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How Critical is Low Frequency Noise for Micrositing?

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Summary

Many national and regional Environmental Impact Assessment (EIA) guidelines state that low frequency noise impact from wind turbines must be examined, but only a few have described a specific procedure for this examination. The result is that low frequency noise is often either ignored, shrugged off as irrelevant or examined using a randomly selected approach that may or may not produce useful results.

Three countries, Finland, Sweden and Denmark, have described detailed procedures for calculating low frequency noise impact and, while not valid outside their respective countries, these procedures can be used for testing whether low frequency noise is potentially relevant for consideration.

This study presents and discuss the three guideline approaches and compares the low frequency impact across guidelines at dwellings located on the boundary for regular noise targets by testing if low frequency noise is critical according to the guidelines when regular noise targets are met.

This is done by using a number of anonymized noise datasets from actual commercial wind turbine types available to EMD. The datasets are tested by applying them to each of the three national noise codes in as many situations as they describe, such as onshore/offshore settings, day and night conditions and light dwellings versus regular dwellings. A narrow margin or an exceedance of guideline target criteria for low frequency noise means that low frequency noise would be a problem using this guideline and therefore could potentially reveal a problem in third countries without a specific guideline.

By using as many noise datasets from as many turbine types as possible, the extent of low frequency problems is uncovered to verify if the general assumption that low frequency noise is becoming less of a problem in planning as modern turbines are shifting noise emission away from the low frequency range, is true.

1. Introduction

A decade or so ago low frequency noise from wind turbines was a hot topic with concerns raised on health issues and on how to regulate the impact of low frequency noise from wind turbines. Since then the topic has to some extent cooled down, which begs the question if the low frequency issue is now a thing of the past and, secondly, how can we take low frequency noise into account in the planning process?

For planning it is useful to have a code with an operational methodology and tangible targets. Such targets may be based on a health consideration, but from a planning point of view we are mostly interested in the target itself. If we can stay within the target, we are good. Some countries have written low frequency noise into the national noise codes, either as a formalized model or in a loose formulation on that low frequency noise must be considered. The first of these are useful for planning, the latter less so. It would be desirable to get specific targets rather than fluffy ones, but only if low frequency noise is actually critical. If we could work on the assumption that low frequency noise from wind turbines is a thing of the past and that modern wind turbines will always comply with low frequency noise targets when they comply with regular noise targets, maybe there is no point to include low frequency noise in planning.

Colloquially there is a number of rules of thumbs going around in the wind energy community

1. Modern turbines do not have low frequency issues. Those were problems on older models. If you can comply with the standard noise target, you will not have problems with low frequency noise.
2. Reducing noise on wind turbines in the form of noise reduced operation reduces regular (normal range frequency) noise, but does little for low frequency noise
3. The larger the wind farm the more important low frequency noise becomes, because the target moves away from the wind farm and low frequency sound is attenuated less with distance than higher frequency sound.

The purpose of this study is to test these claims.

To achieve this goal we use the Danish, Swedish and Finnish codes for low frequency noise from wind turbines to test if low frequency noise becomes critical at a distance from the wind farm where the standard noise target is just met.

This test is conducted with a selection of anonymized modern turbines to get a representative, but not exhaustive sample group. The point here is not to point fingers at specific turbine types, but to answer the general question on whether low frequency noise can be critical for planning.

2. Noise codes

Denmark, Sweden and Finland have each defined a code for low frequency noise in planning of wind farms. The codes are different from each other and it is therefore useful to test each of these against the wind turbine types.

2.1 The Danish noise code

The currently valid Danish noise code is “Bekendtgørelse nr 135 af 07/02/19” (Miljø og Fødevareministeriet, Denmark, 2019). It defines noise targets as well as methodology in assessing the noise impact.

It operates with two types of planning zones: open land and areas of increased sensitivity with normal noise targets at 6 and 8 m/s at 10 m height as in table 1. The low frequency target is 20 dB(A), summed up in the frequency range 10 to 160 Hz. Recently a distinction has been made between standard dwellings and light dwellings (sommerhuse), where reduced noise insulation values are used based on a study from the Danish EPA (Søndergaard, 2016). Light dwellings are only considered as such if they are in an area of increased sensitivity.

Table 1. Wind turbine noise targets, Denmark

Zoning	6 m/s	8 m/s
Open land	42 dB(A)	44 dB(A)
Area of increased sensitivity	37 dB(A)	39 dB(A)
Low frequency: Any	20 dB(A)	20 dB(A)

The methodology for both regular and low frequency noise is a logarithmic model. For low frequency calculations the calculation point is indoor while it is outdoor for regular noise. For offshore wind turbines a reduced ground attenuation is used as well as multiple reflections.

2.2 The Swedish noise code

The Swedish noise code for wind turbines is administrated by Naturvårdsverket. For the present the guideline concerning regular noise is described in “Ljud från vindkraftverk” (Naturvårdsverket, 2010), while the low frequency guideline is only described on the home page of Naturvårdsverket (Naturvårdsverket, 2019). However, a new guideline is expected in 2019 at which point the methodology described here may be rendered invalid.

There are several noise targets in place for regular noise, but the most commonplace is 40 dB(A) at 8 m/s at 10 m height. The guideline methodology is a logarithmic model and the calculation point is outdoor. However, it is possible to use alternative calculation methodologies such as Nord2000.

