

# Multi-criteria assessment of prospective wind farm sites for municipal-level planning

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ENERDAY 2026  
27.03.2026, Dresden



# Agenda

- Introduction
- Multi-criteria decision analysis (MCDA)
- Results analysis
- Summary and outlook

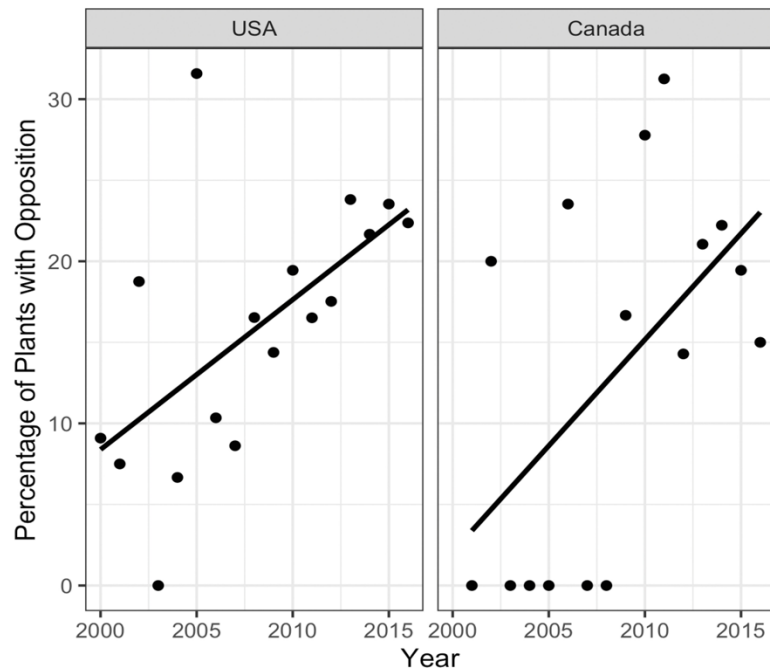
# Introduction

Wind energy is expected to nearly double its capacity globally by 2030

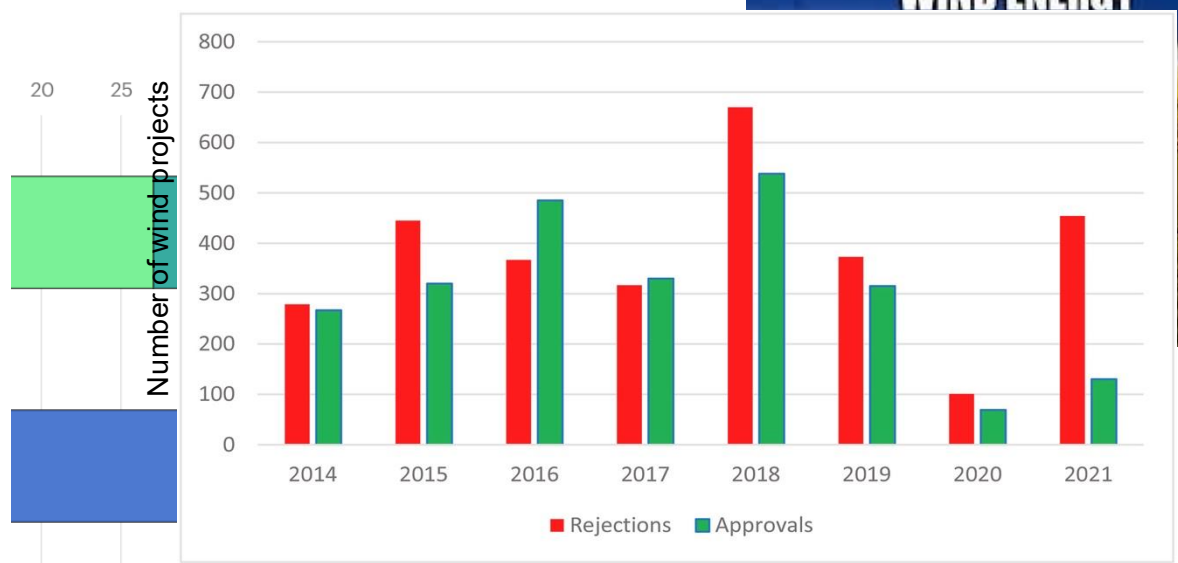
Wind projects' approval rates remain low

Global electricity generation by renewable energy technology

Wind opposition over time in north America [1]



