Real-Time Insights into the Impact of Turbine Noise and Shadow Flicker

Interactive App for Understanding the Impact of Wind Turbines

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As wind energy continues to expand to meet global sustainability goals, its growth often encounters challenges related to community acceptance. To address these concerns, an interactive tool was developed that combines advanced forecasting and community feedback to enhance communication, transparency and mitigation strategies for socially sustainable wind energy development.

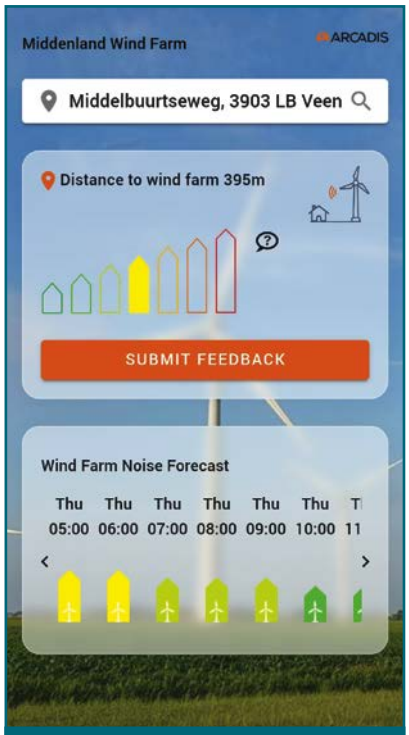

Figure 1. Impression of the noiseforecast app

Understanding the Daily Impact of Wind Turbines

While wind turbines offer a clean and renewable source of energy, they can also affect the quality of life for nearby residents. The impact is influenced by the unpredictable nature of wind turbine noise and shadow flicker, which depend heavily on changing weather and environmental conditions.

What if we could make wind turbine noise and shadow flicker more predictable for residents? Could this reduce their impact? With these questions in mind, Arcadis developed the 'noiseforecast' app, an innovative tool designed to improve the predictability of wind turbine noise and shadow flicker. The app enhances communication, transparency and mitigation strategies to address these challenges effectively.

By including community feedback mechanisms, the app offers a unique approach to understand and reduce the effects of wind turbine operations. Its application in operational projects demonstrates the importance of integrating technological solutions with community engagement to ensure the long-term success of wind projects.

The Challenge of Wind Turbine Noise

Wind turbine noise is a complex phenomenon influenced by factors such as wind speed, wind direction, atmospheric stability, ambient noise levels, and turbine operations. While higher exposure to wind turbine noise generally correlates with increased annoyance, individual and community responses vary widely. Research has shown that non-acoustic factors – such as visual impact, trust in authorities, feelings of fairness, and participation in the planning process – also play a significant role in shaping perceptions of wind turbine noise.

Residents who feel excluded from decision-making processes or receive a lack of information about turbine operations often experience greater annoyance. This underscores the importance of addressing both acoustic and non-acoustic factors when managing wind turbine impacts.

A Practical Tool for Noise Management

The interactive noiseforecast app helps residents better understand and anticipate wind turbine noise and shadow flicker. By incorporating high-resolution weather data, turbine specifications, and local environmental factors, it provides location-specific 48-hour forecasts for noise and shadow flicker (see Figure 1). Additionally, it includes local weather forecasts, helping residents understand why noise or flicker might be more noticeable at certain times. The app also displays the energy production and avoided carbon dioxide emissions, highlighting the environmental benefits of wind energy. A key feature of the app is its feedback mechanism, which allows residents to share their experiences with the wind turbines, fostering transparency and engagement. Residents can anonymously report how they experience wind turbine noise (using a 7-point annoyance scale) and shadow flicker (using a 5-point scale) at any time, day or night. With user consent, these reports can be linked to specific dates, times and locations, and weather, environmental and turbine conditions.

