Evolution of the social impact of wind energy development

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1. Development of wind turbines
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C. ENVIRONMENTAL NOISE LIMITS

Mainly aural impact considered but visual certainly important

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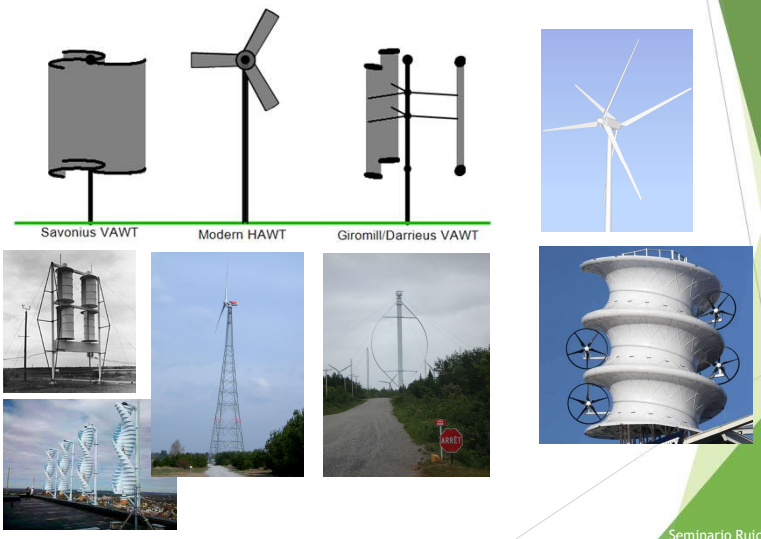
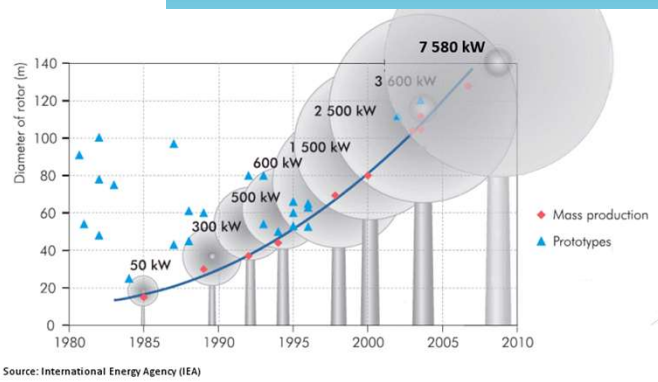
A1.2 Development of wind turbines: type



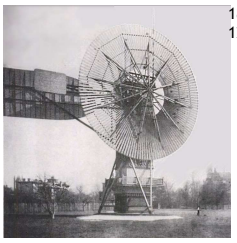
Wikipedia: Wind turbine

A1.1 Development of wind turbines: size



N.N. Sound production proportional to 10*log(rated power)

A1.3 Big wind turbines (at their time)



1887: first automatic operating WT;
12 kW, Φ 17 m, Vtip 18 m/s

1983: 'Large wind generator';
3 MW, Φ 100 m, Vtip 97 m/s

1979: NASA MOD1:
2 MW, Φ 61 m, Vtip 112 m/s

2014: Vestas V164: 8 MW, Φ
160 m, Vtip 101 m/s

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A2.1 History of impact; an impression

Originally (until '80s/'90's):

- many WT types and experimentation
- but low numbers and no wind farms
- no clear regulations
- if complaints, mainly about (tonal) gear noise

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A2.2 History of impact

Later ('90/'00s):

- Large differences between regions and countries
- Impact on landscape increased with size and numbers
- Indications impacts had been underestimated
- Worries about impact on birds

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A2.3 History of impact

These days ('10s):

- No effective approach of handling (social) effects
- Dwindling trust in authorities (and science)
- More and more expert/effective opposition