Municipal approval rate of wind power applications in Sweden [2]



● Solar PV ● Wind ● Hydropower ● Other renewables

DIE SCHWEIZ IST KEIN WINDLAND

PAYSAGE LIBRE SUISSE  
FREIE LANDSCHAFT SCHWEIZ

# Introduction

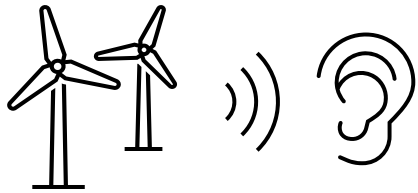
High social barrier due to various real and perceived impacts [3]

Landscape impact

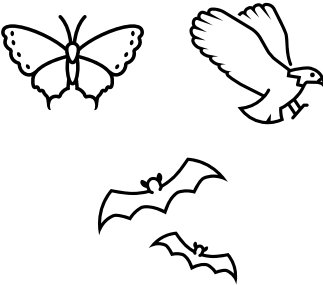


Source: [Basler & Hofmann](#)

Noise emission



Wildlife disturbance

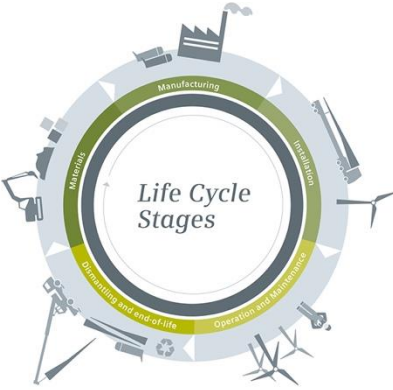


Shadow flicker



Source: [U.S. Department of Energy](#)