For low frequency noise, a dwelling must be considered if the difference between C and A weighted noise at the receptor is higher than 20 dB (range 32-200 Hz). The noise target is a frequency curve supplied by Folkhälsmyndigheten (Socialstyrelsen, 2008) in the same range. The noise is calculated indoor. There is no specific model advised, though there seem to be a preference for Nord2000. Nor are there any official noise insulation values available.

The Swedish low frequency noise target is presented in figure 1.

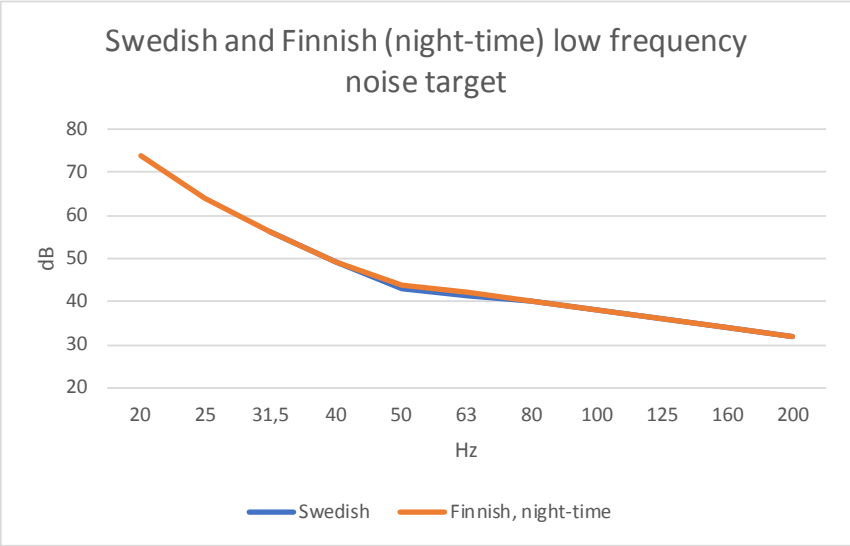

Figure 1. The Swedish and Finnish (night-time) low frequency noise targets are almost identical.

2.3 The Finnish noise code

The Finnish target for regular noise impact is described by statutory order (Miljöministeriet (Ministry of the Environment), 2015) to 40 dB(A) at night and 45 dB(A) at day for most receptors of interest. The low frequency noise target is not covered by the statutory order, instead the national residential health guideline (Sosiaali- ja terveysministeriön (The Finnish Ministry of Social Affairs and Health), 2003) is commonly used. This guideline sets the target as an indoor day and night frequency curve from 20 to 200 Hz, of which the night spectrum is the stricter.

The methodology is described in a guideline (Miljöministeriet (The Finnish Ministry of the Environment), 2014), advising a method for early stage planning and one for later stage. The early stage used here is a variety of the ISO 9613-2 (International Standards Organization, 1996) model, whereas for low frequency noise a logarithmic model similar to the Danish model is recommended. While the regular noise receptor is outdoors, the low frequency receptor is indoor. No advice is given concerning noise insulation values.

The Finnish low frequency noise target for night-time is presented in figure 1.

3. The test setup

The test setup is fairly simple in principle. For each permutation of the codes, a calculation point is found at the distance to a wind farm where the regular noise code is met. A noise target x with the methodology of noise code y results in a point z meters from the closest wind farm where the target is exactly met. For this point the low frequency noise is calculated with the guideline methodology and noted. If the low frequency target is exceeded, low frequency noise is the critical parameter. The margin to the target can be the margin in dB to the combined target (Danish code) or the margin to the target frequency curve at the most critical frequency (Sweden and Finland).

The tests made are listed in table 2. For the Danish tests, a distinction is made between onshore and offshore and between open land zoning or areas of increased sensitivity zoning. The later with a distinction between standard dwelling and light dwelling.

In the Swedish case only the 40 dB(A) target is used, being the most common target (though targets as low as 35 dB(A) is sometimes used). Since the low frequency target does not change, restricting the regular noise level will make low frequency noise less critical. The night low frequency target is used. As for low frequency propagation model, a Nord2000 model is set up using flat, very hard terrain (class G) and typical temperature and humidity settings. Noise insulation values are adopted from the Danish codes, using the standard insulation values for regular dwellings and light dwelling values to represent wooden houses.

For the Finnish case, the night 40 dB(A) target is used for regular noise and the night frequency curve as low frequency target. Standard values are used for the terrain. As for noise insulation the Swedish considerations are applied.

