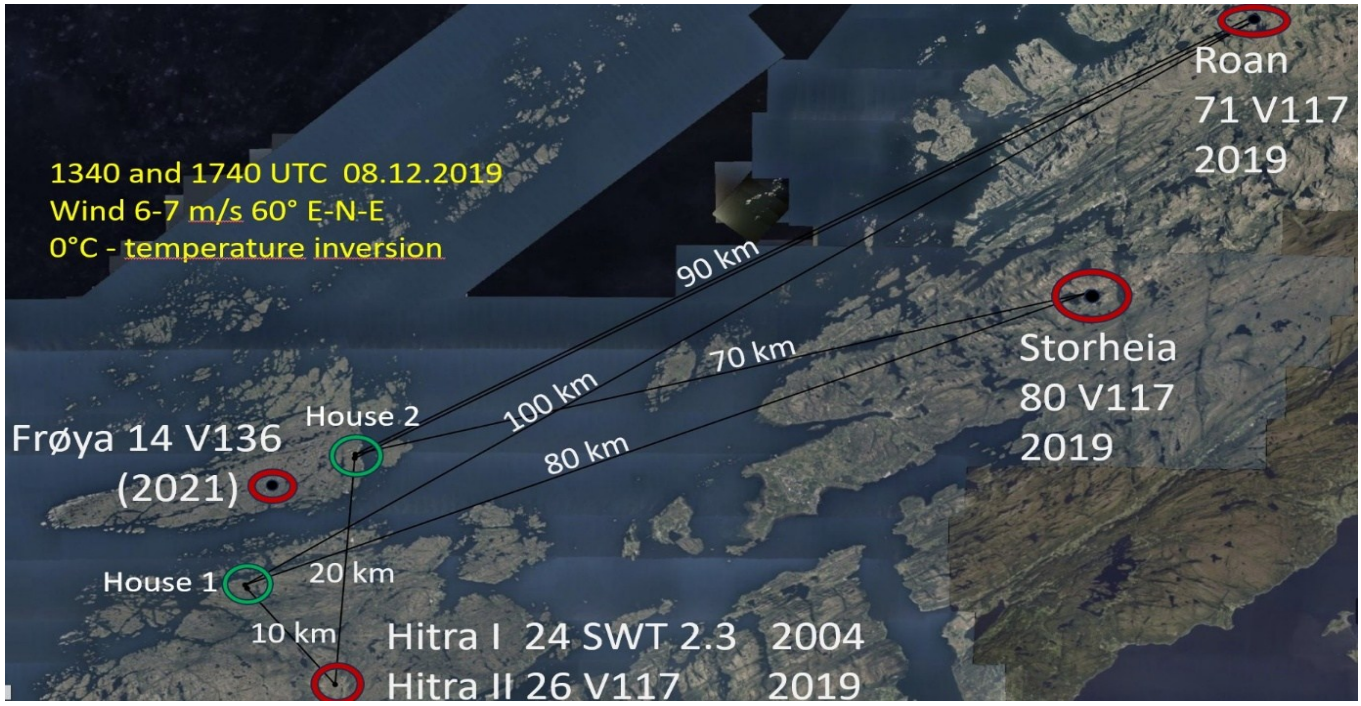

Figure 9 Fosen area in Trøndelag, Norway

Hitra 1&2 with 24 SWT2.3 and 26 V117 to the bottom left and Storheia and Roan with 80 and 71 Vestas V117 turbines respectively. Frøya with 14 Vestas V136 started production autumn 2021. The house with the 2021 recordings is not marked on the map. It is located ten kilometres north, northwest of the Hitra 1&2 WTFs

3. Discussion

The Hitra 1&2 wind turbines located ten kilometres away from the Hitra house were the prime suspected cause for the newly arisen noise and sleep disturbances starting in the autumn of 2019 after Hitra 2 came into commission. However, it is likely that the Roan and Storheia WTFs also contribute to the infrasound signature as they consist of 151 of the same Vestas V117 turbines and the wind coming from the east-northeast.

