A proposal to use determinants of annoyance in wind farm planning and management

Frits (G.P.) van den Berg[1]

1   Mundonovo sound research, Baflo, the Netherlands; fvdberg@mundonovo.nl

Abstract: Wind energy in Europe is aimed to grow at a steady, high pace, but opposition from residents to local wind farm plans is one of the obstacles to further growth. A large body of evidence shows that local populations want to be involved and respected for their concerns, but in practice this is a complex process that cannot be solved with simple measures such as financial compensation.

The visual presence and the acoustic impact of a wind farm is an important concern for residents. Generally environmental noise management aims to reduce the exposure of the population, usually based on acoustics and restricted to a limited number of sources (such as transportation or industry) and sound descriptors (such as Lden). Individual perceptions are taken into account only at an aggregate, statistical level (such as percentage of exposed, annoyed or sleep-disturbed persons in the population). Individual perceptions and reactions to sound vary in intensity and over different dimensions (such as pleasure/fear or distraction). Sound level is in fact a weak predictor of the perceived health effects of sound. The positive or negative perception of and attitude to the source of the sound is a better predictor of its effects.

This article aims to show how the two perspectives (based on acoustics and on perception) can lead to a combined approach in the management of a wind farm aimed to reduce annoyance, not primarily of sound level. An important aspect in this approach is what the sound means to people: is it associated with the experience of having no say in plans, does it lead to anxiety or worry, is it appropriate? The available knowledge will be applied to wind farm management: planning as well as operation.

Keywords: wind farm, annoyance, social acceptance, worry, noise sensitivity, noise management

1. Introduction

In 2021 wind energy installations in Europe (EU+UK) had a total capacity of 236 GW and this corresponded to 15% of the electricity consumed in 2020, where electricity consumption is about 23% of total energy consumption in Europe [2]. This was expected to grow in the next few years with 15 to 20 GW per year, but in 2021 the EU set a new target of 30 GW per year to arrive at a total of 451 GW in 2030 [3]. To achieve this will depend on how national and local authorities in Europe are able to balance the need for renewable (wind) energy with the growing opposition to wind farms.

Renewables Now [4], the 'global renewable energy community of actors from science, governments, NGOs and industry' reports substantial growth in renewable energy, but observes the share of 'modern renewables' (wind, solar, biofuel) in the total energy consumption to be less impressive. In the years 2009 - 2019 the total demand for modern renewables increased to 15.1 EJ (exajoule), but total final energy consumption grew with 60.9 EJ. Thus, renewables could not even keep up with the increase in energy demand during this decade. The report notes that, with respect to wind energy, there are

policy and social factors that slow progress, such as delays in permitting procedures and public opposition, and the shift to auctions of wind projects has an indirect negative impact on social support for wind farms. The wind industry in Europe acknowledges in a 2022 report that governments' commitments are still 'fairly modest' and expects that in a 'realistic scenario' Europe will install at an average rate of 17.6 GW a year, well below the 32 GW per year that is necessary to reach the 40% renewable energy target [1]. This is even more unfavourable in a 'low scenario' of little policy support where governments do not solve restrictions in permitting issues and spatial planning requirements. Lack of such policy support is also a barrier to renewables deployment reported by the International Energy Agency (IEA) [6]. The others barriers are grid integration and a lack of grid availability, financial risks and lack of remuneration as well as 'challenges' concerning social acceptance of wind (and hydropower) projects that increasingly cause delay or cancellation of projects. The EU Joint Research Centre observes that 'social acceptance is a key challenge for the deployment of wind energy and could limit the overall wind resource we are able to exploit to meet climate change targets' [7]. From a survey among experts involved in wind plans in 13 EU countries Dütschke et al. conclude that, similar to an earlier study [8], 40% of the plans met with resistance which led to a change in plan, delay or termination of the plan [9]. Social acceptance rests on a network of factors that interact, so there is no simple way to include it in wind farm planning: it 'cannot be achieved through isolated 'fixes' such as community benefits or just more consultation, but must be a more fundamental change' [7].   Hirsch and Sovacool [10] recall Langdon Winner who, already in 1982, noted "an obsession with economic indicators and cost-benefit analyses among policymakers" which "obscures historical and social concerns that influence energy policy" with the result that "energy policy remains shortsighted about noneconomic considerations" [11].

In a survey amongst German residents Zaunbrecher et al. investigated preferences in two situations that were presented to the respondents [12]. One was a plan for a new power line in their neighbourhood, the other for a new wind farm. Characteristic 'attributes' in the scenarios were: health complaints, compensation payment, location (in forest, near other infrastructure, on a field) and distance to mast (pylon or wind turbine). The results show that health concerns were the most important attribute, while compensation payments were least important. This was the same for both pylons and wind turbines and also for mobile phone base stations from another study.

The impact on health is one of the main topics in the debate on effects of wind farms, which is reflected in many reviews (e.g. [13-17]). Van Kamp and van den Berg conclude that health effects on residents near wind farms can be related to exposure to and/or annoyance from the wind turbines, but they are also -and perhaps more so- the result of other factors such as participation in the planning process, procedural justice, feelings of fairness and balance of costs and benefits from wind turbines [16]. Simos et al. conclude from their review that when wind turbines are erected, persons in their neighbourhood may experience anxiety and distress, though annoyance is the only symptom backed up by solid scientific evidence [17]. This lack of evidence for health effects directly related to wind farm exposure does not mean that residents are not concerned. Chapman et al. [18] suggested that in Australia public concern increased when anti wind farm groups started to stress health problems. Stirring up such 'health anxiety' in the planning phase could lead to interpreting common health problems as being caused by wind turbines [18]. In Canada Deignan et al. analysed newspaper coverings of wind farms and health in different geographical areas and found that four 'fright factors' were frequently mentioned [19]. Nearly all articles (94%) mentioned 'dread' (as such or in other terms) and about half of them mentioned 'poorly understood by science', 'inequitable distribution' and 'inescapable exposure'. Such terms may lead residents to worry about the effect a wind farm may have for them personally. Dällenbach and Wüstenhagen used data from a national Swiss survey on the acceptance of low-carbon technologies and policies and from a public consultation process for a specific wind farm plan

[20]. Within 1 km from the planned wind farm noise concerns were related to the expected noise impact. There was no such relation for 93% of the objectors who lived at larger distances, where calculated noise impacts were low or negligible. A similar result was found from the survey: 18% of the respondents within a 5 km radius from a planned wind farm expressed noise concerns, as did 19% of the respondents living at greater distances. Of the respondents familiar with wind turbines (they could see existing wind turbines) 12% expressed noise concerns, which differed significantly from the 20% of respondents unfamiliar with wind turbines. The authors concluded that "(lack of) familiarity with wind energy and issues related to procedural and distributional justice appear to provide a better explanation for the geographical spread of noise concerns".

