

Wind Turbines in Germany: Review of Opposition and Health Effects on Humans

Examination of the current state of research

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Graphical Abstract

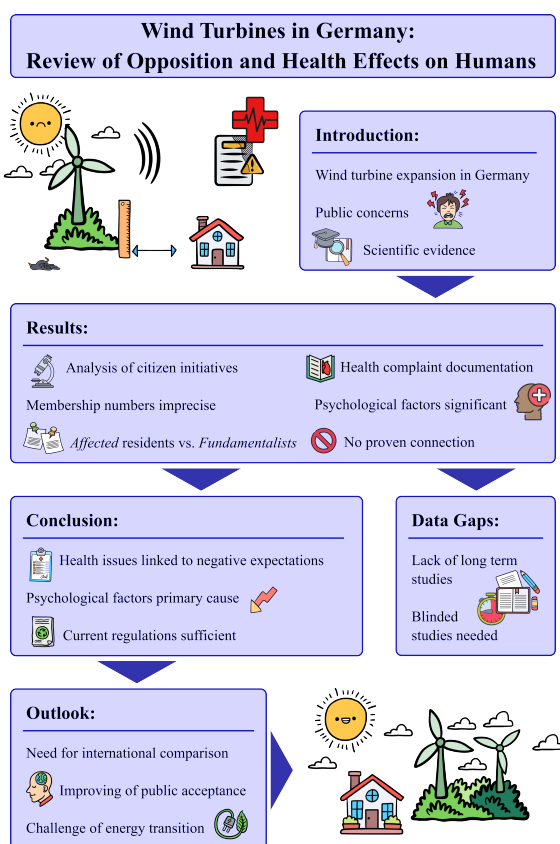


Fig. 1: Graphical Abstract

Abstract

This review examines opposition to wind turbines in Germany and associated health effects on nearby residents. Analysis reveals that while initial claims suggested widespread resistance, actual opposition is limited. Research identified two distinct opposition types: affected residents seeking fair implementation while supporting renewable energy, and fundamentalists categorically rejecting energy transition.

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The health complaints reported and investigated include noise annoyance, shadow flicker disturbance, and vibration issues. The number of documented health complaints varies considerably between the individual studies. However, high-quality studies indicate many reported symptoms correlate strongly with psychological factors and nocebo effects rather than direct physiological impacts. The results of the studies show that health complaints often only occur when opposing groups become active in the communities, indicating a strong correlation between negative expectations and the reporting of symptoms.

The current state of information indicates that the existing legal regulations in Germany provide sufficient protection for the health and well-being of local residents, even if some opposition groups are in favour of stricter requirements.

While research gaps remain, particularly regarding long-term exposure effects and the interaction between multiple environmental factors, evidence suggests most health concerns are influenced more by psychological and social factors than by actual turbine operations. Understanding these dynamics is crucial for improving public acceptance of wind energy and advancing Germany's energy transition goals.

Keywords: Wind Turbines, Health Effects, Public Opposition, Infrasound, Nocebo Effect

1 Introduction

The expansion of wind turbines in Germany is progressing and has reached a new high. In the past, this has repeatedly led to protests and citizens' initiatives. The reasons for these concerns were usually the supposed negative effects on the environment and, above all, the human organism. Local residents in particular had concerns about the noise, infrasound and shadows cast by wind turbines [1].

Different and partly outdated scientific publications, such as the recently uncovered miscalculations of sound pressure levels by the Federal Institute for Geosciences and Natural Resources (BGR) [2, 3], are used to spread concerns about possible health risks from wind turbines, e.g. through the transmission of infrasound emissions.

The first aim of this review is to investigate the level of resistance to the construction of wind turbines and the introduction of renewable energies among the German population. It will be examined whether certain reasons for people's resistance to wind turbines can be identified. Furthermore, it will be examined whether a comparison with other countries is possible or whether there are limiting factors that make a cross-country comparison impossible.