Empowering Residents Through Feedback

What sets the app apart is its interactive nature. By enabling residents to report their real-time experiences (see Figure 2), the app creates a feedback loop that

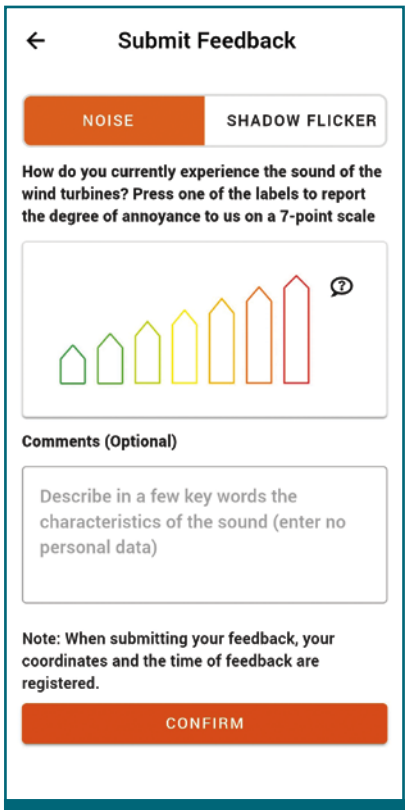

Figure 2. Inviting feedback from residents

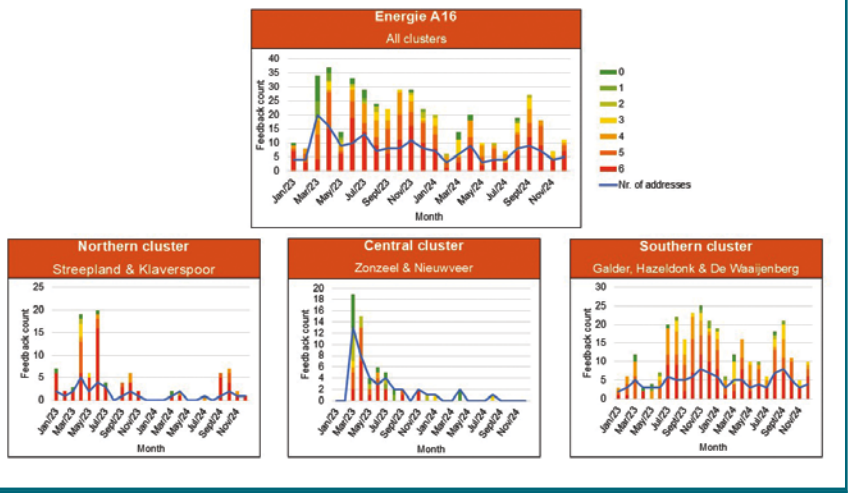

Figure 3. Monthly number of feedback responses and annoyance ratings for the Energie A16 clusters. The blue line indicates the number of distinct locations providing feedback

allows wind farm operators to correlate annoyance levels with specific weather, environmental and operational conditions. This analysis helps to identify patterns of annoyance and the factors contributing to them, enabling targeted improvements.

By giving residents a platform to voice their concerns, the app provides a sense of control, reduces irritation, and encourages constructive dialogue. While their feedback reflects subjective responses, feedback from many residents presents an objective picture. Experience from projects has shown that the vast majority of residents submit honest feedback.

Operators can use resident feedback to fine-tune turbine operations based on localised insights, improving noise mitigation strategies and strengthening community relations. Ultimately, the app bridges the gap between residents and operators, supporting effective noise management and socially sustainable wind energy development.

Application in Projects and Key Findings

The app has been implemented in multiple wind energy projects across the Netherlands, involving over 100 wind turbines and more than 17,000 neighbouring residential addresses. It provides valuable data on annoyance patterns and operational impacts.

Residents living within 1.5 kilometres of turbines participated in a year-long pilot project near a newly operational wind farm. Surprisingly, all feedback indicated low levels of annoyance, with 88% of responses reporting 'no nuisance'. Residents attributed this lack of annoyance to the masking effect of background noise from a nearby motorway.

In another project, noise measurements revealed that sound levels at certain frequencies were higher than expected, leading to significant annoyance among residents. The app played a crucial role in identifying the weather and turbine conditions under which annoyance peaked and in developing targeted mitigation measures. Subsequent adjustments to turbine operations resulted in a significant reduction of sound and annoyance levels.

Insights from a Two-Year Study of the Energie A16 Wind Project

The Dutch project Energie A16 involved 26 turbines distributed across three geographically separated clusters along a busy motorway. Over two years, residents reported their experiences with the turbines, revealing significant differences in annoyance patterns between the clusters (see Figures 3 and 4).
Proximity played a key role: 16.4% of residences within 500 metres reported high annoyance at least once compared with only 0.1% of those 1 to 2.1 kilometres away. Annoyance peaked at wind speeds of 8 to 13 m/s at hub height, when turbines produced their maximum noise.