The upper levels recorded in the Hitra house were 116 dB outdoors and 109 dB in the bedroom. The Frøya house had 111dB outdoor and 99 dB indoor upper levels.
The twenty kilometres distance from Hitra 1&2 to the Frøya house explain an attenuation, yet it is not calculated how much the meteorological conditions contributed that day.

Note that the Frøya house has a ten kilometres closer proximity to the Storheia and Roan WTFs which are seventy and ninety kilometres away, versus eighty and hundred kilometres for the Hitra house.
Comparing data from the two houses, the wind turbines 70/90 and 80/100 kilometres away are likely contributors to the sound pattern. The temperature inversion over the large body of water between Hitra and Frøya and the Fosen region of Trøndelag and the downwind that day facilitate the transmission of infrasound over these long distances.

Further recordings and analysis are required to determine how much the Roan and Storheia WTFs contribute to the infrasound and blade pass harmonics on Hitra and Frøya. Without any connection to the topic of infrasound propagation, these are the same WTFs that the Norwegian Supreme Court ruled against in October 2021 for breaching the Sápmi's human rights by limiting their reindeer herding possibilities. [9]

4. Two cases concerning newly arisen health issues in persons living ten kilometres from the Hitra 1&2 WTFs

A person with a serious sleep disturbance
In December 2019 a person contacted me for help to map newly arisen noise in their house. The spectrograms and graphs in figures 1,2,3 and 4 are from this person's house.
They had lived ten kilometres from the Hitra 1 WTF for nine years without any health issues and were favourable to wind power generation.
After Hitra 2 WTF, also ten kilometres away started production, the rooms in their house started to rumble and boom when the windspeed rose above 5 m/s and came from certain directions.
Occupancy had become a burden and more time was spent out of the house. They would go out and about at night looking for the source of the noise, without any success. Sleep had become seriously affected and they often had to abandon the house to get sufficient rest.

A person with recurring atrial fibrillation
In 2021 a person in their late fifties also living ten kilometres from the Hitra 1&2 WTFs developed atrial fibrillation and received DC conversion five times due to relapses within a week after returning to the house. After an ablation, a procedure to break up or insulate the electrical signals in the heart that cause irregular heartbeats, the atrial fibrillation can still recur when in the house, yet abates within a day after vacating the house, see graphs in figures 10 and 11.