This review will also look at which complaints are documented by the people affected and whether there is documented data and a scientific basis in the form of systematic studies for the health problems mentioned. In summary, it will be discussed which of the reported complaints can be substantiated and whether there are other explanatory models.

The results of the data collection are also compared with the current laws and regulations for the construction of wind turbines in Germany. It is considered whether the current building regulations in Germany are sufficient for the protection of the resident population according to the current state of research.

2 Materials and Methods

In order to answer the initial questions, studies of the measurable and perceived effects of wind turbines and other sources of disturbance were examined. The study results were compared with each other in order to identify differences and to determine the current data situation.

The AI programs Perplexity and Inciteful were used to research, review and sort the sources and data. The AI program Anara was used to support the writing of the article and as a citation aid.

2.1 Initial Questions

The first question is: how high is the number of complaints regarding the erection of wind turbines? A comprehensive German study examined citizens' initiatives against wind power and found the following: Initially, anti-wind-energy websites claimed over 1,000 citizen initiatives existed in Germany. However, detailed analysis revealed this number was significantly inflated. The actual findings showed: only 290 active citizen initiatives against wind power exist. It is estimated that between 121,000 and 342,000 people

in Germany actively organized against the construction of wind turbines in 2019. For comparison, 1.4 million people demonstrated for climate protection in September 2019 [1].

The second question investigated is which health complaints were registered, with what frequency and whether there is a scientifically investigated basis for the corresponding complaints. To this end, it was investigated whether there were corresponding studies and systematic surveys.

Regarding health complaints specifically, studies show varying rates of documented impairment near wind turbines: Noise annoyance was documented by 4.1-45 % of residents, shadow flicker annoyance rates 7.8-31 %, visual annoyance around 12.9 % and vibration complaints are documented by 1.5-4 % [4, 5]. The wide range of reported annoyance rates can be explained by the scope and methodology of the different studies, the selection of participants and the local conditions [4]. Study quality significantly impacts reported rates. Higher quality studies generally show lower prevalence of complaints compared to studies with methodological weaknesses such as potential selection bias [4] [5]. Different definitions of 'annoyance' in the various studies also influence results and detailed comparability [4, 5].

2.2 Studies

A large number of health complaints associated with wind turbines have already been scientifically researched. As explained above, the individual studies show strongly fluctuating rates of complaints, whereby an influence of potential selection bias and the study quality on the results is recognisable [5].

For specific health impacts, sleep disorders were linked to noise levels in some studies, with disturbances spiking at 40-45 dBA rather than increasing linearly [5]. Several studies found no direct relationship between turbine noise and stress effects or biophysiological sleep variables [5].

The scientific literature reveals diverse research on wind turbine health effects, with varying study types and durations:

2.2.1 Long-term Studies:

Several large-scale cohort studies have examined prolonged exposure effects. Danish studies tracked health outcomes over multiple years, investigating links between wind turbine noise and cardiovascular conditions like atrial fibrillation, finding limited evidence of direct health impacts [6]. A nationwide cohort study found no significant association between long-term exposure and myocardial infarction or stroke [7].

2.2.2 Technical Studies:

Research has extensively measured sound emissions, particularly focusing on infrasound and low-frequency noise [8]. Technical measurements consistently show that infrasound levels from wind turbines fall well below human perception thresholds at typical residential distances [9]. Studies have examined noise propagation patterns, sound pressure levels, and acoustic characteristics of different turbine designs [8].

2.2.3 Other Health Effect Studies:

Cross-sectional studies have documented various reported health effects, including sleep disturbance, annoyance, and quality of life impacts [8]. Laboratory experiments have investigated physiological responses to turbine noise exposure [9]. Psychological studies have examined placebo effects and the role of attitudes in symptom reporting [5].

Research gaps remain, particularly regarding the interaction between multiple exposures (visual, acoustic, vibration) and their combined health impacts [5]. Studies recommend more prospective research designs and objective health outcome measurements [10].

3 Results

In the following, the results of the investigations of the described health impacts of wind turbines are presented: the extent of organised resistance, the reported health effects and investigated causes, as well as German legislation to protect the population.