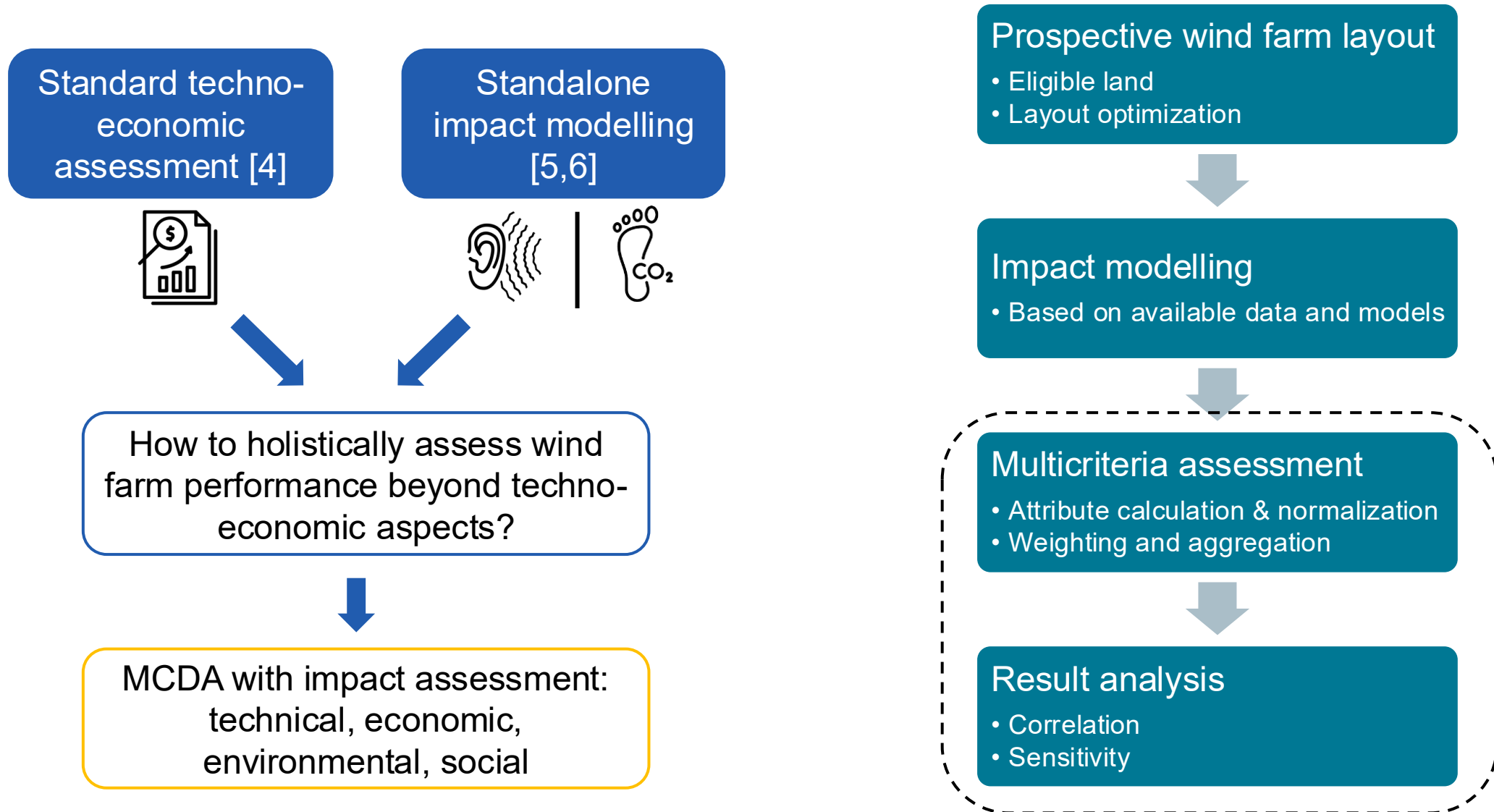
Climate change impact



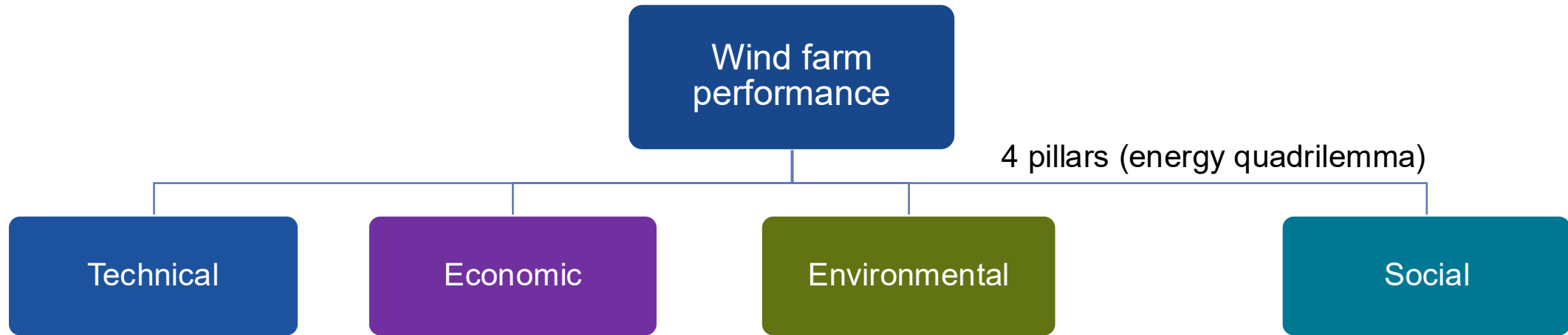
Source: [DTU](#)

Addressing these concerns in planning is important!

# Research gap & workflow



# Objective hierarchy



Criteria  
(based on model and  
data availability and  
resolution)

Attribute

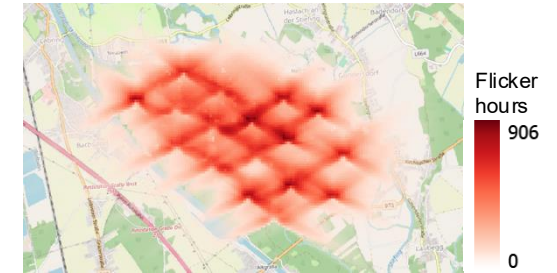
Job  
creation

Land use  
change

Safety  
risks



# Attribute calculation: socio-environmental



Shadow flicker [7]

Simulated annual flicker hours (30 m × 30 m) considering terrain changes × population

Noise [7]

Affected population by computed 24-hour average noise indicator above 45 dB (100 m × 100 m)

Landscape scenicness [8]