Crichton et al. [21] studied anticipated health concerns by exposing a student population to moderate wind turbine sound with or without added infrasound, after either 1) a TV-presentation of residents attributing symptoms to a local wind farm or 2) TV-interviews of experts stating wind farm infrasound could not cause symptoms. Participants viewing the first presentation reported significantly more and more intense symptoms in both exposure groups (with or without infrasound) when compared to the second presentation. As in this study the infrasound exposure was very low (40 dB at 5 Hz), Tonin et al. [22] reproduced the study with realistic wind turbine infrasound of 80 dB average level (91 dB peak level) administered by way of headphones. The participants, in this study from a large age range and professional backgrounds, were divided in four groups according to the two exposure conditions and two presentation types (that were now viewed before exposure). The authors conclude from this study that the infrasound itself did not influence the number of intensity of symptoms. The expectancy manipulation did have some influence, but not to a significant degree. However, the notion of harmfulness of infrasound that participants already had before the study did have a significant influence. As mentioned by Crichton et al. [21], it is not only for wind turbine sound that expectations influence the number and intensity of health symptoms, but it has been found also for other environmental agents, such as pesticides or odour.

Of course, the lack of evidence for a direct relation between the impact of a wind farm and reported health effects do not exclude an indirect relation or a relation obscured by other factors. Several studies show there is a relation between a subjective perception (annoyance) and self-reported health effects (e.g., see [23-25]). The lack of a direct relation may be due to other factors, such as sleeping with open/closed windows, side of the bedroom façade or noise sensitivity.

Noise seems to be the dominant residential impact of wind turbines (e.g., see [17, 26, 27]) and concerns about its effects a dominant reason to oppose wind farms. Perceived fairness and visibility are certainly also key issues, but are less easily identified and objectified. Already in 1989 Wolsink found that in the case of three Dutch wind farms and one single, large (at that time) 1 MW wind turbine, visual impact was a main source of opposition, but people "know that using visual criteria is probably not the best bet in formal procedures" [28]. As Hirsch and Sovacool put it: "…. (opposition)… will often focus on more 'rational' reasons to make cases to regulatory bodies and others. After all, an environmental agency would respond more favourably to opponents' assertion that endangered species of birds would be killed by wind turbines than to claims that the technology seems 'out of place' " [10]. In fact, some visual factors are highly correlated to sound level [29, 30] and the combined annoyances of visual factors and noise explain most of the variation in perceived health effects [31].

In this paper we consider factors that have an influence on the perception or annoyance from or associations with a noise source in general and a wind farm in particular. There are many acoustic and non-acoustic factors that influence the relation between annoyance and noise level, certainly at an individual level. How do we interpret sounds, how do sounds get associated to meaning? A host of studies and reviews show that for

environmental noise sources there is often a significant relation between its noise level at a residence and the annoyance that residents feel. The added annoyance due to source and noise characteristics can be taken into account by using different relations per noise source and corrections based on noise character, but even then the noise level only explains a small part of the total annoyance. The view developed here will be based on general knowledge of (psycho)acoustics and health effects from noise (including annoyance), and supported by the more limited knowledge related to wind turbines. We will focus on factors that can be influenced on a local level, independent of national policies or regulations. The purpose of this is to arrive at an understanding of how to decrease the impact of a wind farm and help in building trust that a windfarm can and must be an acceptable 'neighbour'.

2. Perception and effects of sound

2.1. Meaning of sounds

Environmental sound usually refers to sound from transport sources and business activities, but can extend to all sounds in the (home) environment. In practice environmental sound levels extend from about 20 dB(A) to less than 80 dB(A). At both ends of this range there is generally agreement about the perceived quality: very quiet and very noisy, respectively. But in between there is a broad range where some find the situation noisy and others do not. This is illustrated in Fig. 1 where respondents near Dutch wind farms at any specific sound level in the range 30 to >45 dB Lden gave qualifications ranging from 'don't hear' to 'very annoying' [32]. The acoustic quality of the sound and a host of other non-acoustic factors are at the base of these differences.
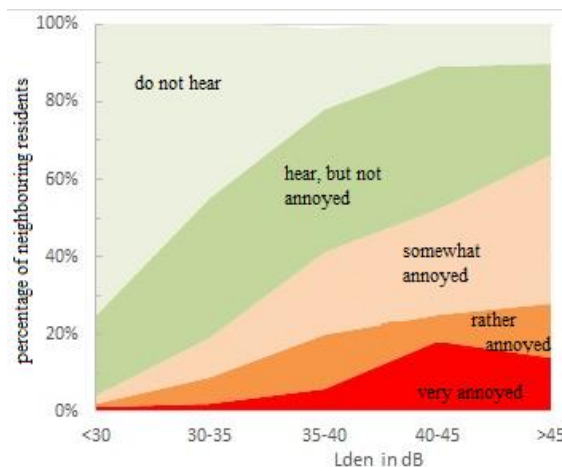
Figure 1. Reactions to wind turbine noise