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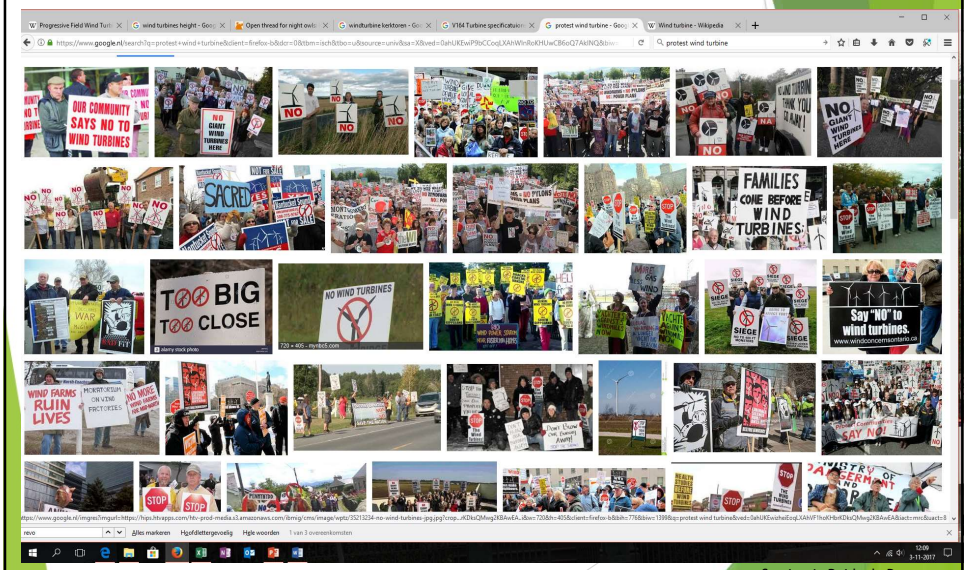
A2.4 Clash of visions



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A2.5 Main themes now

- Alternatives for wind farms (solar, energy saving)
- Alleged pathogenic effects of LF/infrasound
- 'Who owns the horizon'