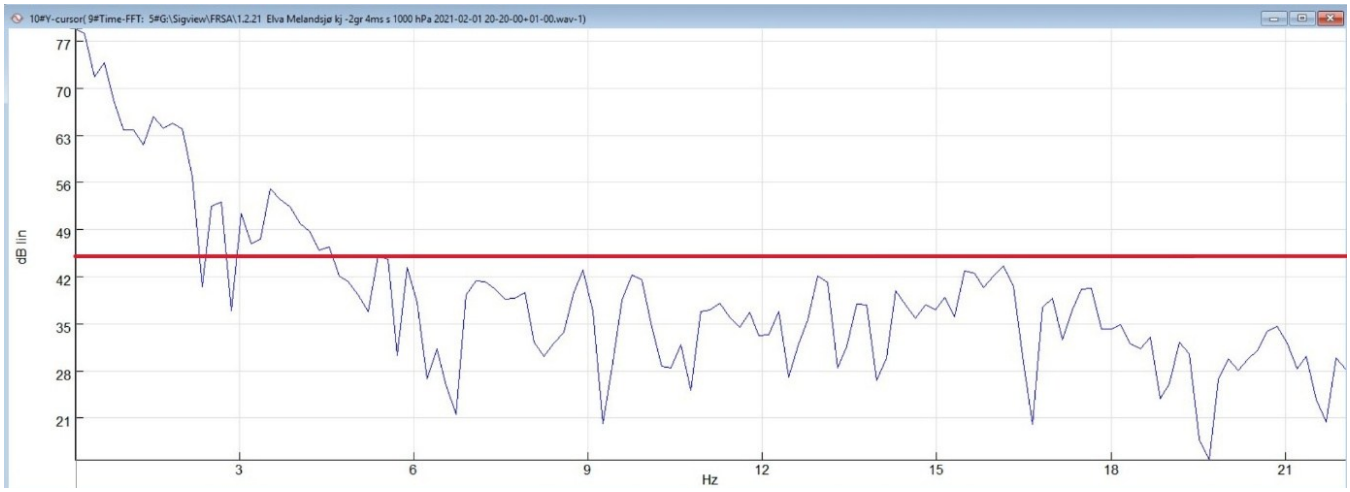

Figure 10 Hitra outdoor X axis 0.17-22Hz, Y axis dB 1910-1920 UTC Feb. 1st 2021

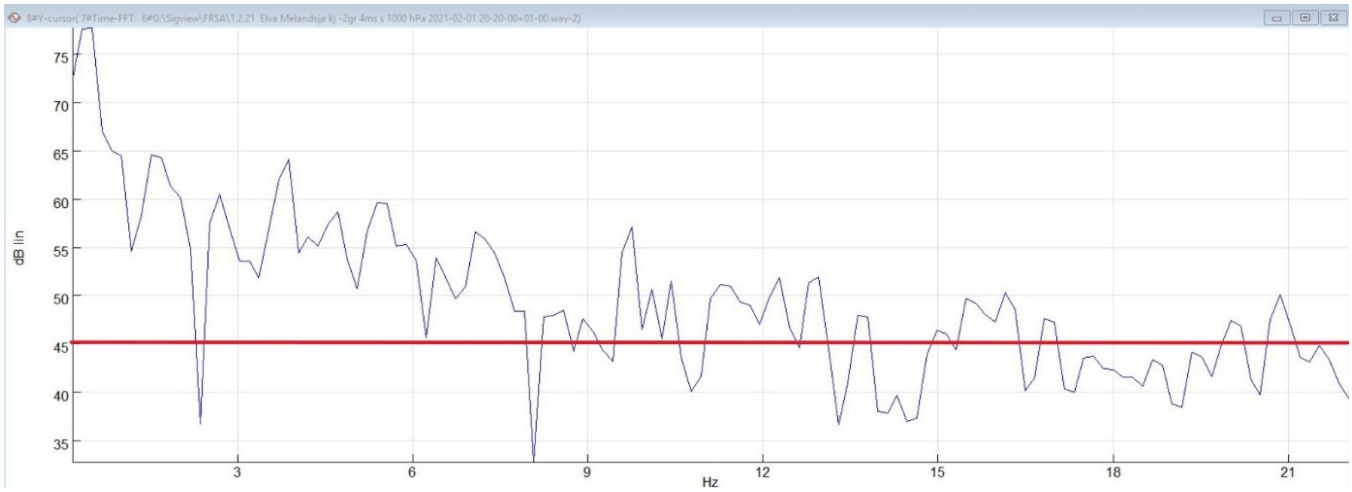

Figure 11 Hitra bedroom X axis 0.17-22Hz, Y axis dB 1910-1920 UTC Feb. 1st 2021

The sound mapping in both houses with affected persons shows a similar pattern in the spectrograms and graphs with large bedroom peak to trough levels in the blade pass harmonics. The person with heart arrythmia had substantially higher levels of infrasound in their bedroom than outdoors, see figure 11.
The two persons describe themselves as highly sensitive - HSP. Approximately one out of five people are HSP.

It is notable that health issues started when turbines with larger blades that produce a higher level of infrasound were added to the WTFs. These two health cases prove nothing about any cause and effect from rhythmic infrasound emissions generated by wind turbines.
However, they give reason for further health studies of residents living within ten kilometres from wind turbine factories.

5. Health Survey amongst residents within two kilometres from Tysvær WTF

A health survey was commissioned by the Tysvær municipality in 2023 after having received a number of health complaints after the Tysvær WTF started production in 2021. This is the second health survey of residents living near a WTF in Norway. [10]

Table 3 Health issues reported in the Tysvær health survey

Numbers in percent	Norway n=1000	Reference community n=200	Tysvær n=140	Total percentage over the reference community
Sleep disturbances	63	51	89	37
Muscle pain	56	53	70	17
Dizziness	33	39	55	16
Headache- migraine	24	21	41	20

Forty-seven percent of the 140 responders in the survey were severely annoyed by the audible noise from the WTF. Sixty-three percent were non-favourable to the WTF as opposed to seventeen percent in favour of them.
One notable feature is the high incidence of migraine in Tysvær, almost double of the national and reference community.