Table 2. Test scenarios

Code	On- or offshore	Zoning	Noise insulation
Danish code	Onshore	Open land	Standard dwelling
		Areas of increased sensitivity	Standard dwelling
			Light dwelling
	Offshore	Open land	Standard dwelling
		Areas of increased sensitivity	Standard dwelling
			Light dwelling
Swedish code	Onshore	40 dB zoning	Standard dwelling
			Light dwelling
Finnish code	Onshore	40 dB zoning	Standard dwelling
			Light dwelling

Calculations are done in windPRO for three different turbine configurations: 1, 5 and 21 wind turbines. The 5 and 21 turbine configurations are presented in figure 2

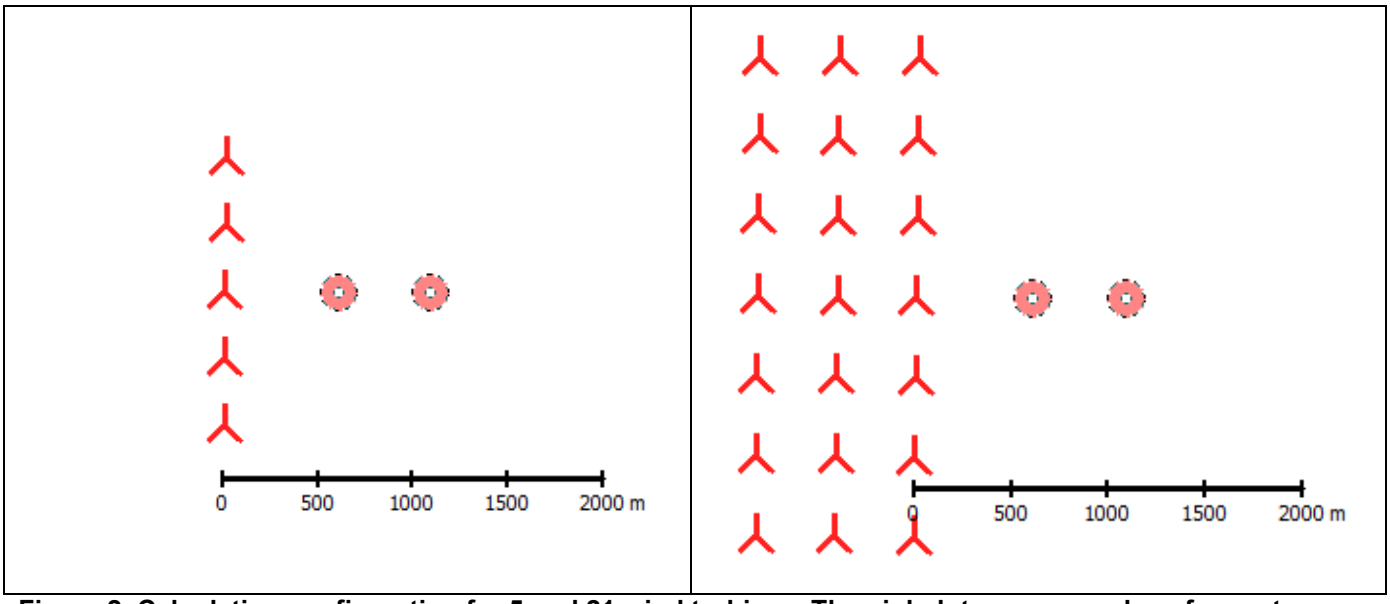

Figure 2. Calculation configuration for 5 and 21 wind turbines. The pink dots are examples of receptors.

4. Selection of wind turbine samples

The selection criteria for the wind turbine types to be used for the test were the following

1. The wind turbines had to be modern types in use for current developments
2. The wind turbines had to be comparable in size. The size range is 3.5 to 4.5 MW and 115 to 145 m rotor diameter.
3. The wind turbines had to be representative across suppliers, hence models were used from five different suppliers
4. Low frequency data had to be available to EMD
5. Each turbine type had to be able to be operated in a standard and in a noise reduced mode.

Most importantly the data had to be anonymized, as we have no intention of pointing fingers at specific wind turbine models. Furthermore, the data used are the data that suppliers make available for planning purpose (sales data) as these data are, if not public, then fairly easy to obtain.

An early consideration was to use measured data as supplement. However, these have a much higher confidentiality sensitivity and those in our possession are often from the prototype phase and are consequently not necessarily representative of the commercial version of the wind turbine. Therefore, only supplier provided data was used.

If available, data for serrated blades are used as these will typically be employed near settled areas. The standard mode will therefore, if available include serrations. No particular criteria are set for selecting a noise reduced mode, except that the noise reduction must be significant. This may be achieved through reduced rotational speed or reduced power or a combination of the two. It is possible that low frequency noise responds differently to these methods of reducing regular noise, but it was outside the scope to investigate this.

In total 10 turbine types from 5 suppliers were used, labelled 1 through 11 (model 4 was cancelled). Standard operation mode carries the suffix a and noise reduced mode the suffix b.

5. Results

5.1 Compliance

The low frequency noise impact on dwellings located exactly where the regular noise target is met was calculated for each of the scenarios in table 2 with each of the wind turbine types in two operation modes. The results are presented for a selection of the scenarios below.

For the Danish code case, the calculated low frequency noise impacts at the dwelling are presented with the orange columns, up towards the target of 20 dB(A). The black lines represent the distance from the dwelling to where the low frequency target would be met. In most cases there is a comfortable margin up to the target and the dwelling may be a safe distance away from where the target is met, but not for all turbines.

For onshore sites a single turbine type will be in trouble in the single turbine layout at the receptor in open land. At the area of increased sensitivity, the stricter regular noise target means that the low frequency impact is well beneath the target, but a change to light dwelling noise insulation gives a result very similar to the open land scenario.