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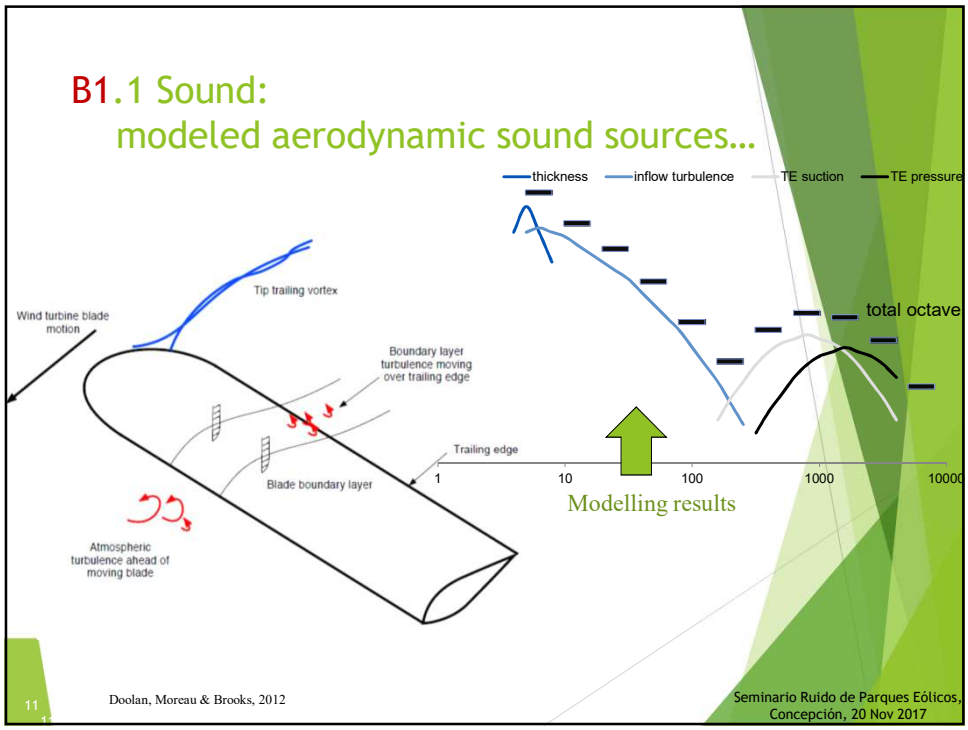
B1.1 Sound:
modeled aerodynamic sound sources…
thickness
inflow turbulence
TE suction
TE pressure
total octave
Wind turbine blade motion
Tip trailing vortex
Boundary layer turbulence moving over trailing edge
Trailing edge
Blade boundary layer
Atmospheric turbulence ahead of moving blade
1
10
100
1000
10000
Modelling results
Doolan, Moreau & Brooks, 2012
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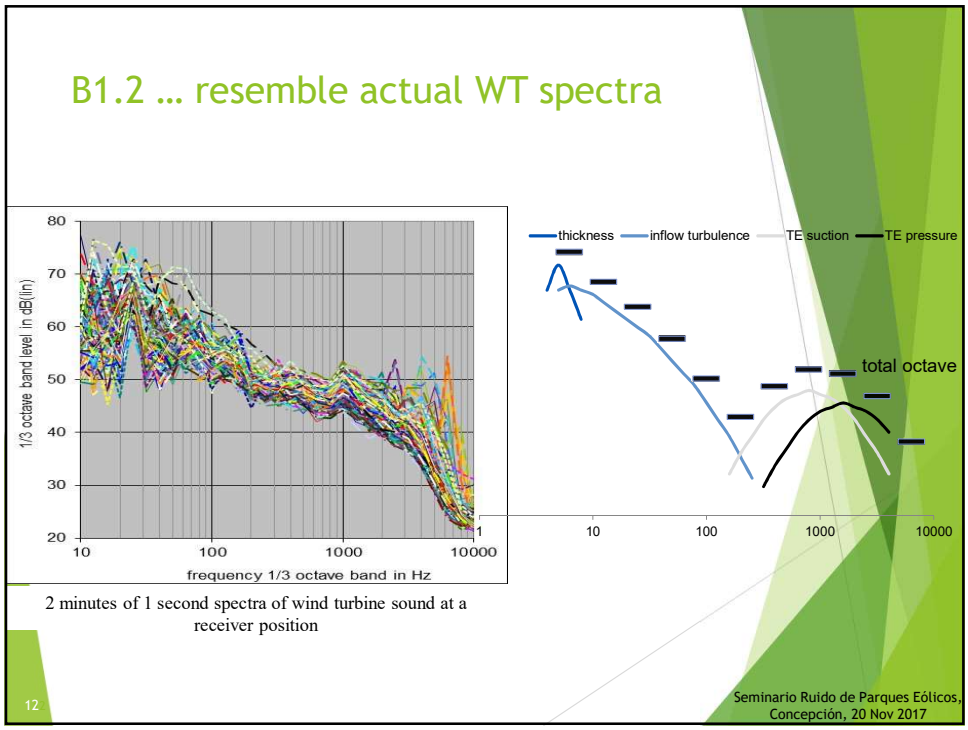
B1.2 … resemble actual WT spectra
1/3 octave band level in dB(lin)
80
70
60
50
40
30
20
10
100
1000
10000
frequency 1/3 octave band in Hz
2 minutes of 1 second spectra of wind turbine sound at a receiver position
thickness
inflow turbulence
TE suction
TE pressure
total octave
1
10
100
1000
10000
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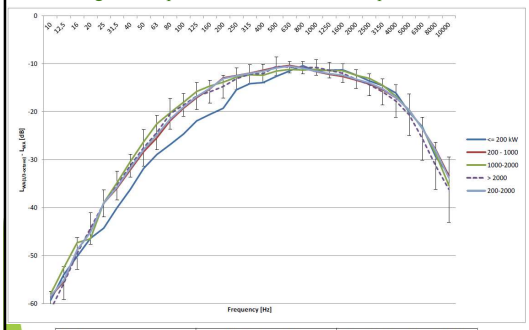
B1.3 Spectral level and form depend on type…

