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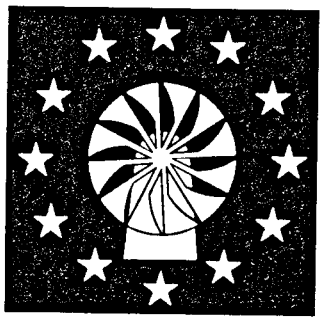

1993 European Community Wind Energy Conference

Proceedings of the International Conference held at Lübeck-Travemünde, Germany 8-12 March 1993

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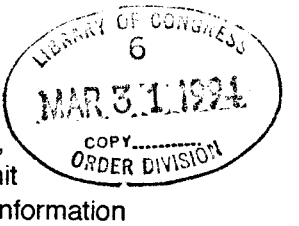

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PREFACE

I am happy to introduce the proceedings of the European Community Wind Energy Conference 1993 held in Lübeck-Travemünde in Northern Germany. This conference was sponsored and organised by the Commission of the European Communities and was the major European event of the year in Wind Energy. It was attended by more than 600 delegates from all the European Community member states and 30 other countries around the world. Moreover, there were 150 industrial and commercial participants in the exhibition which presented a complete cross section of the European wind industry and was another highlight of the conference.

I take this opportunity to express my gratitude to the Bundesministerium für Forschung und Technologie in Bonn for co-sponsoring the conference and supporting it in many ways. It was a particular honour that State Secretary Hermann Neumann gave an important opening speech putting wind energy into the perspective of German energy policy. I am also grateful to the government of the host Land Schleswig-Holstein for its great interest and support for this event.

The conference marked an important milestone in wind energy achievement in Europe, namely the installation of the first 1000 MW of wind power in the European Community countries. The many thousands of operational turbines demonstrate the efficiency and vigour of Europe's industry which is leading the world in this emerging sector.

The main subject of discussion during the five days of the conference was the state of the art in wind technology and the current problems of wind energy implementation. During the conference, 90 papers were presented orally and 167 others as specialist papers.

The conference confirmed that wind technology is becoming increasingly competitive with conventional power sources for large-scale electricity production. The potential for further technological innovation was highlighted by the Commission's programme for the development of a new generation of wind turbines in the megawatt size as well as a whole new range of technical concepts.

At the closing session, Dr. Hermann Scheer, member of the Bundestag and President of Eurosolar, introduced the newly created Poul la Cour prize, named after the Danish pioneer who, 100 years ago, developed the world's first wind turbine for electricity production and was a great promoter of the social and technical implementation of wind turbines in rural areas. The prize was awarded by Dr. Andrew Garrad to Mr. Grove Nielsen for his important contribution to the modern development of wind turbines which started in the middle of the 1970s in Denmark.

I hope that these proceedings will become a reference work for the current state of wind technology and will provide practical support for all those working for the further development and promotion of electricity from the wind.

Brussels, 7 April 1993

Dr. Wolfgang Palz
Conference Director
Commission of the European Communities

ANNOYANCE FROM WINDTURBINE NOISE ON SIXTEEN SITES IN THREE COUNTRIES.

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SUMMARY: On locations in Denmark, the Netherlands and Germany the actual annoyance caused by wind turbine noise was investigated. Residents of communities living around existing turbines were interviewed and emitted noise levels were computed based on site measurements. The number of people actually indicating annoyance by wind turbine noise is fairly small. But at the same time the amount of annoyance is hardly related to the objective sound level.

1. INTRODUCTION.

1.2 Wind turbine noise.

Noise has been recognized as one of the main factors in potential environmental impact of wind energy application. Nevertheless much is still unknown about the actual annoyance caused by noise produced by wind turbines.

The European Community partially financed a research project on the annoyance from wind turbine noise. The most important question to be answered was the actually existing annoyance caused by operational wind turbines. On several locations in Denmark, the Netherlands and Germany, residents of communities living around existing wind turbines were interviewed. At the same time the emitted noise levels were computed based on sound measurements on the sites. The main objectives of the study were to establish the level of annoyance, and the amount of annoyance that can be attributed to possible other causes than the objective sound levels.

1.2 Other causes of annoyance.

The establishment of annoyance from noise is not easy, because simple dose-effect models appear to be inadequate (1). Apart from the source (the windturbines) many other causes for negative feelings may exist. These are interfering the direct relation between the level of noise and the amount of annoyance. In order to estimate the annoyance caused by wind turbines these intervening variables must be included in the research.