In psychological terms sound can have different affective (i.e., related to emotion) dimensions: arousing, exciting, pleasant, relaxing, sleepy, gloomy, unpleasant, distressing [33]. Annoying, the only affective aspect used in environmental assessments, is in between exciting and distressing and the opposite of relaxing rather than pleasant [34]. Sound is evaluated at several levels: as an immediate, unconsciously processed impression; its information content; its relation to the context present; its loudness [35]. Playing children 'belong' in many home environments, but not at night or in an industrial environment. Also, the sound of playing children has an influence on road traffic sound: the total sound is experienced as "better" and "more natural", but not "more calm" than the road traffic itself [36]. At the same physical sound levels pleasant sounds are experienced as less loud than unpleasant sounds [37]. The affective meaning of wind power was studied in a Swiss survey [38], where respondents were asked to give up to five associations they had with wind energy and then rate this according to their affective value ranging from 1 (very negative) to 7 (very positive).   Positive associations were predominantly related to renewable wind power production and categorized in the

study as ecology, power production and wind. Dominant negative associations were related to environmental impacts: landscape, noise and wildlife. Older respondents and respondents not familiar with wind energy had significantly less positive associations compared to younger persons and those familiar with wind energy. When comparing groups more or less supportive of wind energy, all groups had positive and negative associations, but the balance shifted from more positive to more negative when support-iveness decreased. Zaunbrecher et al. found similar types of spontaneous associations with wind farms: visual impact, environmental effects and energy (and related terms) [39].   Hirsch and Sovacool state that wind turbines have great symbolic value: attractive to some, but repulsive to other stakeholders. In a positive sense they are popular sym-bols of 'progress, modernity and environmental consciousness', in a negative sense they represent an industrialization of relatively unspoiled and natural environments [10].

2.2 Perception

People are very different from sound meters: we do not hear sound as an acoustic presence, but as a representation of a source. When we hear a sound, we cannot but as-sociate it with a source. There is no 'acoustic' impression or observation, but a voice that speaks or a dog that barks, a car or a bicycle bell: we hear what causes the sound [40]. If consciously heard, this leads to associations: the pleasure of a familiar voice, the fear of damage from a billowing storm, the expected sleep disturbance from the nearby wind farm. The sound as such is not the cause of stress or fear, but the awareness of the source of sound is. Thus, a wind turbine is not perceived as a neutral object, a vertical bar with three 'spokes' on top, but as a human-built machine that may summon positive or nega-tive associations.

People see, hear, feel, smell –in short: experience- all aspects of an environment at the same time with each person's personal associations. Coherence between different aspects of perceptions is important for the total sensation. In environmental research there is no indicator for the total perception of an object in the environment (such as a road, airport or wind farm) nor for its total impact, but only for specific impacts, sepa-rately for each object (source) and sense (visual, aural, odour, tactile). Interactions be-tween these impacts is not taken into account. For example: a visually highly regarded natural environment is less appreciated when unnatural, mechanical sounds are heard [40]. In a nationwide survey Van Rompaey et al. [] used pictures of various landscapes with or without wind turbines.   A visual quality index was based on the percentage of forest, built up area, hilliness/flatness, and absence/presence of human elements. The survey results showed that wind turbines affected the visual quality: low-quality land-scapes were perceived as improved, high-quality landscapes as degraded. According to Frantal et al. [42] the influence of wind turbines on visual aspects of the landscape is highly dependent on the local environmental and socioeconomic context. Also, annoy-ance from the visual presence of wind turbines may add to and even reinforce the noise-related annoyance (and vice versa). Voicescu et al.   found that flicker shadow annoy-ance was best predicted by noise level [30], whereas Haac et al. found that visual impres-sion (did respondents like the look of the wind farm?) was the most important factor to predict noise annoyance (the next important factor was noise sensitivity) [29]. Michaud et al attempted to integrate separate annoyances from a wind farm in an 'aggregate an-noyance' and higher scores on this scale showed to be correlated with a number of health conditions (blood pressure, perceived stress, sleep quality, physical health, psy-chological well-being, chronic pain, tinnitus, migraines/headaches, dizziness) [31].

2.3 Noise annoyance and other health effects

It is generally assumed there is a monotonous increase of the percentage of an-noyed persons when the noise level increases. But level explains only part of individual annoyances. In a large number of studies Job [43] found relations between sound level and individual annoyance with correlation coefficients (c.c.) varying from 0.22 to 0.61 with a mean value of 0.42. This means that the variance (square of c.c.) was 0.04 to 0.37, with an average of 0.17 or 17%. This 17% is the degree in which a variation in noise an-noyance is explained by a variation in noise level. Almost 30 years later Brink [44] re-ported similar values: generally variances were from 0.1 to 0.2. The annoyance at group level (groups with each many individuals) was better correlated to noise level with a variance of 0.31 to 0.98 and an average of 0.67. For wind turbine sound, correlation coef-ficients were found in the same range. In a Dutch survey Pedersen et al. [45] found a c.c. between wind turbine sound level and annoyance of 0.51. In an earlier Swedish study [46] the c.c. was 0.42.

In the context of the WHO noise guidelines Basner and McGuire [47] concluded that transportation (air, road, rail traffic) noise has a direct effect on sleep as it influenced objectively measured physiological indicators of sleep. But they also concluded that sound level may not directly influence self-reported sleep disturbance, but indirectly through individual factors: "This suggests that for self-reported measures it is annoy-ance or attitude to the night-time noise that may be driving the increase of reported sleep disturbance outcomes with Lnight level" [47]. Van den Berg et al. [48] found simi-lar results from a survey that investigated noise annoyance and self-reported sleep dis-turbance from various noise sources (transportation, neighbours, industry): correlation coefficients between both effects varied from 0.75 to 0.84 and the annoyance thus ex-plained 56-70% of the variation in sleep disturbance. This is high in comparison to noise level which explains on average only 10% of self-reported sleep disturbance [49]. Mean-ingful noise may disturb sleep more than meaningless or neutral noise [48, 50]. For ex-ample: 'meaning' could be a perception of inconsiderateness or even malignancy at the part of the noise source and thus may be related to the attitude towards the source. It has been shown for wind turbines and church bells that attitude can influence the effect of noise [50, 51]. Michaud et al. found that self-reported sleep disturbance was not related to WT sound level, but closing the window because of sleep disturbance had a strong association with annoyance [24]. Cardiovascular health effects such as ischaemic heart disease and hypertension have also been found to correlate with (high) sound levels [52]. Although a direct effect of sound cannot be ruled out, it is plausible that cardiovas-cular effects are the result of noise-induced stress [53].   Chronic annoyance leading to stress is probably the most important route leading to further health consequences [54]. For wind turbines there is no clear evidence that the sound level is directly related to sleep disturbance, stress or other health effects, but there is a correlation between such effects and annoyance [17, 55]. Michaud et al. [31] have shown that the sum of annoy-ances from noise, blinking lights, flicker shadow, visual impact and (to a lesser extent) vibrations are correlated to perceived health symptoms.