Pitch regulated: spectra relative to maximum power



Class	Number of spectra	Number of spectra at 10 Hz
≤ 200 kW	16	5
]200 kW – 1000 kW]	108	5
]1000 kW – 2000 kW]	27	1
> 2000 kW	62	27
]200 kW – 2000 kW]	135	6
> 2000 kW new	34	23
> 2000 kW old	28	4

pitch regulated WTs → max. L at ≈ 8m/s;
stall regulated → louder with wind speed

example: WTs at 10 m/s, having same spectrum at 8m/s

Sondergaard, 2013

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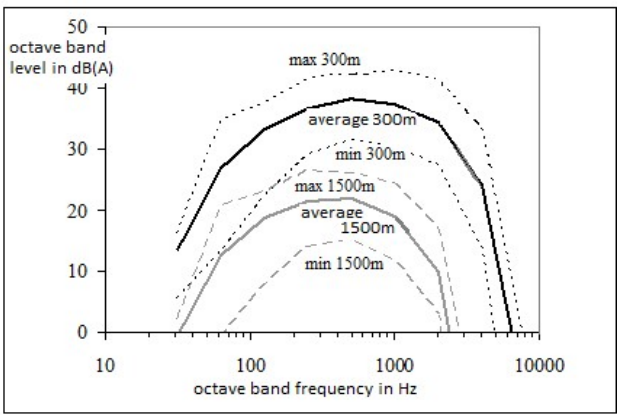
B1.4 … and distance



maximum, average and minimum immission sound levels due to a (loud, average or 'quiet') wind turbine at two distances

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B1.5 Sound not just sound *level*!

- (irregular) rhythmic character typical for wind turbine
- sound does not abate at night
- tonal components can still occur
- sometimes (sudden) sounds machinery (e.g. yaw motor)

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B2.1 Effects on residents

Direct health effects for residents may result from:

- noise and vibrations
- visual impacts (landscape, shadow flicker, blinking lights)
- electromagnetic fields *
- accidents *
- impacts in construction phase *

(* not considered here)

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B2.2 Effects of wind turbine sound

Investigated:

- annoyance
- sleep disturbance
- mental health effects (distress) and quality of life

Not investigated:

- cardiovascular effects (may occur if caused by stress)
- effects on performance, interference with speech communication (perhaps at high levels)
- hearing impairment (highly unlikely)

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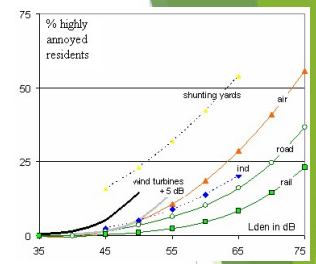
B2.3 Noise annoyance

Annoyance is main effect related to sound level: WTs are relatively annoying

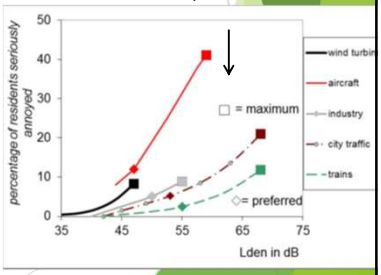
Even though many residents are not (highly) annoyed

But annoyance also depends on situation (visibility WTs, orientation house/bedroom) and personal factors (noise sensitivity, attitude, economic benefits)



AM → + 5dB appropriate

new aircraft dose-response relation



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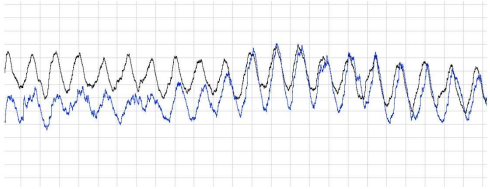
B2.4 AM: Amplitude Modulation of sound

Main causes:

- Near field: Doppler amplification and directionality
  (→ more sound in front of blade)
- Far: wind gradient → changing angle of attack

Other causes may contribute:

- Blades pass through area of lower wind speed before mast
- Changes in tip height → changes in ground effect



Example of AM (Bowdler, 2011)

black: high pass (240Hz-2kHz)
blue: low pass (1-210Hz)
2 dBA/1 sec grid

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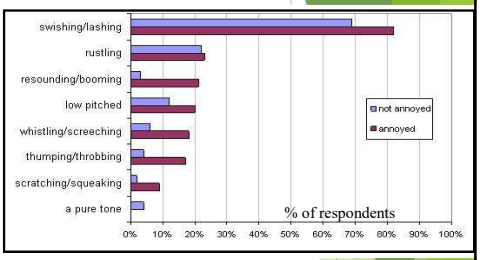
B2.5 Amplitude Modulation of sound

'Swishing' or similar mentioned most by residents

What does the wind farm sound like?



