ENERDAY 2026 - 20th International Conference on Energy Economics and Technology

Contribution ID: **63**

Type: **not specified**

Multi-criteria assessment of prospective wind farms for municipal-level planning

Friday 27 March 2026 11:30 (20 minutes)

Onshore wind energy is a cornerstone of the energy transition, yet its expansion has faced increasing opposition at the local level, where many projects are rejected due to social and environmental concerns. As the project's planning progresses towards site selection, municipalities often play a decisive role in the final approvals. However, municipal decision-making is often supported by fragmented assessments that inadequately capture the trade-offs among technical performance, costs, and local impacts.

This study develops a spatially explicit multi-criteria decision analysis (MCDA) framework to assist holistic municipal wind farm planning by systematically integrating diverse impact assessments into a transparent decision support tool. Using two case studies in Styria, Austria, we compile outputs from techno-economic resource assessment, life-cycle assessment (LCA), wildlife habitat suitability study, noise propagation model, shadow flicker model, and landscape scenicness prediction into a set of normalized performance attributes. These attributes are categorized into four decision pillars: technical, economic, environmental, and social, and weighted using a combination of survey results and data-driven approaches.

The framework is applied to explore trade-offs and synergies across pillars using correlation and principal component analysis (PCA). Additionally, with various combinations of pillar weights, the sensitivity of wind farm performance and total generation potential with associated costs under different pillar prioritization can be investigated. By comparing our model-based outcomes with empirical preferences from a stakeholder workshop, the policy relevance and robustness of this study is assessed.

The results reveal pronounced trade-offs between technical and social performance, with smaller wind farms tending to achieve higher overall performance due to lower social impacts (noise, shadow flicker, and landscape scenicness), despite larger farms offering technical advantages. The PCA shows a strong alignment between social and environmental dimensions (LCA and habitat suitability), while economic pillar exhibits weak correlations with local impacts. Sensitivity analyses further demonstrate that increasing technical pillar weight disproportionately favors large wind farms, highlighting a central policy tension between maximizing energy yield and minimizing local externalities.

From a municipal planning perspective, applying stricter MCDA selection thresholds reduces both generation potential and system costs, but the magnitudes of these effects depend strongly on regional context and prioritization scenarios. The empirical preferences from the stakeholder workshop shows strong agreement with our model-based results under the environmental prioritization scenario, suggesting that participatory preferences converge with analytical indicators that emphasize minimizing environmental burden.

Overall, the study demonstrates that integrating diverse model outputs into a transparent spatial MCDA framework reveals critical synergies, trade-offs, and policy relevance that conventional single-objective or macro-level analyses overlook or simplify. The framework is transferable to other regions or technologies and can be extended to incorporate additional criteria, alternative weighting schemes, or participatory inputs at different planning stages, providing a basis for more robust and socially attuned renewable energy planning.

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Session Classification: Renewable Expansion & Planning