2.4 Factors influencing noise annoyance

Miedema et al. [56] collected survey responses from about 64,000 respondents to determine the relation between sound level and annoyance with respect to transporta-tion sound. They also investigated factors that could influence this relation [57], using data from almost 43,000 respondents in 34 studies. Eight of these factors were demo-graphic (gender, age, level of education, occupation, household size, homeownership, dependency on and use of noise source), two were 'attitudinal variables' related to per-sonal traits (fear of noise source and noise sensitivity). The response for each variable

was assigned to a number of categories, e.g. four categories of education level (1st level to university level) or three categories of noise sensitivity (tertiles of 0-100 scale). The results showed that noise annoyance was not related to gender, but significantly related to the other demographic factors, albeit to a low or very low degree. In nearly all cases the extra noise annoyance related to each factor was equivalent to a change in Day-Night-Level DNL (= Ldn ≈ Lden) of -2 to +2 dB.   Larger effects were found for young (10-20 years) and old persons (70+) and those economically dependent on the noise source in question: these groups were relatively less annoyed (equivalent to 4, 3 and 2.6 dB, respectively). In contrast, the personal factors noise sensitivity and fear had a far bigger influence on noise annoyance.   Noise sensitivity was assessed with a single question ('Are you sensitive to noise?"); the extra annoyance for those highly sensitive (upper tertile) was equivalent to 11.2 dB when compared to the low sensitive persons (lower tertile). In the reviewed studies fear was assessed with different questions, but all were related to aircraft/road/rail accidents. Fear had an even stronger effect: the extra annoyance in the highest tertile was equivalent to 19.5 dB when compared to the lowest tertile. Miedema et al. suggested that this effect could be because of a (personal) disposition towards fear or an actual experience of fear [57].

The relation between annoyance and worry -one of the expressions of fear- has been investigated by Van den Berg et al. [58] who used results from an environmental health survey in the Amsterdam area.   Respondents were asked if they were annoyed by a number of noise and odour sources and if they were worried about possible hazards. Answers to these questions were given on an 11-point scale, ranging from 0 (not annoyed/worried at all) to 10 (extremely annoyed/worried). The list of nine noise sources as well as the list of five odour sources included road traffic and aircraft. The list of thirteen possible hazards included situations related to road traffic and aircraft: living in a busy street, living close to an airport and living under the air route of a main airport. The coefficient for the correlation between annoyance scores from road traffic and worry scores of those living near a busy road was 0.49 and for odour annoyance and living near a busy road was 0.46. For aircraft noise annoyance and living near an airport or near an air route, the correlation coefficient was higher: 0.63 and 0.59, respectively. Associations between aircraft odour annoyance and living near an airport or near an air route had similar correlation coefficients (0.57/0.56).   On average the annoyance score increased with two units for every unit increase in worry score; this applied to noise as well as odour annoyance. Further results suggested that being worried seemed to be related to a disposition rather than an actual threat as worry scores for very different situations were also significantly correlated. For the 78 possible pairs of worry scores each correlation coefficient was ≥ 0.45 and in half of the cases even ≥ 0.60.   This may be obvious for related situations (e.g., living near an airport and living near an air route), but less so for unrelated situations (e.g., living near an airport and living below sea level). However, results showed that correlation coefficients for unrelated pairs were not clearly lower than for related pairs.

The large contribution of worry to annoyance from wind turbine noise has been confirmed in the Canadian Noise and Health Study [24] where the contribution to noise annoyance of all personal and situational variables included in the survey was studied. Eleven variables explained most of the noise annoyance. Of these, six variables concerned a response to wind turbines (closing bedroom window due to wind turbines, annoyance from blinking lights/vibration/sight, self-reported sleep disturbance, complaints about wind turbines), together leading to a variance of 0.46. This means that all these reactions to the wind farm operation explained 46% of the annoyance from noise. The others factors, including sound level, explained a further 14%. When the variables were restricted to those that were expected not to be a direct response to wind farm operations, the resulting eight variables explained 40% of the noise reaction. Here the single most important factor was concern about physical safety (explaining 17%), followed by wind turbine sound level (11%) and noise sensitivity (7%). From his review Simos

concludes that when wind turbines are built, people in their neighbourhood may experience anxiety and distress and anxiety is an important risk factor linked to cardiovascular diseases and mental health conditions [17].

Fear is an important driver of animal and human behaviour. According to Wikipedia "fear is an emotion induced by perceived danger or threat, which causes physiological changes and ultimately behavioural changes, such as mounting an aggressive response or fleeing the threat. Fear in human beings may occur in response to a certain stimulus occurring in the present, or in anticipation or expectation of a future threat perceived as a risk to oneself (….). In humans and other animals, fear is modulated by the process of cognition and learning. Thus, fear is judged as rational or appropriate and irrational or inappropriate." [59] Feelings of fear or worry (which is an anticipation of fear) are not necessarily based on actual or 'objective' danger such as acknowledged by institutions or authorities, but can be based on individual perceptions, beliefs and/or cognitive or attitudinal dispositions. These individual positions may be influenced by the community: "individuals' fears (….) are also shaped by their social relations and culture, which guide their understanding of when and how much fear to feel" [59]. Cousse at al. found that a first association of Swiss residents with wind energy is often positive followed by somewhat more negative 'second thoughts' [38]. They suggest that social acceptance could increase when project developers make sure that the local population could overcome such "second thoughts".