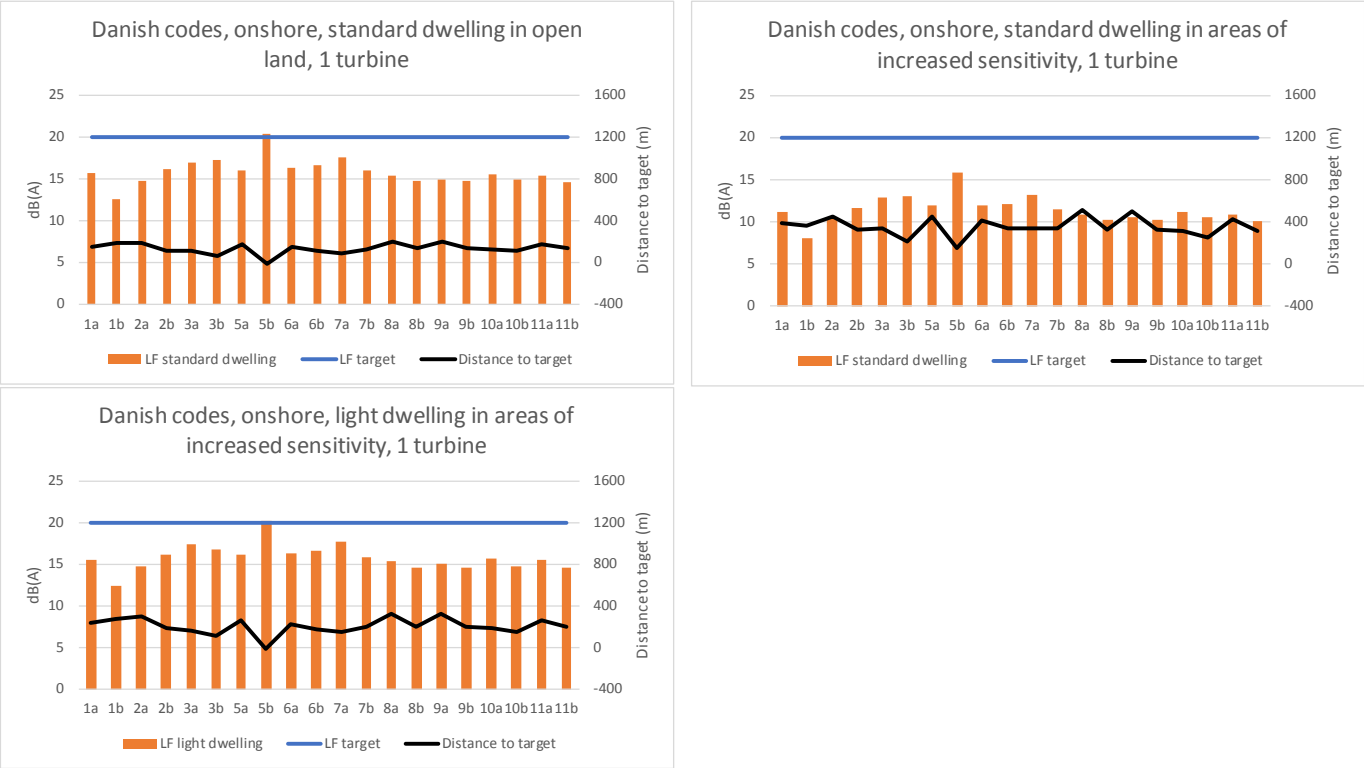

Figure 3. Results for three types of receptors using Danish codes, onshore with a 1-unit layout. Orange columns are the combined, A-weighted low frequency noise from 10 to 160 Hz. The black lines are the distance from the dwelling to the point where the low frequency target is met. A positive value means that this point is closer to the wind farm.

Increase the wind farm to 21 wind turbines and all the wind turbine types are pushed closer to the target, some of them critically close and, in one case, above the target. In the light dwelling scenario, there are now two types, 3a and 5b, that are above the target and a third, 7a right on the target.