AM may aggravate existing annoyance, but does not annoy persons who have a positive attitude towards or benefit from WTs

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B2.6 LF sound, peer-reviewed knowledge

Low frequency character not a clearly relevant factor:

- not dominant in total sound (but increasing?)
- other common sources contain similar/higher LF sound levels
- WT infrasound usually inaudible → no effect
  (except perhaps for specific medical conditions)
- but: inaudible infrasound may produce signal in brain

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B2.7 Worries about LF sound

Popular view: low frequency impact underestimated!

- high unweighted levels
- disregarded in measurements and calculations
- important for new, larger wt's
- lots of people complain
- why else would people get sick?

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B2.8 Understanding LF sound complaints

Worries have some support:

- noise in dwellings from outdoors always contains a relatively high LF level
- LF sound level increasing with WT size?
- effects infrasound unlikely, but (some) doctors state infrasound can have effect
- (some) people do feel ill because of WTs
- confusion with low AM frequency?

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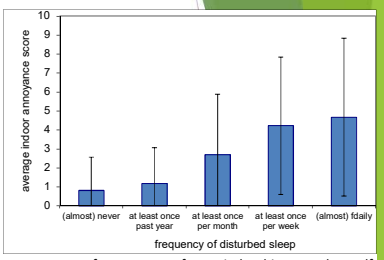
B2.9 Sleep disturbance

Apparently related to WT sound level.



average score for annoyance from wind turbine sound vs. self reported frequency of sleep disturbance by (any) sound

However, self-reported sleep disturbance:

- may equal nighttime annoyance
- is not related to WT sound level when including annoyance
- is not clearly related to objective sleep disturbance

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B2.10 Sleep disturbance

Psychological distress, sleep disturbance and annoyance interrelated.

Significant routes:

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B2.11 Health related Quality of Life (QoL)

Effect on physical and environmental domains of HrQoL:

- Lower perceived sleep quality and energy-level (self-reported)
- Decreased environmental condition and individual space

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B2.12 Wind Turbine Syndrome (WTS) and Vibro-acoustic disease (VAD)

Scientific doubts about WTS:

- alleged effects at much lower sound/vibration levels than supported by other research
- not a new syndrome, but a combination of stress symptoms

…and VAD:

- results only from one group
- attribution to WT sound not demonstrated
- affliction not supported by (other) research

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B2.13 Physical and personal factors influencing reaction to WTs

- visibility of WTs: increases annoyance
- economic benefits: almost no (serious) annoyance
- predictability and (lack of) control
- attitude and fairness
- noise sensitivity
- fear/worry related to noise source

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B2.14 Social factors influencing reaction to WTs

- trust and recognition authorities recognise impacts;
- ability to speak to and be listened to by authorities;
- awareness of economic and social benefits of noise source, noise control costs, etc;
- compensation, e.g. noise insulation, house purchase;
- home owners more concerned about property value;
- understanding; attitudes can be based on (ir)relevant and/or (in)correct information

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B2.15 Conclusions on effects of sounds

Wind turbine sound is relatively *annoying*:

- relevant acoustical factor: AM (infrasound improbable)
- relevant non-acoustical factors: economic benefits, visibility, unpredictability, perceived lack of control, perceived balance of advantages and disadvantages

Sleep disturbance: related to annoyance
Distress: related to annoyance and sleep disturbance
Quality of life: related to sleep and energy-level, environmental condition and individual space

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B2.16 Conclusions on effects of WTs

Siting and designing wind farms is probably the main (social) challenge.