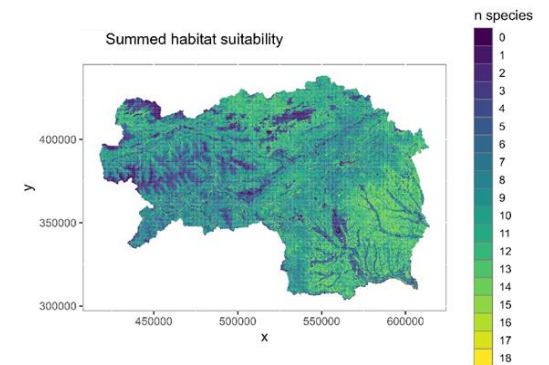
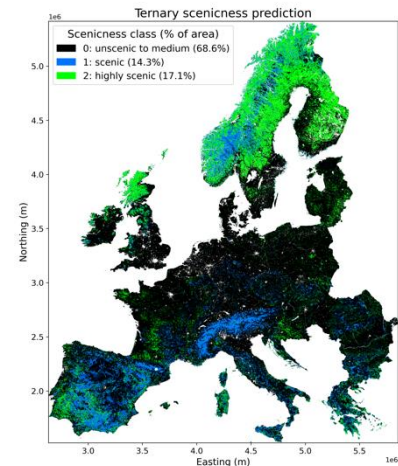
Area of (highly) scenic landscape based on model prediction (1 km × 1 km)

LCA [9]

Climate change impacts (in kgCO<sub>2</sub>eq) with geographically refined inventory data (100 m × 100 m)

Habitat suitability [10]

Modelled habitat suitability for 23 species in Styria, Austria (250 m × 250 m)



# Normalization, weighting, aggregation, correlation and sensitivity

## Normalization

- $[\varepsilon, 1]$  with 5<sup>th</sup> and 95<sup>th</sup> percentile ( $\varepsilon$ : small value to avoid zero - worst, 1: best)
- Opposite signs for **beneficial** (e.g. capacity factor) and **undesirable** (e.g. costs, noise exposure) attributes

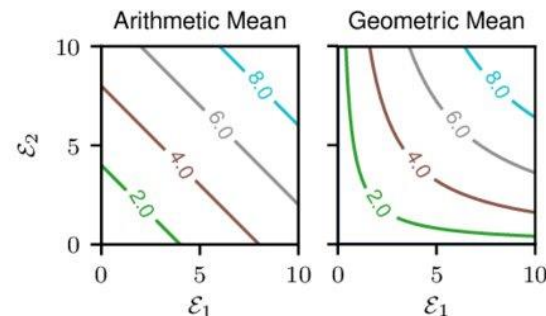
## Aggregation

Arithmetic mean (AM)

$$AM = \frac{1}{n} \sum_{i=1}^n x_i$$

Geometric mean (GM)

$$GM = \left( \prod_{i=1}^n x_i \right)^{\frac{1}{n}}$$

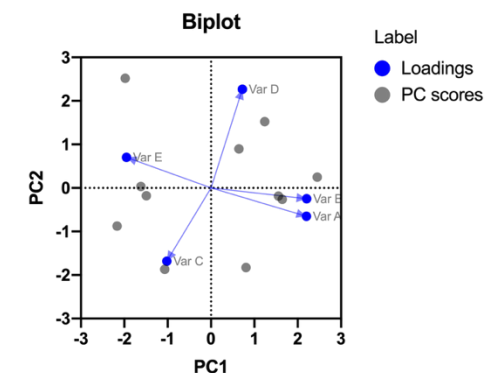


## Weighting

- Criteria weighting
  1. Equal weights
  2. Entropy weights (more variation, more importance)
  3. Survey-derived weights
- Pillar weighting

## Correlation & sensitivity analysis

- Principal component analysis (PCA) - key directions for most variation
- Spearman correlation
- Sensitivity to weights