3. Application to wind farm management

3.1. Social acceptance

Even though a positive attitude towards wind energy is linked to a higher acceptability on an individual level, several authors have stressed that a positive attitude towards wind energy in general does not imply a higher degree of acceptability of a local community [60, 61]. Wolsink concludes from data gathered between 1986 and 2002 that planners assume support because of the environmental benefits, but disregard feelings about equity and fairness [60]. A recent study of two large Finnish wind farms shows that residents were often passive with respect to participation, but active participation was perceived as symbolic and did not lead to a real influence of participants [61]. Dütschke et al. conclude from their survey under experts in the wind sector that project developers start some form of public participation mainly after preparation of the project, and when the project officially starts public opposition may already have formed [9].

Many studies stress the importance of a fair planning process and of local involvement and participation. For example, in surveys in Poland and Germany Liebe et al. found that respondents were willing to accept new wind turbines in their neighborhood if they could participate in decision making, if turbines are owned by a group of citizens, and if the generated electricity is used in the region (and not exported) [62]. The authors also conclude that, as respondents who already have turbines in their area were more inclined to accept new ones (compared to those not familiar with them), negative opinions may be overestimated in the planning and implementation process. In a case study of a Scottish wind farm MacDonald et al interviewed 'key players' from different stakeholders. Inadequate engagement of the community led to negative perceptions of the plan and a non-negotiated community benefit program increased these negative perceptions as this program was perceived as ineffective and a means for the developer to obtain planning permission [63].   With a survey amongst a large sample of German residents Gölz found that variations in perceived fairness explained variations in acceptance to a large degree, where fairness was influenced mainly by trust in local stakeholders and attitudes towards wind power [64]. However, even in the four regions of Germany (North, East, South, West) they found that the influences of these and other factors could vary considerably. This led to the conclusion that acceptance will profit from more

respect to regional views and conditions. The authors note a possible conflict with the German practice of public tendering of wind farms. Wolsink and Breukers also found differences between regions (Netherlands, North-Rhine Westphalia and England) that were rooted in different historical developments and planning approaches [65]. They concluded that a strategy including facilitating local ownership, early participation in project planning and development, favouring initiatives in socio-technical innovation enhances legitimacy of and reduces opposition to projects. These differences illustrate that social participation is advisable for each project as only then local issues will come to light.

Potential problems with the acceptability of new projects are not unique for wind energy.   For example, in the case of a municipal waste incineration plant Subiza-Pérez et al. found that predictors of acceptance were trust in the information provided by the local government and perceived risk for human health [66]. Cataldi stated that for geothermal energy projects the main factors contributing to social acceptance are environmental impact, adverse effects on human health and tangible benefits for the local population [67]. With respect to the expansion of two European airports, Liebe et al. concluded from a survey that aspects of environmental and participatory justice have much more influence on acceptability than economic and distributive justice (a more even spread of impacts) [68].

The acceptability of a wind farm is not about accepting renewable or wind energy as such, but about involving -not only informing- the community in decisions on the planning and operation of a wind farm.   Simos et al. state that "The empowerment of affected populations is a central tenet of health promotion. Its efficacy and usefulness have been demonstrated in many settings across the world. Empowerment also tends to increase the acceptability of projects" [17].   In their review Simos et al. recommend to recognize the feelings of local residents and to take their points of view into account. In practice however, if there is participation, it is often unclear which factors actually are open to participation and if the community has the power to influence decisions. In the proposal below the focus is on involving the community predominantly with respect to the impacts they expect to experience in the planning phase and will actually experience in the operational phase. All measures leading to a prevention or reduction of annoyance will also lead to a reduction in perceived health effects relate d to annoyance.   The proposed approach can also be applied to existing wind farms.

3.2 General considerations

From the previous sections it can be concluded that:

- noise annoyance is the primary reaction to noise (i.e., sound that disturbs).
- further health effects are likely to result from chronic noise annoyance, although a direct physiological effect of sound is not excluded.
- annoyance from a noise source is related to the sound level from that source, but only to a modest degree; other factors contribute substantially to noise annoyance.
- of these other factors fear, worry or concern in relation to the noise source and noise sensitivity appear to be the most important factors. Because of beliefs, associations and experiences with the sound source and possibly of characteristics of the sound it may carry a meaning that the presence of the sound source is 'unsafe'.
- noise is only one of many possible environmental factors and its impact is not experienced separately from other factors

From this we can infer that reduction of the impact of environmental sound can be reached in different ways. One way is to reduce the impact of sound as such, either by reducing sound level or by reducing annoying characteristics of the sound (such as tonal content) or other exposures from the same source. A second way is to reduce negative perceptions of and/or associations with the noise source. This of course is neither simple nor straightforward as the perceptions and associations may, at least in part, be realistic

and reasonable. But they can also have another cause: amongst others, earlier experiences or 'fear of the unknown' or a lack of control can play a role. To explore this way of reducing annoyance it is also necessary to consult members of the exposed population as any mitigation measures should diminish worry in that population. The third important factor, noise sensitivity, cannot be reduced by itself as it is a stable, individual characteristic. But a reduction in sound level and noticeable characteristics will help. Apart from that, awareness of noise sensitivity may be of use in noisy areas: if the sound level cannot be reduced, it may help to warn people who consider moving there when they think of themselves as being noise sensitive. For those living in the area, individual mitigation measures may help.

3.3 Wind farm impact

The general conclusions in the previous section also apply to the case of wind farms. In a recent review of the residential effects of wind turbine noise Van Kamp and Van den Berg [25] conclude that health complaints (other than annoyance) related to wind farms are primarily related to annoyance which again depends on a range of non-acoustic factors and the actual exposure. Such factors include "noise sensitivity, attitudes towards wind turbines, health concerns, visual aspects and aspects related to the procedure preceding the building of a wind park. The role of factors such as participation in the planning process, procedural justice, feelings of fairness and balance of costs and benefits from wind turbines are even more strongly supported by current evidence" [25]. It is not just the sound from a wind farm, but also visual effects and perhaps vibrations that can lead to annoyance.   Simos et al. suggest to find a balance between energy production and healthy living conditions by reducing the impact by turning wind turbines on or off or changing their rotational speed, depending on conditions such as time of day or weather.