Sound is 'only' one impact, mainly characterized by calculated, average levels.

A strategy to little used is to let residents participate and reduce their concerns.

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C.1 Setting a noise indicator/limit

A(ny) noise indicator should be unequivocal, depend on the impact, matching the purpose, and be transparent.

Examples:

- Setback distance to a wind farm is easy to understand but allows for a range of noise levels (and visual layouts).
- Common, averaging indicators (Lden/DNL/Leq24h) are hard to understand but are relatively precise for noise impact.

Common noise indicators may describe the noise impact, but explain less than 25 % of the noise annoyance.
How about the other 75^{+} %?

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C.2 Criteria for a noise indicator (EU)

Indicator must have scientific validity and must be practical:

- valid: must have relation with effect
- practical: easy to measure/calculate, practical decision tool
- transparent: simple, easy to explain
- enforceable: in case of changes or exceeding limit
- consistent: with current practice/policy; new preferred only when there are significant advantages

(European Commission: Position paper on EU noise indicators)

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C.3 Possible noise indicators

In use are (all A-weighted and broadband):

1. maximum level at (near) nominal power: L_{max}
2. level at specific wind speed: $L_{xm/s}$ (x = 6, 8, ..)
3. average level over time T: Leq,T (T = 8, 18, 24 h)
4. weighted average level over 24 h: L_{den} of DNL

Other possibilities:

5. A-weighted low frequency level
6. A-weighted 1/3 octave band levels
7. Loudness (similar to NC-curves)

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C.4 Possible noise limits

Limit can be based on exposure…:

1. Acceptable sound level (used for other sources)
2. Maximum over background sound level

…or effect:

3. Acceptable percentage annoyed
4. Acceptable percentage sleep disturbed

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C.5 Limiting exposure

Limit value based on:

- other sources (e.g. WTs and industrial noise)
- practical feasibility ('how low/high can we go')
- legal necessity

For an absolute limit effects may be obtained from (later) research

For a relative limit effects are not known. Except for high background levels (leading to actual masking effects), the influence of background sound on noise annoyance has not been demonstrated.

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C.6 Limiting effects

Limit value can be based on:
- Reducing noise annoyance
- Reducing sleep disturbance
- Reducing complaints

The relation between effect and noise indicator must be relevant and discriminating.
However, noise annoyance is never a result of sound level only.

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C.7 A health based approach

Martin van den Berg (former Dutch ministry of the Environment):

In a blank situation the general approach for a noise regulation – indeed for many environmental or other types of regulation- would be:

1) assessing the impact on the population
2) evaluation of impact
3) assessing options to avoid or reduce impact considered undesirable.
4) cost-benefit analysis of the options or of mix of options
5) assessment of the preferred option
6) implementation

A general principle which applies to all the steps, is the discussion with stakeholders, the affected as well as the producers.

(Health based guidelines for wind turbine noise, WTN2011, Rome)

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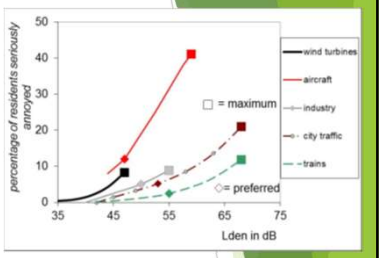
C.8 Limit values



Available data show that severe (!) noise annoyance from WTs does not occur below 35 dB Lden (sound level on façade).

WHO states 40 dB Lnight is the threshold level for sleep disturbance from noise. Available research show that this holds for WT sound (Sl.Dist. shown to occur at or above 40-45 dB).

For a temperate climate Lden ≈ Lnight + 6 dB.

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C.9 Noise indicators and limits: experience

WT noise limits are often in the range 35-50 dB.

Noise annoyance and complaints do occur, perhaps more than expected when compared to other sources.

WT sound (and sight) has a rhythmic character and as such is different from all other environmental sources.

WT noise issues are linked to other (visual and social) issues and cannot be treated as a separate issue.

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The end

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