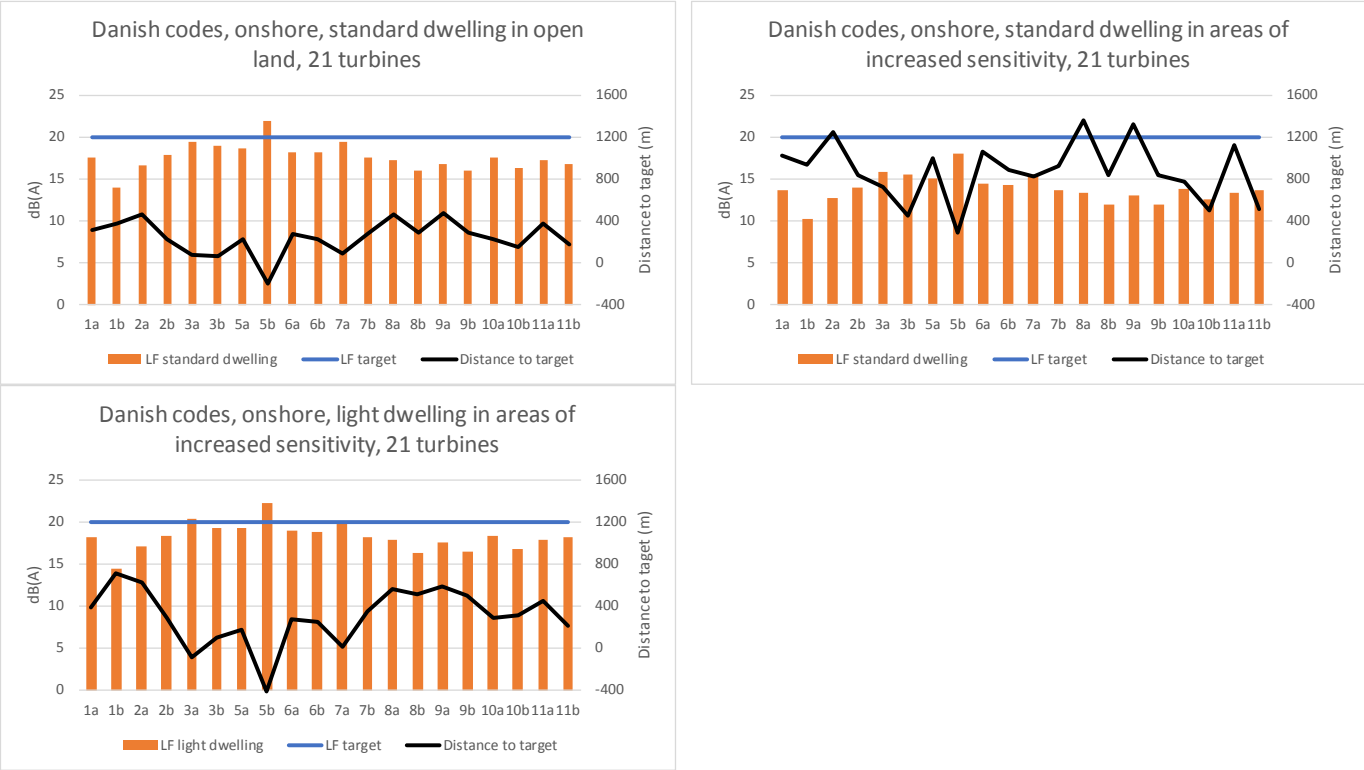

Figure 4. Results for three types of receptors using Danish codes, onshore with a 21-unit layout.

Moving offshore gives a marginal increase in the 1-unit scenario, but a larger increase in the 21-unit layout. Several wind turbine types are now very close to or exceeding the target.

Figure 5. Results for three types of receptors using Danish codes, offshore with a 1- and 21-unit layout

The results using the Swedish codes are presented in figure 6, with orange and green columns representing the margin in dB between the impact and the target at the most critical frequency. Orange is for light dwellings and green for standard dwellings. The black graph is the C-A weighting criteria which in all cases are above 20 dB (meaning low frequency noise must be considered).

In the single wind turbine case, most wind turbine types will have a safe margin to the target, especially with the noise insulation of a standard dwelling, but change to a light dwelling and two types, 3 and 5 will exceed the margin. If the impact of 3b is plotted against the target spectrum we can see that the impact is actually safely within the target except for a single frequency (figure 7).

Considering the larger 21-unit layout, the problem is more pronounced with type 3 and 5 clearly exceeding the target, even with a standard dwelling. Three other wind turbine types are close to the margin.

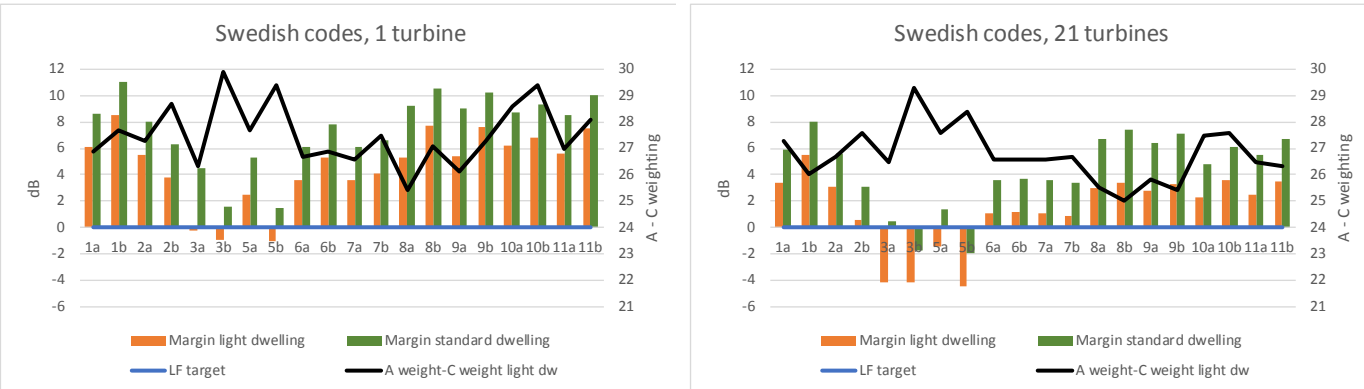

Figure 6. Results with Swedish codes, 1- and 21-unit layouts. Orange and green columns are the margin from the noise impact to the target value at the most critical frequency for light and standard dwelling respectively. A positive value means that the noise impact is within the target. The black lines are the difference between C- and A-weighting. A value above 20 dB means that low frequency noise at the dwelling must be considered.