Citizens confronted with a wind farm plan in their area may be concerned about the consequences for their health and other environmental effects (such as animal mortality). Not taking these concerns seriously is likely to fuel more opposition. At least part of the concern is not unreasonable as many national limits for noise and shadow flicker do not exclude the occurrence of (severe) annoyance and possible further health consequences. Thus, some residents will be affected if the wind farm is built and operational, and worrying about this in the planning phase may lay the roots for (more) annoyance in the operational phase. On the other hand, at least a measure of severe annoyance (and possible further health consequences) is generally considered acceptable when it concerns transport noise. Also, if society does not embrace renewable energy in the short term, there will be serious other public health consequences related to climate change.

The present approach to environmental effects is based on 'objective' quantities: sound level, shadow flicker time and safety risks. Usually these are calculated and it may be impractical or even impossible to measure these quantities locally. However, most residents do not care that much about objective limits: they do not want to be affected by the presence of the wind farm, especially not when the pros and cons are out of balance. In the international Wind Turbine Noise Conference 2021 this was explored in two sessions concerning 'being good neighbours' in relation to wind farms. Employees of a wind farm operator said that they want to reduce annoyance from the wind farm as much as practical and residents near a wind farm said they would welcome efforts of their neighbouring wind farm operator to reduce the impact on residents. Good neighborship is a form of social recognition which is one of the key determinants of health [17].

3.4 Proposed approach: reduction of annoyance from wind farms

The preceding information suggests that a noise management approach based on reducing annoyance as much as possible seems to be promising. It is also a way to express good neighbourliness which should be pursued in order to achieve sustainable

energy goals. Of course, it may not eliminate annoyance entirely as it seems unlikely to find solutions for every individual resident. This approach is in fact an application of the ALARA principle (As Low As Reasonably Achievable), where 'reasonable' is an optimal balance between the cost of mitigation and the reduced exposure of the target group. EAN, the European ALARA Network strives to apply this principle "for the management of occupational and public exposures and patients in all exposure situations" [69], though as yet it has not been applied to wind energy. General measures would apply to the population near the wind farm and can be based on what we know about residential effects of wind farms. An individual perspective may help to understand residential reactions, certainly with respect to persons who are affected more than average because of their situation or their condition.

Noise annoyance management can be based on measures in the planning phase and in the operational phase. This is part of a process that acknowledges the importance of other factors such as mentioned above (participation in planning process, procedural justice, feelings of fairness, balance of costs and benefits, other exposures).

Planning phase:

1. It is important to respect residents' worries in relation to the planned wind farm and to address these in an early stage.
2. Minimize impact: no (or as little as possible) flicker shadow; wind turbines with below-average sound production; no permanently blinking aircraft warning lights; consideration of visual impact.
3. Perhaps other measures can be discussed, such as synchronization of the wind turbines' rotation or possibilities to reduce the rhythmic sound character (amplitude modulation).
4. For the most impacted and/or vulnerable residents individual mitigation measures are possible, such as planting trees, moving the bedroom to the quiet side, adding insulation, etc.
5. In the planning phase it is important to install trust that mitigation measures in the operational phase, where necessary, will be implemented and which financial and technical means are available to do this.

Operational phase:

6. As amplitude modulation (AM) of wind turbine sound is an important characteristic and in annoyance equivalent to an increase of sound level of 3 to 5 dB or more, reduction of this can have a significant effect. Only one case study has been reported that concerned AM mitigation [70].
7. The presence of tonal noise is not a universal characteristic of wind turbines, but also not a rare phenomenon. Tonal noise leads to increased annoyance and mitigation measures should be applied as soon as possible. For the time the tonal noise is present, this should be compensated by a reduction in sound level and/or exposure time.
8. Residents can be consulted about the actual impact of the wind farm, and especially about situations where the annoyance is above average. Consultation is possible with representatives from the community (sounding board group), periodic meetings and/or surveys and more permanent two-way communication means (website, app, complaint desk).
9. It is reasonable that a wind farm operator sets funds aside to implement mitigation measures.

4. Conclusions

The lack of social acceptance to wind energy plans is likely to slow down the transition to sustainable energy. To be able to achieve the goals the European Union set for 2030 it will help to understand concerns and interests of residents near projected wind farms

and act to reduce the planned and actual impact of the wind farm. It is recommended that a project developer establishes from the start a policy of good neighborhood with the resident community by involving residents in minimizing the negative impacts.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

.

References

1. Wind Europe: Wind energy in Europe 2021: Statistics and the outlook for 2022-2026. Wind Europe Report,   February 2022

2. Eurostat. Statistics explained- Energy statistics - an overview.   Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview#Final_energy_consumption (accessed 29-12-2021)

3. Wind Europe. The EU Commission wants 30 GW a year of new wind up to 2030. Available online: https://windeurope.org/newsroom/press-releases/its-official-the-eu-commission-wants-30-gw-of-new-wind-a-year-up-to-2030/ (accessed 29-12-2021)

4. Renewables Now (REN21). Renewables 2021 Global Status Report. REN21 report, Paris, 2001

6. Renewables 2021: Analysis and forecasts to 2026. IEA Report, December 2021

7. Ellis, G.; Ferraro, G. The social acceptance of wind energy. Report EUR 28182 EN, 2016

8. Windbarriers. Administrative and grid access barriers to wind power. Report European Wind Energy Association, 2010

9. Dütschke, E.; Schneider, U.; Wesche, J. Knowledge, Use and Effectiveness of Social Acceptance Measures for Wind Projects. Z Energiewirtsch 2017, 41, 299–310

10. Hirsh, R.F.; Sovacool, B.K. Wind Turbines and Invisible Technology: Unarticulated Reasons for Local Opposition to Wind Energy. Technology and Culture 2013, 54 (4), 705-734

11. Winner, L. Energy Regimes and the Ideology of Efficiency. In Energy and Transport: Historical Perspectives on Policy Issues, edited by George H. Daniels and Mark H. Rose, 261-77. Beverly Hills, CA: Sage Publications, 1982

12. Zaunbrecher, B.S.; Linzenich, A.; Ziefle, M.A mast is a mast is a mast…? Comparison of preferences for location scenarios of electricity pylons and wind power plants using conjoint analysis. Energy Policy 2017, 105, 429–439

13. Schmidt, J.H.; Klokker, M. Health effects related to wind turbine noise exposure: a systematic review. PLoS ONE 2014, 9 (12), e114183