The appraisal of noise is a highly subjective matter and therefore several factors of individual nature will affect it, beside turbine noise itself. Psychological research on reactions to environmental noise fully agrees on the influence of the following attitudinal factors (2):

* The awareness of non-noise problems increases annoyance.
* Fear of the noise source increases annoyance.
* The belief that the noise source is important decreases annoyance.
* The belief that the noise could be prevented increases annoyance.

In the case of wind turbines the first factor will be mainly visual intrusion, because it is the strongest determinant in public acceptance of wind power application. The second factor will be of very little weight. The third and fourth factor may be affected by the decision making process in the phase of planning the wind turbines. We will refer to them in the section were the results are discussed.

Beside these attitudinal factors some situational factors may also moderate annoyance. The literature on this subject is ambiguous. For instance the hypothesis that annoyance decreases with time, is sometimes supported. In about the same number of studies the opposite hypothesis is accepted (2).

The only clear situational factor is the impact of non-noise intrusion caused by the same source: it increases noise annoyance. The most important factor of wind turbines in the view of the public, is the visual impact. The characterization of the visual impact as 'spoiling the scenery' is only one side of an evaluative scale of turbines in the landscape. The other side of it is a positive scenic evaluation of wind turbines, which is made by a substantial part of the population, mainly dependent of the type of landscape on the site of the turbines. Therefore this situational factor is basically the same as the first attitudinal factor, the awareness of non-noise problems.

Even more complicated is the relation between noise and psycho-social stress or health effects (4). Annoyance caused by wind turbine noise may cause stress, but at the same time many other intervening variables exist. Stress due to noise may be caused by other sources of noise, but also by factors that are not related to either wind turbines or environmental noise. In general residential dissatisfaction and daily hassles will be the main causes for stress. High levels of stress from situational and personal factors (and therefore that are not linked in any way to wind turbine noise) may also cause an increase in the perceived turbine noise and the level of annoyance. Actually wind turbine noise is only one of many factors that may decrease residential satisfaction.

2. RESEARCH DESIGN.

2.1 Sites and respondents.

As the installed capacity grows the noise problem will become more significant in siting decisions of wind turbines and wind farms. At the moment the number of sites of wind farms in Europe is still considerably small. Sites were easily selected without annoying anyone, although some planning mistakes have been made (6).

One of the major problems in this research was the selection of operating turbines with people living near them. The research was carried out in the three European countries with the largest installed capacity: Denmark, the Netherlands and Germany. Nevertheless the actual number of persons that objectively can be annoyed by noise from operating turbines in these countries, does not exceed a few hundred. In these countries sixteen sites were selected with residents living within the 35 dB(A) region. These sites are marked in the figures 1A-C.

Because a certain variance had to be included in the study, some residents below the sound level of 35 dB(A) were included in the survey. The total number of valid interviews in the study was 574 (see table 1). In Denmark

Table 1: Total sample: country and number of sites.

country	N of sites	N of respond.	% of total	residents (%) longer than 5 yrs
Netherlands	4	159	27.7	75
Germany	3	216	37.6	62
Denmark	9	199	34.7	75
Total	16	574	100	70

and the Netherlands the average time people were living in their homes was about the same. In Germany the time was considerably shorter. This was caused by the site of West-Fehmarn, were the type of housing was different. Many cottages are sited around the wind turbines there and a different type of residents resulted. One out of four respondents in Germany was living less than two years in the house were they were interviewed.

All other demographic variables as sex, age, etc. were evenly distributed. One third of the subjects (32%) were living in a household with persons below 14 years of age.

2.2 Questionnaires.

For the design of the questionnaire a research model was constructed. Attitudinal and situational variables as outlined in section 1.2 were included in the questionnaire. It was constructed in Dutch and then translated into Danish, German and English. In the research model the following construct-variables were included.

For the appraisal of wind turbine noise three variables were constructed: annoyance, perceived loudness and interference. These are the central variables of which the dependency of the noise-stratum has to be established.

Attitudes to wind power application were measured and a list of attributed aspects of wind power application were judged by the respondents, as used in wind energy research (7,8).

The perceived residential quality and satisfaction was measured by a set of nine statements ("we enjoy living in our home", "it's a pleasant area to live in", etc.). Annoyance of noise from other sources (traffic and work activities) is a part of residential quality and it was included in the questionnaire.