3.1 Opposition Groups

The analysis of the number of people organised against wind turbines shows two distinct opposition groups: *Affected* residents who support renewable energy but want fair implementation, and *Fundamentalists* who categorically reject the energy transition [1]. The *Fundamentalists* use dramatic rhetoric about landscape destruction and unproven health risks to stoke public fears, revealing ideologically-driven resistance rather than evidence-based concerns. The research shows a correlation between rejecting climate change and opposing wind energy, suggesting that underlying ideological biases, rather than just local concerns, shape some opposition to wind energy [1].

Opposition groups that are not fundamentally opposed to the energy transition focus their concerns primarily on personal disadvantages. These include nearby turbines, concerns about the environment, especially birds, bats and forests. Support for decentralised renewable approaches such as solar and hydropower is also frequently mentioned. The affected

group's bias stems from direct impacts: they seek more involvement in planning and fair distribution of burdens, while supporting renewable energy in principle [1].

The study found many listed initiatives were either duplicate entries, inactive or unreachable or no longer existing. The study concludes that while opposition exists, its extent has been overestimated, and most critics support renewable energy generally while opposing specific local implementations [1].

3.2 Health Effects

Several health complaints are reported in connection with wind power, though their causation and severity are often debated. The documented complaints include the following points:

Noise-related impacts are most commonly reported, with studies showing wind turbine noise is associated with annoyance, which varies based on factors like noise sensitivity and attitudes toward turbines [5]. Sleep-related issues are frequently reported, though research shows mixed results - while some studies report sleep disturbance, others find no association between wind turbine noise and biophysiological sleep variables [5].

Specific reported symptoms include headaches, migraines, dizziness, balance problems, tinnitus, excessive fatigue, and cardiovascular disorders [5]. Some residents report psychological effects including anxiety, distress, and reduced quality of life [5, 11]. Visual impacts also trigger complaints, with shadow flicker, blinking lights, and blade movement causing annoyance in some residents [5].

The controversial *Wind Turbine Syndrome* encompasses multiple symptoms including vertigo, nausea, panic attacks and sleep problems, allegedly caused by infrasound exposure [11]. However, no case-control or cohort studies with control groups have confirmed its existence [8]. Recent research suggests many reported health effects may be influenced by psychological factors like negative attitudes, visual impact, and perceived procedural unfairness in wind farm development [11].

3.3 Causes

The documented complaints related to wind turbines, though the evidence suggests many are influenced by psychological and social factors rather than direct physical effects. Danish population studies found a significant correlation between wind turbine proximity and increased prescription of sleep medications and antidepressants [7]. However, when examining objective sleep parameters using clinical testing (polysomnography, actigraphy) and validated sleep questionnaires,

no connection was found between sleep quality and wind turbine exposure [7].

The findings on wind turbine noise annoyance reveal a more nuanced reality that challenges simplified perceptions of direct health impacts. While multiple studies confirm a significant association between wind turbine noise and annoyance, the relationship is moderated by several personal and situational variables rather than just noise exposure levels or visual effects. Psychological attitudes, expectations, and social factors play a crucial role in how people experience and report annoyance [5, 7].

Notably, studies found no direct relationship between wind turbine noise and stress effects or biophysiological sleep variables [5]. Interestingly, negative expectations and beliefs about wind turbines often led to increased reporting of symptoms, suggesting a psychological component [5]. The findings indicate that annoyance reactions are influenced by psychological and social factors than, challenging the notion that physical noise exposure alone determines health impacts.

Several commonly reported complaints lack strong scientific evidence to support them:

Direct physiological effects from low-frequency noise lack scientific validation [7]. Large epidemiological studies found no connection between wind turbines and diabetes, heart attacks, strokes, or high blood pressure [7]. The *Vibro-Acoustic Disease* claims also lack of reliable evidence given actual sound levels produced by turbines [8].

The *Wind Turbine Syndrome*, has no support from case-control or cohort studies [8]. Studies show infrasound levels from wind turbines fall well below human perception thresholds [7].