The low rate of participants in the health survey, fifty-three percent of the 262 persons living within a two kilometres radius of the WTF, could have given higher relative numbers of health complaints. Assuming that persons without any health issues were less inclined to participate in the survey.

6. Infrasound from WTFs

Often the wind power industry, and even the Ministry of Energy in 2021, refer to a 2020 study: *"Infrasound Does Not Explain Symptoms Related to Wind Turbines"* [11]
In the study twenty neighbours to a WTF with noise complaints were invited to a ten minutes long listening test of a years recorded and compiled sound taken 2.5 kilometres from the WTF. When they could not discern the sound, nor had a rise in blood pressure or pulse, the conclusion was that WTFs are not the cause of any health problems for residents living near WTFs. The problems could be in their heads and self-inflicted.
The sound levels in the study are way below the 95dB or higher levels of infrasound people living near WTFs are exposed twenty-four-seven whenever the wind blows.

You can compare the design of the study to one that shows that smoking is not detrimental to your health by letting twenty non-smokers smoke two cigarettes in ten minutes and them not getting sick.

7. Public health's dealing with health issues presumed to be caused by living near a WTF

Conflict of interests: None, other than a fine for civil disobedience in September 2020 which was upheld in a lower court ruling February 2021.
The disobedience was to set focus on the lack of following the precautionary principle, prescribed in the Norwegian Public Health Act of 2011, in the concession given for the wind turbine factory on Frøya in 2016. [12]

I am aware of how both physical and psychological bias influence research and analysis. I have tried to approach and discuss my findings with an open mind.

However, I do have strong opinions on how health issues from affected neighbours near WTFs are met by the Norwegian Institute of Public Health - NIPH.

We had a meeting with them in January 2020 presenting recordings with high levels of infrasound in a house five hundred metres from a WTF in Egersund, Norway. The parents were having adverse health reactions, very likely attributable to the WTF.
We appealed for health surveys and monitoring of persons living near WTFs, yet were brushed off citing lack of funds. Likewise, an appeal for legislation to make the industry prove the safety of their products, ever larger wind turbines that produce ever higher levels of infrasound, was dismissed.

The NIPH website updated in May 2022 states: *"Although neither infrasound nor low-frequency sound are specific to wind turbines, there has been particular concern about the health consequences of infrasound from wind turbines"* [13]

Infrasound from WTFs is specific with signatures comprised of blade pass harmonics with high peak to trough levels, as opposed to randomly generated broad band infrasound from traffic and in nature.
The 2 channel recordings show how resonance and perchance interference increase the infrasound's peak to trough levels in the house

The health survey from Tysvær is not mentioned in NIPH's chapter on WTFs and health. However, the one other health survey from Lista in 2015 is noted. 2/3 of the residents living within 1 kilometre from the WTF in Lista experience strong noise annoyance.

8. Infrasound effects in human and animal physiology at a cellular level

Recent knowledge of how infrasound affects cell physiology is presented by Ursula Maria Bellut-Staeck in the 2023 study: "*Impairment of the Endothelium and Disorder of Microcirculation in Humans and Animals Exposed to Infrasound due to Irregular Mechano-Transduction*." [14]

Her study adds to the work of Vladimir Stepanov et al from 2003. They presented increasingly lower recommended Maximum Pressure Limits- MPLs in the workplace and residences from 1973 and on to 2000. [15]