Stress due to turbine noise was measured with items from a scale developed by King et.al. (5). It contained reported states of mind such as 'angry', 'nervous', 'irritated' and 'anxious'.

The social and psychological data were merged with data on sound levels and environmental conditions, such as surrounding trees and obstacles between turbines and homes. These are based on measurements on the locations themselves.

3. NOISE AND ANNOYANCE.

3.1 Objective sound levels.

Sound levels have been measured on sites, and sound level strata have been calculated with 5 dB(A) intervals. The sound contour strata plots were combined with the actual distance between a subjects' house and the wind turbine location to obtain the objective sound level. Most of the subjects (55%) live in the region surrounded by the 35 dB(A) sound level, one of the sampling criteria.

The average sound level that subjects are exposed to is approximately 35 dB(A) (sd. = 5 dB(A)) from an almost normal distribution (table 2).

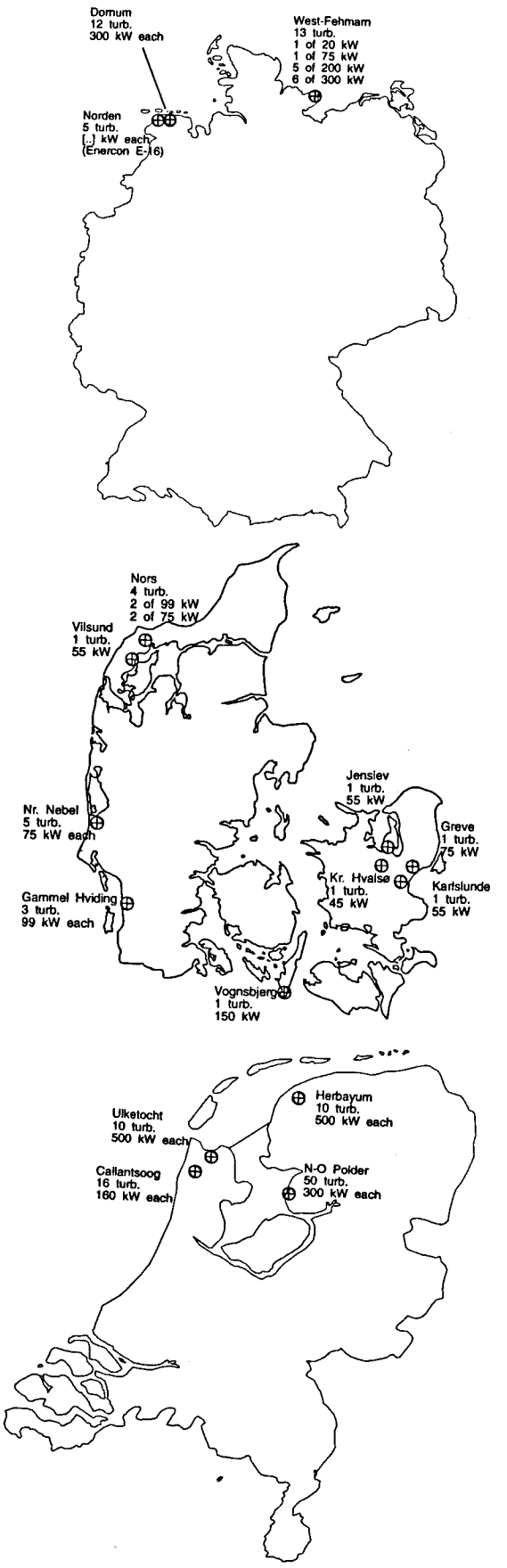

Fig.1: A-C: The sixteen sites in Germany (above), Denmark (middle) and the Netherlands (below).

Table 2: Measured sound levels at residents dwellings.

sound level	N of resp.	% of total
< 25 dB(A)	13	2.3
25-30 dB(A)	64	11.2
30-35 dB(A)	177	30.8
35-40 dB(A)	225	39.2
40-45 dB(A)	69	12.0
45-50 dB(A)	18	3.1
50-60 dB(A)	8	1.4
Total	574	100.0

3.2 Perceived noise annoyance attributed to turbines.

In order to assess *noise annoyance* the respondents were first asked whether they had complaints about noise from various sources in the neighbourhood. Half of the complaints about noise annoyance are attributed to noise from wind turbines (table 3).