Research indicates many health complaints emerge only after wind turbine opposition groups become active in communities [5]. Studies demonstrate that negative expectations and attitudes significantly influence reported symptoms, suggesting a nocebo effect where beliefs about harm lead to experienced symptoms [5]. This psychological component explains why identical infrasound exposure in controlled studies produces symptoms only in people expecting negative effects.

Psychological factors play a significant role in reported health complaints from wind turbines. A revealing study from Australia (1993-2012) found that 73 % of health complaints came from areas where anti-wind energy groups were active, with 90 % of these complaints emerging only after these groups began their campaigns [7]. In randomized studies, participants reported symptoms like headaches, nervousness, and “ear pressure” after watching videos portraying negative effects of infrasound, but not after viewing positive presentations [7].

Notably, these physical symptoms were reversible when people were educated about nocebo effects [7]. This correlation suggests a strong link between the prevailing expectation and the perceived physical effects.

The power of expectation is further demonstrated by the fact that 64.7 % of wind farms received no health complaints at all [7]. Media coverage, particularly negative or threatening *fake news*, significantly influences individual health complaints [7, 12]. This evidence strongly suggests that psychogenic influences and nocebo effects, rather than actual infrasound exposure by wind turbines, are primary drivers of reported health issues [7, 12].

It should be mentioned that some of the opponents of wind turbines do not seem to be open to scientific arguments, or at least not completely [1, 7]. These *Fundamentalists* continue to invoke disproved arguments, such as the *Fluttering Power* concerns put forward by Hans-Werner Sinn, even after these have been scientifically refuted [1].

Higher quality epidemiological studies generally show lower prevalence of health complaints compared to studies with potential selection bias [5, 7, 12]. The evidence indicates that while some people experience genuine distress, many reported health effects may be mediated by psychological and social factors rather than direct physiological impacts [7]. Research shows that negative beliefs and expectations about wind turbines can lead to increased reporting of symptoms and annoyance, even when actual exposure remains constant [5]. This suggests that the common perception of wind turbine noise as a direct cause of health problems may be oversimplified.

While studies have documented the influence of the nocebo effect on health complaints, the specific mechanisms by which psychological factors and media coverage interact with physical symptoms need more detailed examination [7]. Long-term epidemiological studies focusing on actual infrasound exposure levels in real-world conditions are lacking.

A secondary question considered when comparing the studies was whether differences between different countries or individual language areas could be identified. Although it is difficult to compare complaints about wind turbines between different countries, as population density, wind power density, turbine size, legal regulations and public perception vary greatly from country to country. Furthermore, there is no centralized recording and register of complaints in connection with wind turbines. It is therefore not possible to say whether health complaints in connection with wind farms occur more frequently in Germany than in other countries.

3.4 German Law and Health Protection

The legal framework for wind turbine construction is primarily governed by the Federal Immission Control Act (BImSchG) and the Technical Instructions on Noise Protection (TALärm) [13, 14]. These regulations establish specific noise limits that vary by location type.

For nighttime noise levels, the requirements are precisely defined: 70 dB maximum for industrial areas and 35 dB maximum for recreational areas and near hospitals.

Each wind turbine project requires individual sound calculations to determine appropriate setback distances. While some situations, such as single turbines near industrial areas, may only require distances of about 150 meters, the requirements vary based on specific circumstances.

A significant recent addition to the regulatory framework is §249 Abs. 3 of the BauGB (enacted August 14, 2020), which allows individual states to implement mandatory distances of up to 1000 meters between wind turbines and residential buildings [15]. However, scientific evidence doesn't support these extended setbacks when projects already comply with BImSchG and TALärm standards.

Opposition groups often argue for a minimum distance of 1000 metres from inhabited areas for wind turbines, often citing unfounded concerns about infrasound emissions [7]. However, these claims are scientifically untenable if existing noise protection requirements are properly implemented and enforced.