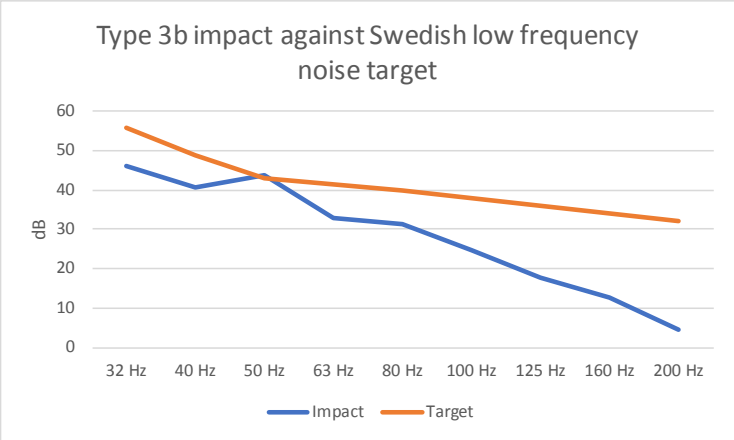

Figure 7. Impact of type 3a against Swedish low frequency target.

In the Finnish case, the pattern is similar, but not identical to the Swedish case despite the almost identical target spectrum. The critical margin is larger for the large wind farm case and the type that had trouble with the Swedish code are still in trouble but less so.

Figure 8. Results with Finnish codes, 1- and 21-unit layouts

5.2 Compliance as a function of wind farm size

Considering that attenuation is less with distance for noise at low frequencies than at high frequencies, it is expected that as the receptor points move further away from the wind farm, low frequency noise will become more critical. This has already been hinted at in section 5.1.

In the diagrams of figure 9, the margins from low frequency impact to targets are presented as a function of wind farm size (by units). A positive margin means that the impact is within the target.

For the Danish code only onshore, standard dwelling in open land and offshore, light dwelling in areas of increased sensitivity are presented, being the most interesting results. Only standard operation mode is included for the ten wind turbine types. The function is practically identical for all turbines, which is not really a surprise. In standard mode, onshore, open land, even the worst performing type will stay within the target even for large wind farms. In the other scenario with offshore codes and light dwellings there are many types that will exceed the target as the wind farm grows larger. Considering that offshore wind farms tend to be large this issue is expected to be relevant, though only for light dwellings near the shoreline as offshore codes in

Denmark are only to be used until the shoreline after which there is a 200 m transition zone before onshore methodology takes over.

For the Swedish codes the gradient is so flat from 5 to 21 units for half the types that it is doubtful if they will ever exceed the target even for very large wind farms. That is the case for both light dwellings and standard dwellings. Those types that are close to the target however have a steeper gradient and are prone to exceed the target at a point as the wind farm grows. That is the case even for standard dwellings.

In the diagrams of the Finnish results, there seems to be no such difference in gradient. The graphs are simply parallel, which means that eventually any turbine type will eventually exceed the target, it will just require a very large wind farm. For standard dwellings even the poorest performing type will take a very large wind farm to exceed the target.