Table 3: Resident reporting (any) annoyance caused by wind turbine noise.

annoyance	N or resp.	% of total
not at all annoyed	537	93.6
(some) annoyance	37	6.4
total	574	100.0

The first obvious hypothesis is about the dose-effect relation. According to the dose-effect model there should be a clear and direct relationship between the complaints about noise annoyance from wind turbines and the objective measured sound level. However, we already stated that many intervening variables exist. Analyses shows that the dose-effect model is not an appropriate description of reality. There is only a very weak correlation between sound level and complaints about noise annoyance caused by wind turbines (Kendall's coefficient for correlating rank order variables $\tau = .09$; $p < .05$).

A second instrument for measurement of annoyance refers to the occurrence of certain characteristics of the noise emitted by wind turbines: loudness, duration, high-low, strong-weak, and intensity. According to Van Kamp (4) the judgments about these sound characteristics were combined to a uni-dimensional index of *perceived loudness*. In general, the perceived loudness is very low with an average of .86 in an empirical range of 0 to 5 (sd=1.00). About one third of the subjects (35%) do not perceive any of the sound characteristics. Residents complaining about wind turbine noise also perceive more sound characteristics ($\tau = .38$; $p < .001$).

A third measurement of noise annoyance relates to the intensity of the *interference* of noise with various *daily activities*. Subjects were asked to indicate to what extend noise interfered with activities like resting, leisuring, sleeping, talking, reading, thinking, listening to the radio, and watching television. There are few complaints about noise interfering with daily activities: the average score on the resulting indicator is only 1.40 (sd=2.47) on a range of 0 to 40. Respondents with complaints about turbine noise reported more interferences of daily activities ($\tau = .56$; $p < .001$).

As established in research on the annoyance of air traffic noise and road traffic noise (4), the three indicators of annoyance show a reasonable correlation. So the three indicators were combined in one uni-dimensional indicator for the level of noise annoyance, based on their relative contribution a single determining factor.

The origin of the noise that is complained most about is the sound produced by the blades, followed by unspecified sounds during operation. Most of the annoyance is experienced between 16.00 pm and midnight. When people are reporting annoyance, in most cases they had that feeling when they were outdoors.

4. INTERVENING VARIABLES.

4.1 Noise annoyance and situational factors

First we will direct our attention to situational factors to determine the level of annoyance among residents in the direct vicinity of wind turbine sites. The distinguished situational factors are:

* the distance between a subjects residence and the wind turbine site;
* the location of the residence relative to the location of the site with regard to the dominant wind direction;
* other buildings between a subjects house and the wind turbine site;
* natural barriers, like trees etc., between a subjects house and the wind turbine site;

In order to estimate the contribution of these factors we used regression analysis with the indicator for noise annoyance as dependent variable.

The result of this analysis is that the amount of noise annoyance is lower when buildings are standing between the respondents home and the wind turbine site. Furthermore none of the situational factors are related to the level of noise annoyance. Even the objectively measured sound level is not significantly related to noise annoyance in this analysis.

4.2 Noise annoyance and characteristics of residents.

The disappointing results with regard to the relation of situational factors and noise annoyance is all the more reason to pay attention to attitudinal and other characteristics of subjects in order to determine the amount of annoyance. We analysed the possible effects of the general attitude towards wind energy, of the visual impact, residential satisfaction, other sources of general dissatisfaction, and the estimated pros and cons of large scale application of wind power.

The analyses of annoyance causes major problems due to the very skewed distributions of the scores on the dependent and some of the independent variables. With regard to the dependent variable, the level of annoyance, most of the residents that were interviewed (93%) were not annoyed by wind turbine noise. They hardly ever heard the wind turbines. They perceived no special sounds in the wind turbine noise (65%); nor did the noise interfere with their daily activities (85%).

With regard to the independent variables satisfaction with housing and neighbourhood and irritation or stress due to wind turbine noise, the situation was very much alike. Most of the subjects were very satisfied with their housing and neighbourhood (about 70%) and a very small number of residents (< 15%) were reporting irritation or stress due to wind turbine noise. The general attitude towards wind power application and the appraisal of the visual impact of wind turbines on the landscape had less skewed distributions.