4 Discussion

The estimate of citizens organized in initiatives against wind turbines shows large fluctuations in membership numbers, as many estimates were based on signature collections and photo documentation of public demonstrations. This type of estimate is correspondingly imprecise.

Furthermore, the citizens' initiatives only provide an assessment of the reservations about the construction of wind turbines. However, there is no central and comprehensive survey of the complaints that actually occur. One problem is the lack of a central reporting office, but also the lack of a standardized definition of registered complaints.

The research on the environmental effects of wind turbines has increased during the last two decades, and study quality has improved over time [5, 10]. The documents don't suggest significant contradictions between older and newer findings, but rather indicate an evolution toward more sophisticated research methodologies and broader scope of investigation [10].

The only temporal development shows that the evidence base has grown substantially, with research becoming more rigorous. Many recent studies on health effects have come to the conclusion that an impact of wind turbines on health is unlikely or impossible.

Nevertheless, various past studies have come to different conclusions as to whether wind turbines have a relevant and measurable influence on the health and well-being of people in the immediate vicinity. Some studies show correlations or at least do not rule them out.

However, some of these studies were carried out with methodological weaknesses. In some cases, the cohorts analysed only had a small number of participants. The small number of samples in those studies ensures relative imprecision. Furthermore, the participants surveyed were not randomly selected in all studies, but were sometimes even specifically examined or questioned according to sensitivity or previous complaints. A corresponding bias can therefore be assumed. Corresponding studies may therefore be more negative than would be the case in a blinded study.

Current research has notable gaps, particularly in field studies specifically examining health effects of infrasound [7]. While laboratory studies have investigated cognitive function, brain connectivity, and myocardial contractility, these were conducted using much higher infrasound levels and frequencies than those typically emitted by wind turbines.

Research gaps also remain, particularly regarding the interaction between multiple exposures (visual, acoustic, vibration) and their combined health impacts [5]. Studies recommend more prospective research designs and objective health outcome measurements [5, 7].

5 Conclusion

Studies show that there is a connection between active, sometimes regional, opposition to wind turbines and documented health problems, presumably caused by wind turbine. This correlation indicates that a large proportion of the documented complaints are not caused by wind turbines or associated infrasound. The conclusion is that health problems are largely caused by negative expectations and the nocebo effect. More recent and higher quality studies and research suggest that the majority of reports are due to this negative bias.

When considering the current legislation, it is worth mentioning that wind turbine opponent group often push for mandatory 1000-meter distances, citing concerns about infrasound emissions. However, these claims lack scientific foundation when existing noise protection requirements are properly implemented.

The current regulatory framework is designed to balance energy development with appropriate environmental and health protections. There is no demonstrable evidence that the current legal requirements are not sufficient to ensure the protection and health of neighbouring residents.

Although there is currently no reliable evidence for the negative health effects of wind turbines and the current research results indicate a correlation between expectation and physical effect, a causal relationship with long-term exposure cannot be completely ruled out. Larger studies should therefore be carried out in this areas in the future in order to verify the current findings. The studies should be blinded in order to avoid the negative bias that can result from the selection of supposedly affected test subjects. The correlation between the activity of opponent groups against existing and planned wind turbines and the occurrence of documented complaints by residents must be analysed more closely for causality. In this context, the effects of the nocebo effect in particular should be investigated more extensively.

6 Outlook

The research of this review included only English and German language publications. For this reason, it is possible that current data bases from other language areas were not taken into account in this review.

One research question that could not be clarified in this review due to a lack of centralised data collection is the difference between complaints in different countries, regions and language areas. Future research can clarify whether there are significant differences and what these differences may be.

Another question is how this knowledge can be used to improve the acceptance of wind turbines and the perceived well-being of the people affected.

The results of the study can contribute to education and acceptance and thus to the success of the German and global energy transition. This is particularly important in Germany, where the energy transition faces challenges in terms of grid stability, energy storage and public perception of the noise and visual impact of wind turbines. Further studies can help overcome public scepticism and encourage greater support for a forward-looking and climate-friendly energy policy. In this way, further research and study results can make a decisive contribution to climate protection.

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