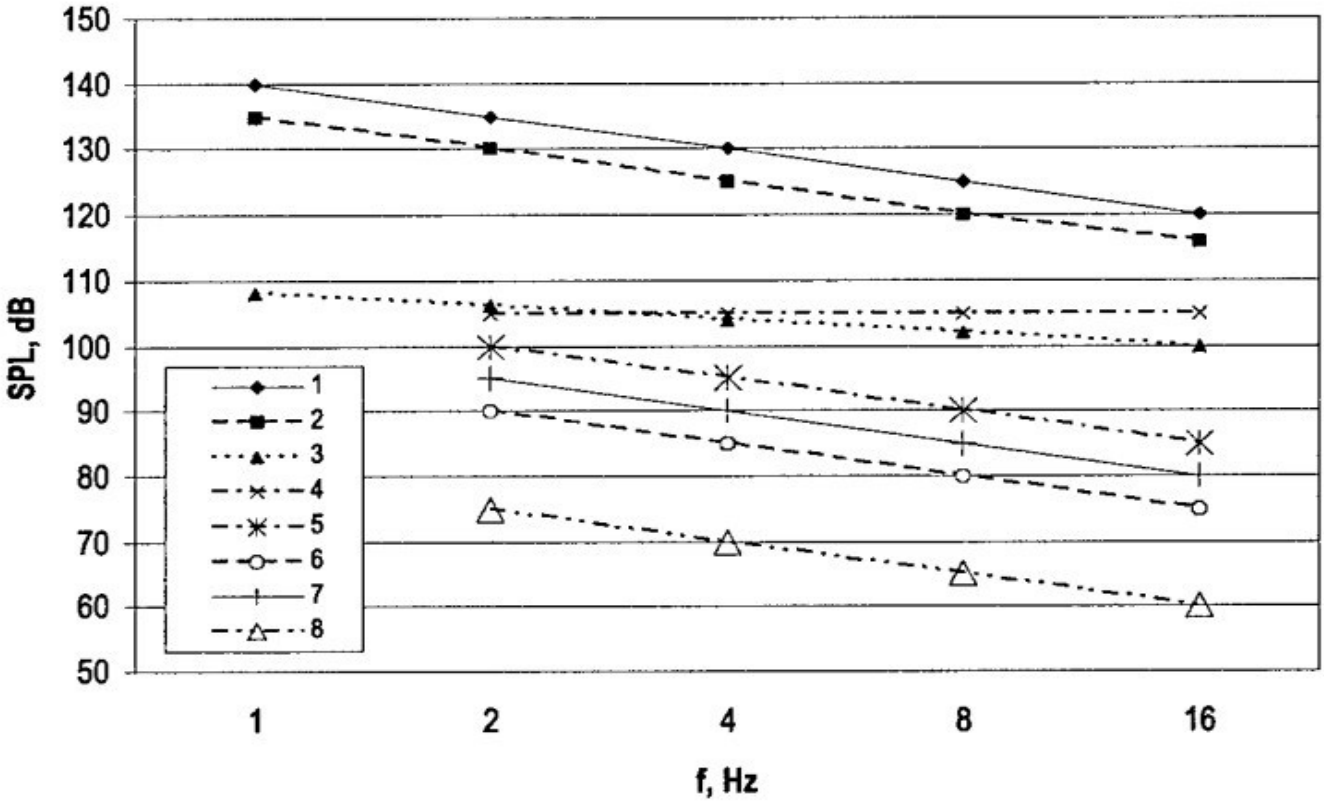

Figure 12 - MPLs dynamics for Low Frequency Acoustic Oscillations and infrasound in 1973-2000

1- *MPLs recommended by D.Johnson and C.Nixon (1973)*
2- *MPLs recommended by Paris International colloquium (CNRS) (1973)*
3- *MPLs recommended by Institute of Biophysics (1979)*
4- *MPLs recommended by Research Institute of Labour Hygiene and Occupational Diseases of the USSR Academy of Medical Sciences et al (1980)*
5- *Modern MPLs recommended by Labour Medicine Research Institute of Russian Academy of Medical Sciences et al (1996) jobs of different intensity inside industrial premises and at the industrial territory*
6- *Intellectual and emotional jobs*
7- *Populated areas*
8- *Living and public premises*

An assumption could be proposed that the large peak to trough levels in blade pass harmonics generate more hysteresis in cells and organs than a constant high level of infrasound with lower peak to trough levels and thereby have a greater disruptive effect at the cellular level.

The descriptions in*: "Examples of hysteresis phenomena in biology"* [16] may explain how myocardial cells are affected by rhythmic infrasound with pronounced harmonics causing atrial fibrosis and arrythmias.