We have tested the hypotheses which directly relate the level of annoyance with:

(a) the general attitude towards large scale use of wind power energy;
(b) appraisal of the impact of turbines in the landscape;
(c) satisfaction with housing and neighbourhood;
(d) an index for other sources of dissatisfaction;
(e) stress caused by wind turbine noise.
(f) objective factors like sound level and buildings between tubines and homes.

Because these factors are related to one another, and may also interfere with some of the situational factors, we carried out a multivariate analyses of the level of annoyance with characteristics of subjects. It shows that stress due to noise of wind turbines is the major explanatory effect of the level of annoyance. Most of the subjects who tend to get stressed by the wind turbines have a high level of annoyance.

The perceived effects of wind turbines in the landscape (i.e., visual intrusion) plays an intermediate role: in general, noise annoyance decreases the less intruding wind turbines are judged in the landscape. This factor shows some remarkable differences between the the three countries when the results are compared. For these differences we did not find an explaination.

No effects were found for any of the situational aspects like the actual objectively measures level of noise, buildings, trees and fences between the wind turbine site and the subjects house. Additional to the subjective characteristics there is however still one intermediate direct and multivariate effect. The longer a turbine site is operational, the less the level of annoyance, even if we control for subjective characteristics. In an equation with standardized effects:

ANN = .69 SN + .11 DH + .10 LS -.06 TIME + -.58 + e

The coefficients give an estimation of the relative weight of each aspect. (ANN = annoyance; SN = stress due to noise; DH = daily hassles; LS = landscape; TIME = time of turbines are operational). The prediction results in an overall explained variance of 53%.

5. CONCLUSION.

The results presented here should be treated with caution. There are a number of methodological problems involved in a project in which subjects from different countries have been interviewed using the "same" questionnaire. Translating questionnaires without loss of information is extremely difficult, and interview effects may interfere differently between countries. It may result in incompatibilities in the data.

Second, there are analytical problems involved due to extremely skewed data. The fact that the actual level of annoyance among the large majority of the subjects is extremely low, leaves very little variation in the major response variables. Extremely little variation means that there is hardly anything left to explain. The prediction that somebody is not annoyed, irrespective of any other effect, is in most cases already the right prediction. Moreover, caution must be taken in order not to ascribe possible effects to outliers, which would make the conclusions not very robust.

The first main result of the study is fact that the number of people actually indicating annoyance by wind turbine noise is fairly small. Of all persons interviewed only 6.4 % is reporting any noise annoyance caused by wind turbines.

The second result is that the amount of annoyance is hardly related to the objective sound level. As a consequence we have to conclude, and that may be disappointing for technical oriented scientists and decision makers, that a reduction in the emissions and a decrease in the sound levels will not result a the disappearance of annoyance and complaints about the noise. The fact that someone is complaining is mainly determined by the personality of the individual. Personal characteristics and circumstances determine the tendency to complain. This conclusion must not be misunderstood. The fact that sound level is not predicting annoyance *does not mean* that people are *not really annoyed* when they are reporting it.

6. DISCUSSION

The fact that only a very small number of resident around operational wind turbines is annoyed by noise can be interpreted as a positive result. It means noise is not a major problem in the case of operational wind turbines. Nevertheless expectations about annoyance in the future caused by wind turbines that will be built, is a crucial factor in the planning phase of wind power projects. From attitude studies we know that the public does not think noise is a problem that is generally troubling the application wind power (7,9). Noise is considered to be a problem that can be prevented, but because of this fact wind power developers must be prudent. All research on noise annoyance indicates that the belief that the noise could be prevented increases the annoyance.

Noise will mostly be an issue when it comes to siting turbines. Utilities and authorities often fail to present projects that sufficiently deal with all locational aspects, such as scenic values and future noise levels. Particularly in this phase of planning wind power projects people want to be taken serious when they have certain doubts.

In judging the way they are treated by the authorities and planners one of the criteria for the community is the way planning agencies use the existing noise regulations and standards. Specific noise standards for wind turbines only exist in Denmark (3). In Germany and the Netherlands the standards are derived from general recommendations. From case studies on siting decisions we know that people feel that noise annoyance is not adequately considered when these standards are use in a flexible way, only to make the siting of turbines possible (9).

The solution is to be found in careful selection of sites and adaptation of the layout of wind farms, not in adjusting noise standards. Most neighbouring residents do not appreciate flexible standards. They feel the standards are manipulated and exactly that will lead to distrust and to the feeling something might be very wrong with the assessments of noise emissions.

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