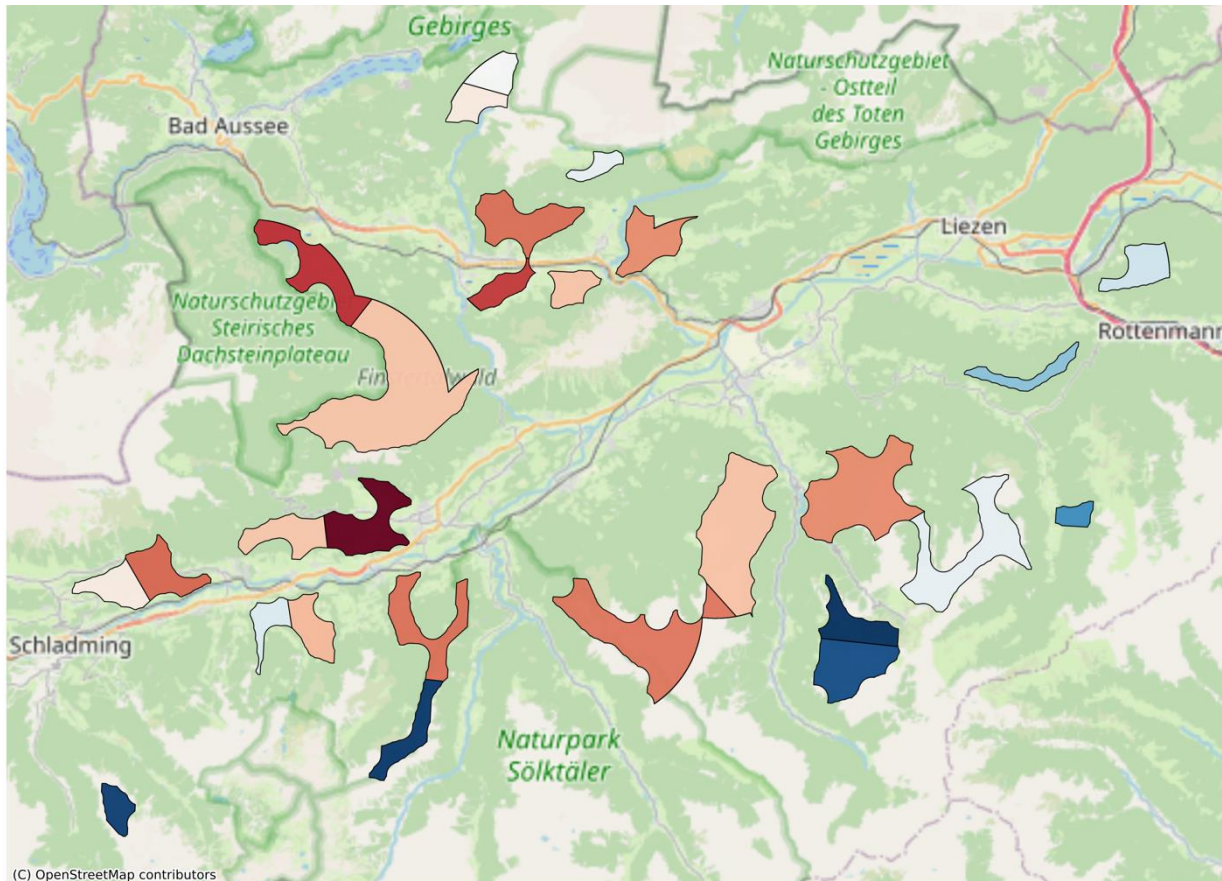
# Criteria weighting

Pillar	Criteria	Baseline (equal weights)	Entropy-based weights	Entropy-survey hybrid weights
Technical	Energy output	0.33	0.21	
	Volatility	0.33	0.17	
	Self-sufficiency	0.33	0.62	
Economic	Turbine costs	0.33	0.74	
	Internal connection costs	0.33	0.16	
	External connection costs	0.33	0.10	
Environmental	Life cycle emissions	0.5	0.51	
	Wildlife habitat disturbance	0.5	0.49	
Social	Shadow flicker	0.33	0.29	
	Noise emissions	0.33	0.42	
	Landscape impact	0.33	0.29	

- 3 weighting schemes: equal, entropy-based, entropy-survey hybrid
- No stakeholder inputs for **technical** and **economic**, only **socio-environmental**
- Entropy:
  - Technical: Self-sufficiency
  - Economic: turbine costs
- Entropy vs. survey:
  - Environmental: similar
  - Social: noise vs. shadow flicker