The study from 2021: *"Infrasound exposure promotes development of atrial fibrosis in rats"* discusses this issue. [17]

9. Conclusions

Working on a small island community as a General Practitioner since 1985 and as Municipal Chief Medical Officer on a rotational basis, sharing the position with my wife Eli, gave me the challenge of having to deal with noise pollution from 2020. As I delved into the literature on infrasound from WTFs,
I came across an abundance of studies with no clear conclusions on health impacts.

Proprietors of WTFs do not have to conduct any post erection measurements of the 45 dBA Lden adopted and calculated standard, nor record any infrasound inside nearby houses.
Any measured results are not divulged due to proprietary and competitive issues amongst the industry.

Were they to be shared the results would most likely not be dealt with, as there are no set limits for infrasound in Norway and fellow Municipal Chief Medical Officers most often have limited knowledge of sound pollution.
The wind power industry has not yet been forced to prove that their products, which are ever larger turbines which generate ever higher levels of infrasound, are not harmful to humans and animals.

Where the Norwegian Water Resources and Energy Directorate, that issues concessions, lacks in public health expertise, they have to rely on the NIPH's lacklustre approach to the issue, and the wind turbine industry gets to maintain the calculated 45 dBA Lden limit.

Without having to deal with infrasound pollution from their products.
Suppose the same lack of certification standards were applied to the licencing of automobiles or with the introduction of new pharmaceuticals?
How come some countries after the Paris 1973 infrasound colloquium adopted ever stringent band specific limits for permitted infrasound in the workplace and in homes, whereas other countries have chosen to not set any limits for infrasound or vibrations?

As it seems that highly sensitive persons are the first to report health issues from living in the vicinity of a WTF, is the eighty percent normo-sensitive population not directly affected by WTFs reason enough to not pursue the issue of suspected health problems related to WTFs?
Were up to twenty percent of the population stricken by a suspected agent, one would certainly push to elucidate the matter.

"The wind industry is relatively new in Norway. The likelihood that there may be errors or shortcomings in both the guidelines and regulations is therefore present, something that Norwegian health authorities should take into account. If more wind industry is to be developed, thorough studies should be carried out by independent actors before licenses are awarded. Furthermore, it should be ensured that the people working on the study have the necessary professional expertise in subjects such as acoustics, environmental hygiene, occupational hygiene, public health and occupational medicine. Negative health effects should be assessed both in isolation and collectively, for the best possible overview." [18]

The Public Health Committee in Motvind Norge has had meetings with The Norwegian Water Resources and Energy Directorate, The Norwegian Environment Agency and The Norwegian Directorate of Health to discuss guidelines for evaluating the sum effects of audible and uneven amplitude modulated noise, infrasound, high-intensity flashes of light at night, shadows cast by -and the sight of moving turbine blades, Bisphenol-A and PFAS spread in nature and drinking water, grief of nature loss and property value loss.
They all give kudos to the group's efforts and agree that these are issues that need to be addressed.

Yet, they admit that they do not have the competence to make any sound evaluations or recommendations, AKA passing the buck. The Norwegian Institute of Public Health does not respond.

Are we up against a similar problem as those that were encountered when dealing with the exposure to asbestos particles and tobacco smoke? Knowledge of the hazards to their exposure was allowed to fester for decades before regulations were signed into law.
Could proceeds from the wind turbine industry be a step to take for the regulatory bodies to fund independent research and set guidelines?

Until then my advice for guarding the public health is to invoke the precautionary principle and mandate infrasound measurements in homes near WTFs, set limits on infrasound in residences as DEPA intended back in 2011 and impose a moratorium on erecting any WTF closer than ten kilometres to residential areas.

Acknowledgements

Being an avid high-fidelity buff chasing the holy grail of perfect sound recording, I bought a pair of Bruel & Kjær 4004 studio microphones back in 1988 to record performances of the choir Havdur, which Eli has been singing with since then. This has offset any looming annoyance for the time I have spent on performing infrasound recordings in and out of houses around Norway pro bono.

Kind thoughts for my parents who encouraged my curiosity since early childhood. This is a trait our children also seem to share, and since we're not cats, the going has been pretty good - so far.

Championing peace cuts it down to the maxim: ***"Justice for troubled wind farm neighbours won't happen until those who aren't affected become as outraged as those who are".***

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