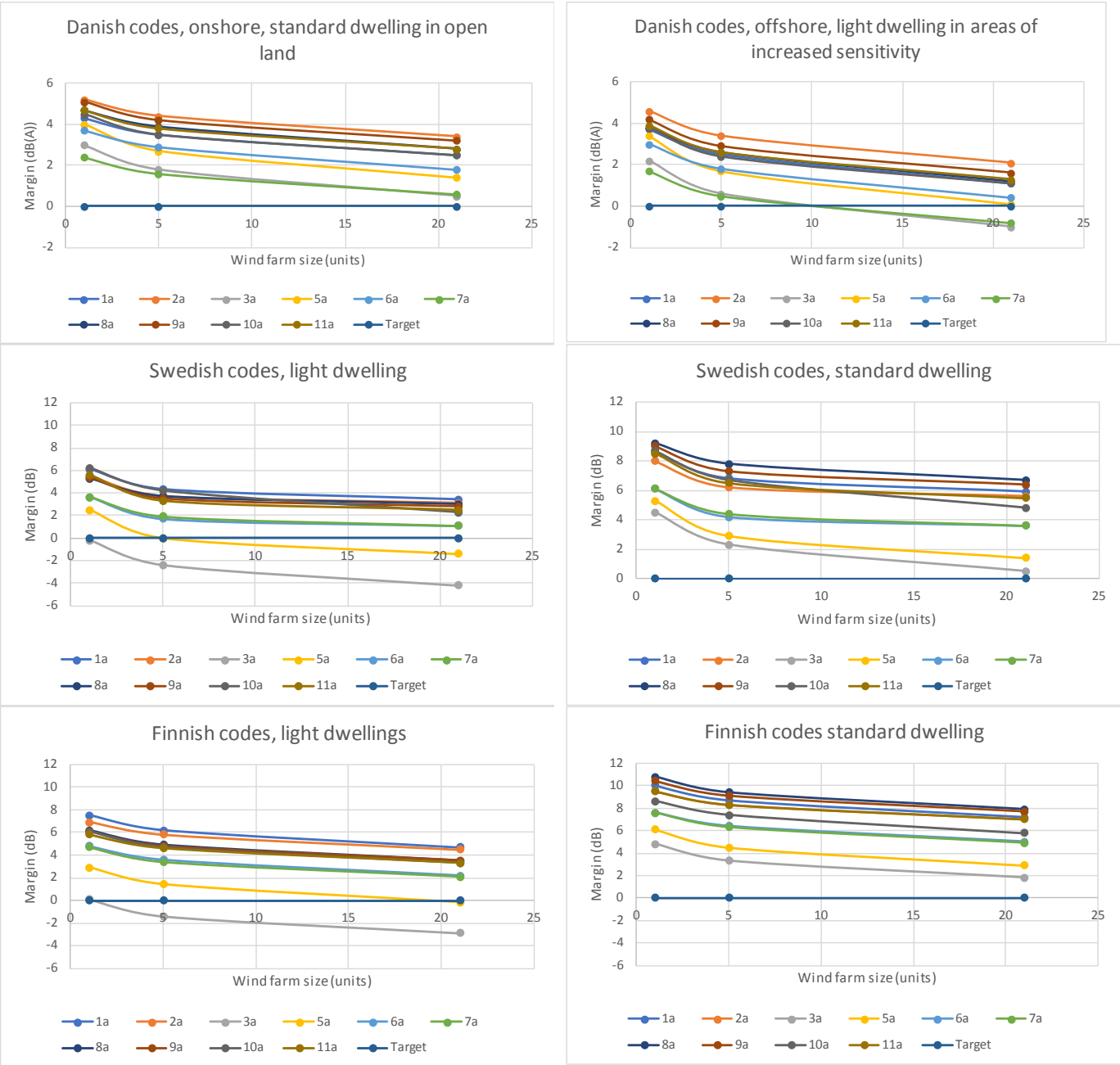

Figure 9. Low frequency noise as a function of wind farm size. The margin presented is the margin from low frequency noise impact to the target. In case of the Swedish and Finnish code, at the most critical frequency. A positive value means that the impact is within the target.

5.3 Changing operation mode

What is then the effect of changing noise mode?

Figure 10 presents the consequence of changing operation mode from standard operation mode to a noise reduced mode. The values presented are the change (increase) in margin from standard operation mode to noise reduced mode. An increase in margin means that low frequency noise is getting less critical while a decrease in margin means that low frequency noise is becoming more critical.

The direction of the change is uniform across the codes. An improvement will be an improvement using any code. But the magnitude is different and more importantly the change varies both in direction and magnitude from type to type. Some types get more critical while others get less critical, meaning that the low frequency response to a change in noise mode cannot be generalized.

A fairly large group of types shows almost no difference using the Finnish code, meaning that a reduction in regular noise is accompanied by a similar reduction in low frequency noise. That same group performs noticeably better using the Swedish code. Here those same types will reduce the noise relatively more for the low frequency test than for the regular noise test. Considering that the noise target is practically the same, this illustrates the difference in propagation model.