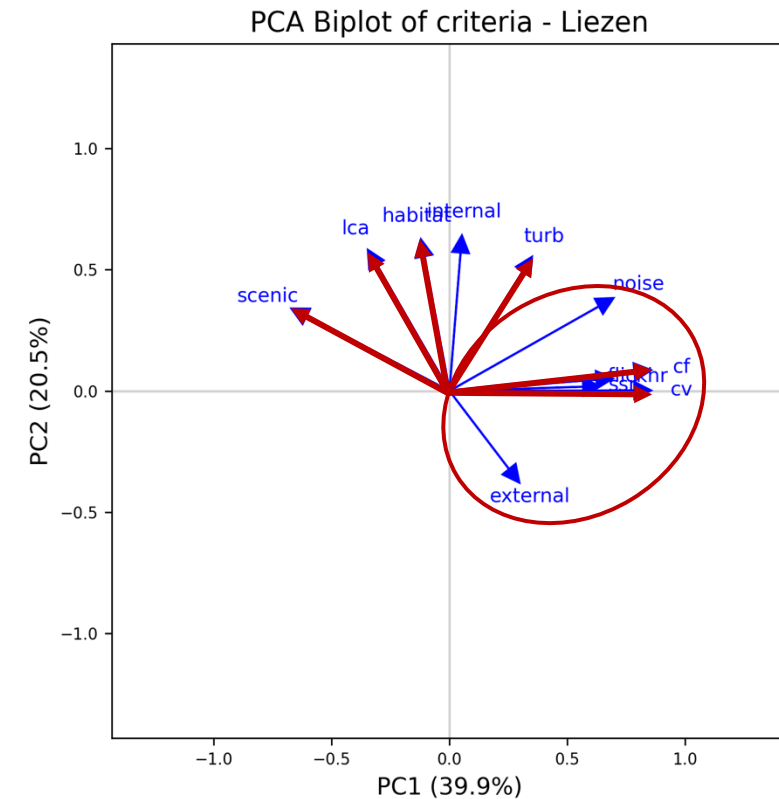
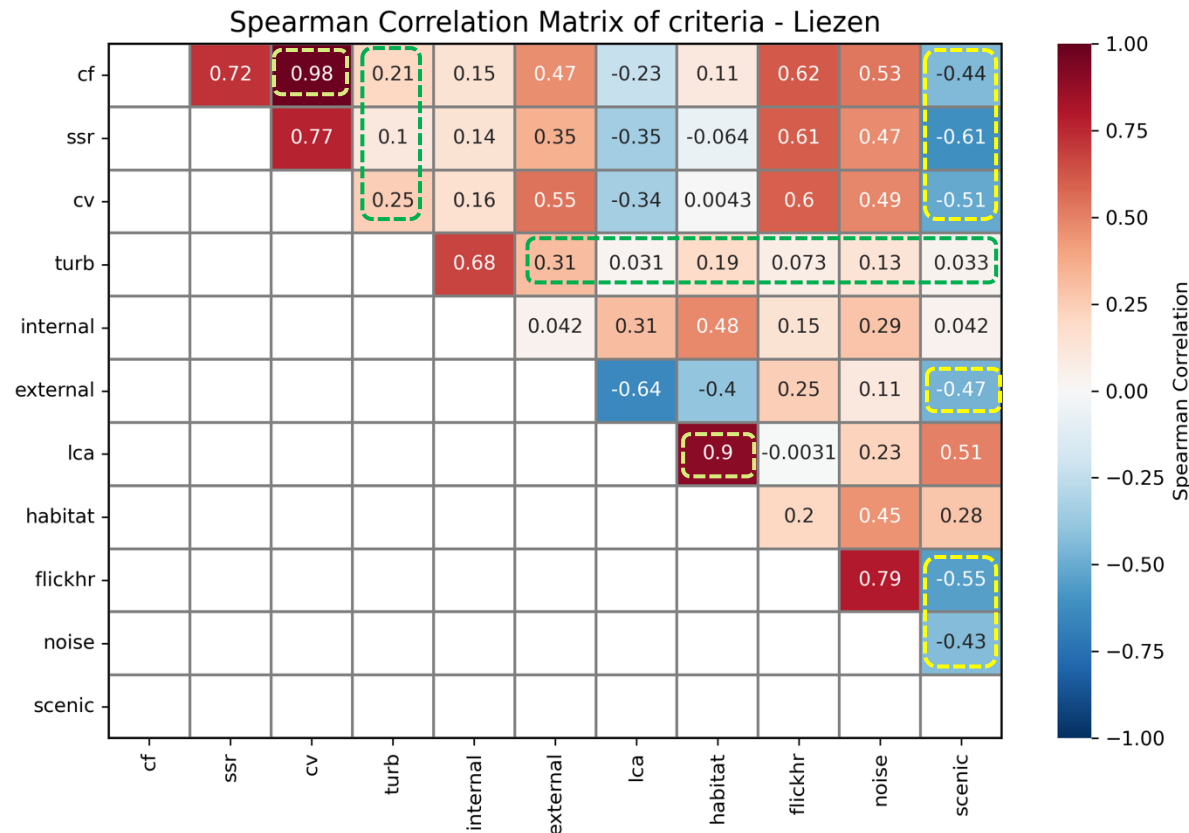
# Case study in Liezen, Styria: wind farm sites