14. Onakpoya, I.J., O'Sullivan, J., Thompson, M.J., Heneghan, C.J. The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies. Environ. Int. 2015, 30 (82), 1–9

15. Freiberg, A.; Schefter, C.; Girbig, M.; Murta, V.C.; Seidler, A. Health effects of wind turbines on humans in residential settings: Results of a scoping review. Environ. Res. 2019, 169, 446–463

16. van Kamp, I.; van den Berg, F. Health effects related to wind turbine sound: an update. J. Environ. Res. Public Health 2021, 18

17. Simos, J.; Cantoreggi, N.; Christie, D.; Forbat, J. Wind turbines and health: a review with suggested recommendations. Environ Risque Sante 2019, 18, 1-11

18. Chapman, S., George, A.S., Waller, K., Cakic, V.: The pattern of complaints about Australian wind farms does not match the establishment and distribution of turbines: support for the psychogenic, 'communicated disease' hypothesis. PLoS ONE 2013, 8 (10)

19. Deignan, B.; Harvey, E.; Hoffman-Goetz, L. Fright factors about wind turbines and health in Ontario newspapers before and after the Green Energy Act. Health, Risk & Society 2013, 15 (3), 234-250

20. Dällenbach, N.; Wüstenhagen, R. How far do noise concerns travel? Exploring how familiarity and justice shape noise expectations and social acceptance of planned wind energy projects. Energy Research & Social Science 2022, 87, 102300

21. Crichton, F.; Dodd, G.; Schmid, G.; Gamble, G.; Petrie, K.J. Can Expectations Produce Symptoms From Infrasound Associated With Wind Turbines? Health Psychology 2013, 33:4

22. Tonin, R., Brett, J., Colagiuri, B. The effect of infrasound and negative expectations to adverse pathological symptoms from wind farms. J. Low Freq. Noise Vib. Act. Control 2016, 35 (1), 77–90

23. Bakker, R.H.; Pedersen, E.; van den Berg, G.P.; Stewart, R.E.; Lok, W.; Bouma, J. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Science of the Total Environment 2012, 425, 42-51

24. Michaud, D. S.; Keith, S. E.; Feder, K.; Voicescu, S. A.; Marro, L.; Than, J.; Guay, M.; Bower, T.; Denning, A.; Lavigne, E.; et al. Personal and Situational Variables Associated with Wind Turbine Noise Annoyance. J. Acoust. Soc. Am. 2016, 139 (3), 1455–1466

25. Maijala, P. P.; Kurki, I.; Vainio, L.; Pakarinen, S.; Kuuramo, C.; Lukander, K.; Virkkala, J.; Tiippana, K.; Stickler, E. A.; Sainio, M. Annoyance, Perception, and Physiological Effects of Wind Turbine Infrasound. J. Acoust. Soc. Am. 2021, 149 (4), 2238–2238

26. Peri, E.; Becker, N.; Tal, A. What Really Undermines Public Acceptance of Wind Turbines? A Choice Experiment Analysis in Israel. Land Use Policy 2020, 99

27. Ki, J.; Yun, S.-J.; Kim, W.-C.; Oh, S.; Ha, J.; Hwangbo, E.; Lee, H.; Shin, S.; Yoon, S.; Youn, H. Local Residents' Attitudes About Wind Farms and Associated Noise Annoyance in South Korea. Energy Policy 2022, 163, 112847–112847

28. Wolsink, M. Attitudes and Expectancies about Wind Turbines and Wind Farms. Wind Engineering 1989, 13 (4), 196-206

29. Haac, T.R.; Kaliski, K.; Landis, M.; Hoen, B.; Rand, J.; Firestone, J.; Pohl, J. Wind turbine audibility and noise annoyance in a national US survey: Individual perception and influencing factors. J. Acoust. Soc. Am. 2019, 146, 1124–1141.

30. Voicescu, S. A.; Michaud, D. S.; Feder, K.; Marro, L.; Than, J.; Guay, M.; Denning, A.; Bower, T.; van den Berg, F.; Broner, N.; et al. Estimating Annoyance to Calculated Wind Turbine Shadow Flicker Is Improved When Variables Associated with Wind Turbine Noise Exposure Are Considered. J. Acoust. Soc. Am. 2016, 139 (3), 1480–1492

31. Michaud, D.S.; Marro, L.; McNamee, J. The association between self-reported and objective measures of health and aggregate annoyance scores toward wind turbine installations. Can. J. Public Health 2018, 109, 252–260

32. Data taken from Project WINDFARMperception: van den Berg, F.; Pedersen, E.; Bouma, J.; Bakker, R. Visual and acoustic impact of wind turbine farms on residents. Final report UMCG/University of Groningen, 2008

33. Russell, J.; Pratt, G. A description of the affective quality attributed to environments. J. Personality and Social Psychology 1980, 38 (2), 311–322

34. K. Craik. Environmental perception and environmental annoyance: issues of measurement and interpretation. Proc. proceedings Intern Symp Environmental Annoyance, Woudschoten, the Netherlands, 1987

35. Carles, J.; Barrio, I.; de Lucio, J. Sound influence on landscape values. Landscape and Urban Planning 1999, 43, 191-200

36. Kawai, K.; Yano, T. A study on the effects of individual sounds on the psychological evaluations of combined environmental sounds. Proc. Internoise98, Christchurch, 1998

37. Namba, S.; Kuwano, S. Psychological study on Leq as a measure of loudness of various kinds of noise. J. Acoust. Soc. Japan (E) 1984, 5 (3), 135-148

38. Cousse, J.; Wüstenhagen, R.; Schneider, N. Mixed Feelings on Wind Energy: Affective Imagery and Local Concern Driving Social Acceptance in Switzerland. Energy Research & Social Science 2020, 70

39. Zaunbrecher, B. S.; Linzenich, A.; Ziefle, M. A Mast Is a Mast Is a Mast…? Comparison of Preferences for Location-Scenarios of Electricity Pylons and Wind Power Plants Using Conjoint Analysis. Energy Policy 2017, 105, 429–439