The late evening (9 p.m. to 1 a.m.) and early morning (7 to 8 a.m.) also showed increased levels of annoyance. Additionally, annoyance was higher when the wind blew from residents towards the motorway, reducing background noise and making the turbines more noticeable.

These findings underscore the importance of considering local environmental conditions, turbine operations, and proximity when assessing the impact of wind turbine noise.

Temporal and Seasonal Patterns in Annoyance Levels Across Wind Projects

Resident feedback over a two-year period from six wind projects reveals consistent temporal patterns in high annoyance levels (see Figure 5). Most wind farms show peaks in annoyance between 9 p.m. and 1 a.m., and again between 7 a.m. and 8 a.m., aligning with quieter periods in the late evening and early morning. Some reports submitted at the end of the night may reflect delayed responses to disturbances experienced earlier.

Monthly data show no clear seasonal trend, although four out of six wind farms reported above-average annoyance in April, August and September. This lack of seasonality is expected, as high annoyance levels are influenced by local factors such as background noise, wind direction, and wind speed. These conditions vary significantly across locations, with specific wind directions and speeds contributing differently to annoyance levels at each wind farm.

Figure 4. Number of feedback responses and annoyance ratings for the Energie A16 clusters by hour of the day. Each time label represents the hour starting at the specified time.

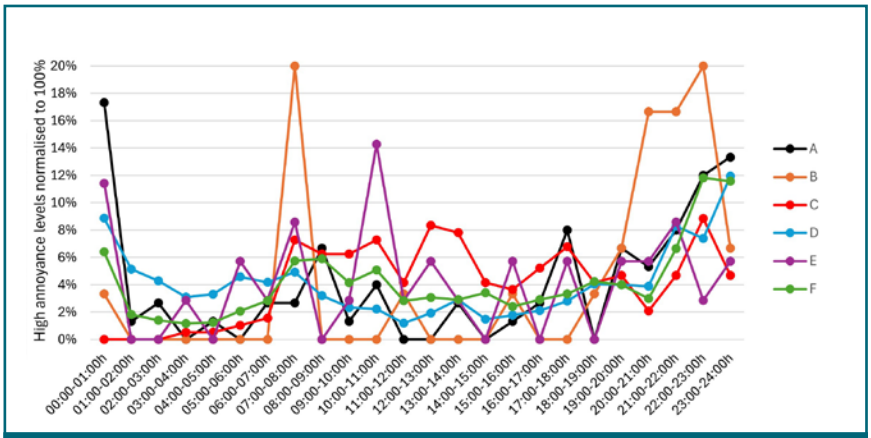

Figure 5. Reported high annoyance levels by hour of the day normalised to 100% over a two-year period for six wind farms

Conclusion

The noiseforecast app helps manage the impact of wind turbine noise on nearby communities. By addressing both acoustic and non-acoustic factors, the app fosters transparency, empowers residents, and supports more effective noise mitigation strategies. Detailed forecasts reduce uncertainty, enabling residents to anticipate and better cope with periods of noticeable turbine noise and shadow flicker, ultimately increasing acceptance.

Operators can identify periods and areas of heightened annoyance and implement targeted solutions, reducing annoyance and improving acceptance. Experience from projects demonstrates that resident feedback is crucial for effectively addressing and resolving real noise issues. Continuous resident feedback highlights persistent issues, enabling adaptive noise mitigation strategies as residents adjust to turbine operations.

By integrating technological innovation with social engagement, the interactive app helps balance energy production with the well-being of local communities. Proactively addressing community concerns and managing excessive nuisance issues is essential for achieving socially sustainable wind energy development.

Further Reading

- Koppen, E., Ekelschot-Smink, M. and Boon, J. 2023. Noise forecast app: positively impacting non-acoustic factors. 10th International Conference on Wind Turbine Noise, Dublin.
- Koppen, E., Ekelschot-Smink, M. and Boon, J. 2025. How do residents experience wind turbine noise? The results of a two-year study. 11th Edition of the International Conferences on Wind Turbine Noise, Copenhagen.

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