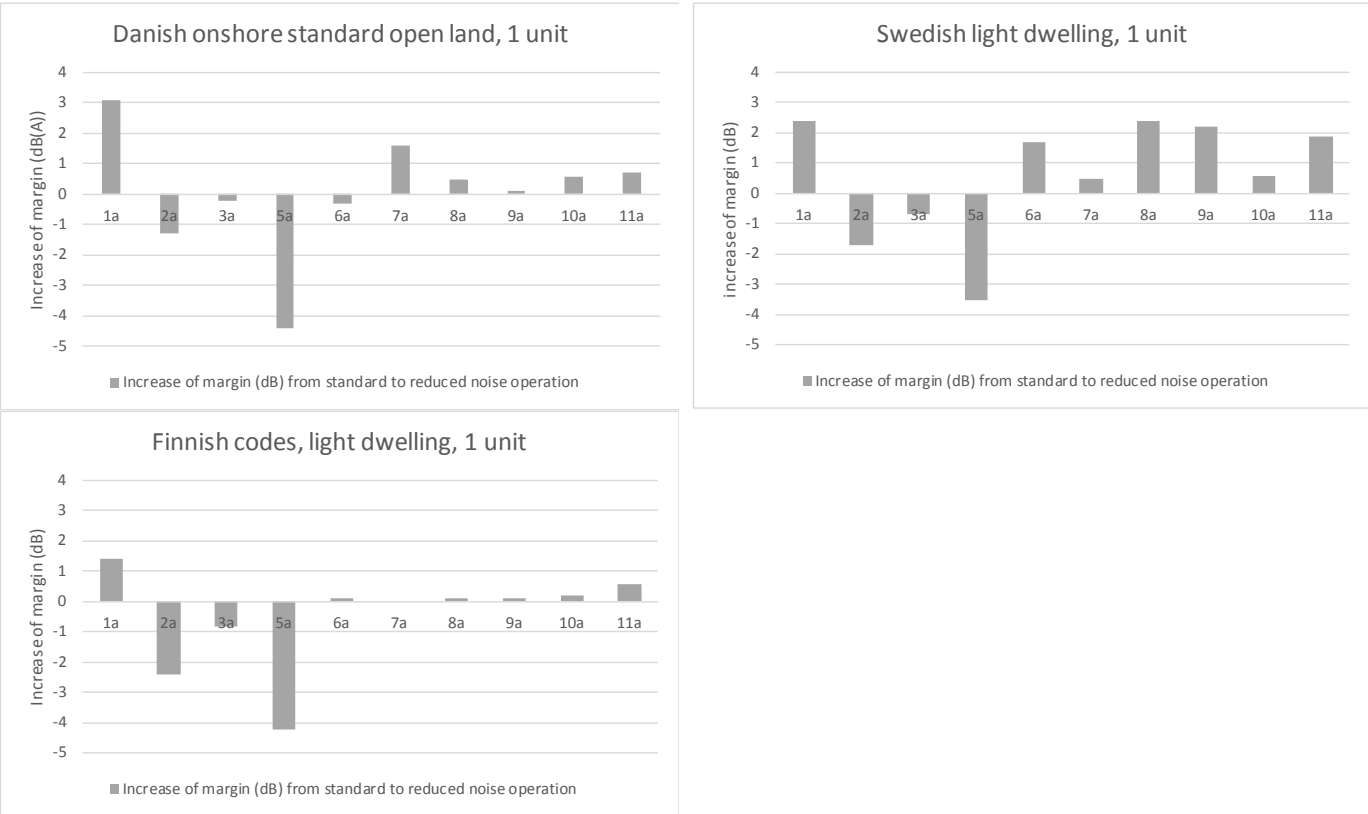

Figure 10. Effect on low frequency noise of changing operation mode from standard to reduced noise. The columns show the change in margin between low frequency noise impact and target as the operation mode changes. A positive value means that the margin is becoming larger while a negative value means that the low frequency noise criteria becomes more critical.

6. Conclusions

So, is it still relevant to test against low frequency noise codes or are we beyond that?

The answer to that is yes, it is still relevant.

While this study is not questioning if the targets in Denmark, Sweden and Finland are meaningful or serves their purpose of protecting the public, they do make up a practical and considered test to avoid excessive low frequency noise in the planning phase.

While some wind turbine types appear to keep comfortably clear of the low frequency targets as long as they comply with the regular (normal frequency) targets, others do not and because of that, it is meaningful to run a test against a low frequency code.

Wind farm size has an obvious influence on how critical low frequency noise gets and for large wind farms low frequency problems are not restricted to a few bad eggs but may be a problem for a larger group of wind turbine types.

Regulating the way out of low frequency trouble requires that reduced noise operation modes actually reduce low frequency noise along with the regular noise. We cannot rule out that the selection of reduced operation mode for some of the types was poorly considered and that there are operation modes available that actually does decrease low frequency noise along with regular, but it is clear from this investigation that selecting a reduced operation mode can go either way. There is no fundamental rule that low frequency noise is a bigger or lesser issue in reduced noise operation. We can only recommend being aware of this issue when considering the use of reduced noise operation mode.

What makes the low frequency noise critical then?

One reason may be found in the codes. If the codes allow a higher noise level for regular noise, but maintain the low frequency target, then the receptors may be allowed closer to the wind farm and the low frequency impact increases. The same goes for the reverse. If the noise target or methodology is tightened for low frequency noise without changing the regular noise, the low frequency issue becomes more critical, as exemplified with the new noise insulation values for light dwellings in Denmark.

The focus of the code may also be an issue. While the Danish code sums the impact over a range of frequencies, the Swedish and Finnish codes requires compliance at each frequency within the spectrum range considered. That means that while the Danish code considers broadband low frequency sound level, a single or two frequencies may be what triggers that low frequency becomes critical in the Swedish and Finnish code. We are not questioning whether this is a good or a bad thing, merely that they are targeting a different aspect of the low frequency sound.

From the wind turbine side, we have seen in later years that the regular noise from wind turbines have not grown much with turbine size (generator and rotor), certainly not as much as expected in earlier studies (Møller, 2011). It appears that particularly for onshore turbines even in standard operation mode attention has been given to reduce noise. Serrations of various sorts have become a standard feature on the blades across the range of suppliers and combined with general efforts to reduce noise that means that the regular noise impact from wind farms is relatively low. If the low frequency emission is not similarly reduced, low frequency noise becomes critical. Boiled down, you can create a low frequency issue by focusing on reducing regular noise. From this study it would appear that some suppliers have been reducing low frequency noise along with regular noise reduction (or have not reduced the

regular noise in the first place), while others may not have managed to reduce the low frequency noise along with the regular noise.

All wind turbine noise data used in this study was obtained from material made available by suppliers for wind farm developments in general. We cannot verify if the values are correct and 1/3 octave data are rarely if ever warranted. Therefore, we cannot rule out that some of the data may be biased. However, we suspect that where that may be the case, it would rather be from simplifications in the calculation methods that provide the source noise data than from deliberately providing misleading values. There is very little to gain from massaging data from suppliers' side. The exercise could be repeated with measured source noise data, but this would likely require a large sample size to counter measurement uncertainty, and EMD does not have such data readily available.

In countries and regions where a low frequency noise methodology is not available in the local code, concerns regarding low frequency noise can be addressed with the Scandinavian models, at least to demonstrate whether or not low frequency noise could be a concern for the wind farm in question.

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