40. Fowler, C. Auditory perception is not special: We see the world, we feel the world, we hear the world. J. Acoust. Soc. Am. 1991, 89(6), 2910-2915

41. Van Rompaey, A.; Vanderheyden, V.; Schmitz, S. Modelling the impact of wind turbines on the visual attractivity of landscapes at a regional scale. Proc. European Wind Energy Conference, Brussels, 2008

42. Frantál, B.; Van Der Horst, D.; Kunc, J.; Jaňurová, M. Landscape disruption or just a lack of economic benefits? Exploring factors behind the negative perceptions of wind turbines. J Landscape Ecology 2017, 15 (2), 139-47

43. Job, R. Community response to noise: A review of factors influencing the relationship between noise exposure and reaction. J. Acoust. Soc. Am. 1988, 83 (3), 991

44. Brink, M. A review of explained variance in exposure-annoyance relationships in noise annoyance surveys. Intern Congress Noise as a Public Health Problem (ICBEN), Nara, 2014

45. Pedersen, E.; van den Berg, F.; Bakker, R.; Bouma, J. Response to noise from modern wind farms in The Netherlands. J. Acoust. Soc. Am. 2009, 126 (2), 634-643, 2009

46. Pedersen, E.; Persson Waye, K. Perception and annoyance due to wind turbine noise—a dose–response relationship. J. Acoust. Soc. Am. 2004, 116 (6), 3460-3470

47. Basner, M., McGuire, S. WHO environmental noise guidelines for the European region: A systematic review on environmental noise and effects on sleep. Int. J. Environ. Res. Public Health 2018, 15 (3)

48. van den Berg, F.; Verhagen, C.; Uitenbroek, D. The relation between scores on noise annoyance and noise disturbed sleep in a public health survey. Int. J. Environ. Res. Public Health 2014, 11 (2), 2314-2327

49. H. Miedema, H. Vos. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav. Sleep Med. 5:1–20, 2007

50. Kuwano, S.; Mizunami, T.; Namba, S.; Morinaga, M. The effect of different kinds of noise on Quality of sleep under the controlled conditions. J. Sound Vib. 2002, 250, 83–90

51. Brink, M.; Omlin, S.; Müller, C.; Pieren R.; Basner, M. An event-related analysis of awakening reactions due to nocturnal church bell noise. Science of the Total Environment 2011, 409

52. Van Kempen, E.; Casas, M.; Pershagen, G.; Foraster, M. WHO environmental noise guidelines for the European region: a systematic review on environmental noise and cardiovascular and metabolic effects: a summary. Int. J. Environ. Res. Public Health 2018, 15 (2), 379

53. Ising H.; Babisch, W.; Kruppa, B. Noise-induced endocrine effects and cardiovascular risk. Noise & Health 1999, 1, 37-48

54. Clark, C.; Stansfeld, S. The Effect of Transportation Noise on Health and Cognitive Development: A Review of Recent Evidence. Intern J Comparative Psychology 2007, 20 (2)

55. WHO, Environmental Noise Guidelines for the European Region (2018) WHO, Bonn

56. H. Miedema, Henk Vos. Exposure-response relationships for transportation noise. J. Acoust. Soc. Am. 104(6), 1998

57. Miedema, H.; Vos, H. Demographic and attitudinal factors that modify annoyance from transportation noise. J. Acoust. Soc. Am. 1999, 105 (6)

58. van den Berg, F.; Verhagen, C.; Uitenbroek, D. The Relation between Self-Reported Worry and Annoyance from Air and Road Traffic. Int. J. Environ. Res. Public Health 2015, 12 (1)

59. Wikipedia, lemma "Fear", available online: https://en.wikipedia.org/wiki/Fear, (accessed 29-6-2021)

60. Wolsink, M. Wind Power Implementation: The Nature of Public Attitudes: Equity and Fairness Instead of 'backyard Motives.' Renewable and Sustainable Energy Reviews 2007, 11 (6), 1188–1207

61. Janhunen, S.; Hujala, M.; Pätäri S. The acceptability of wind farms: the impact of public participation. J. Environmental Policy & Planning 2018, 20 (2), 214-235

62. Liebe, U.; Bartczak, A.; Meyerhoff, J. A turbine is not only a turbine: The role of social context and fairness characteristics for the local acceptance of wind power. Energy Policy 2017, 107, 300–308

63. Macdonald, C.; Glass, J.; Creamer, E. What Is the Benefit of Community Benefits? Exploring Local Perceptions of the Provision of Community Benefits from a Commercial Wind Energy Project. Scott. Geogr. J. 2017, 133, 172–191.

64. Gölz, S.; Wedderhoff, O. Explaining regional acceptance of the German energy transition by including trust in stakeholders and perception of fairness as socio-institutional factors. Energy Res. Soc. Sci. 2018, 43, 96–108.

65. Wolsink, M'; Breukers, S. Contrasting the core beliefs regarding the effective implementation of wind power. An international study of stakeholder perspectives. J. Environmental Planning and Management 2010, 53 (5), 535-558

66. Subiza-Pérez, M.; Marina, L. S.; Irizar, A.; Gallastegi, M.; Anabitarte, A.; Urbieta, N.; Babarro, I.; Molinuevo, A.; Vozmediano, L.; Ibarluzea, J. Explaining Social Acceptance of a Municipal Waste Incineration Plant through Sociodemographic and Psycho-Environmental Variables. Environmental Pollution 2020, 263 (Pa).

67. Cataldi, R. Social acceptance: a sine qua non for geothermal development in the 21st century. Bulletin d'Hydrogiologie 1999, 17

68. Liebe, U.; Preisendörfer, P.; Bruderer Enzler, H. The Social Acceptance of Airport Expansion Scenarios: A Factorial Survey Experiment. Transportation Research Part D 2020, 84

69. EAN. Statuts du Reseau ALARA Europeen: But et composition de l'association (in French). Available online: https://www.eu-alara.net/index.php/presentation.html (accessed 4-1-2022)

70. Cand, M.; Bullmore, A. Measurements demonstrating mitigation of far-field AM from wind turbines. Intern. Meeting Wind Turbine Noise, Glasgow, 2015