Wind farm performance in Liezen: hybrid criteria and equal pillar weights



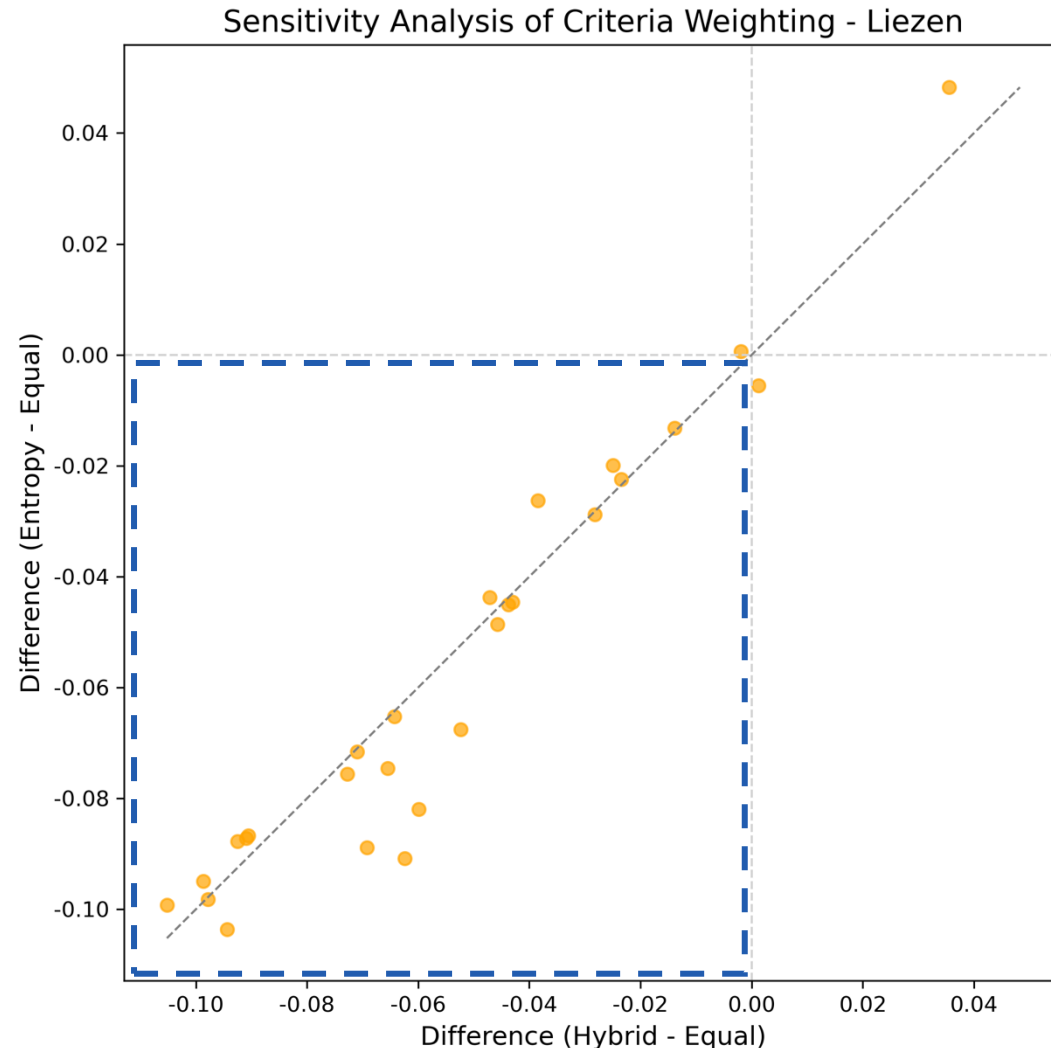
- Wind farms sites considering land exclusion criteria [11]
- Turbine locations: yield-maximizing layout [12]
- MCDA performance with equal pillar weights
- Smaller ( $\leq 10$  turbines) and further farms (from the valley) tend to perform better

# Criteria correlations to identify synergies and trade-offs



- Synergies (positive correlations): life cycle emissions & habitat suitability; capacity factor & coefficient of variation
- Trade-offs (negative correlations): scenic landscape impact vs. (technical & other social criteria & external connection costs)
- Independence (low correlations): turbine costs vs. others

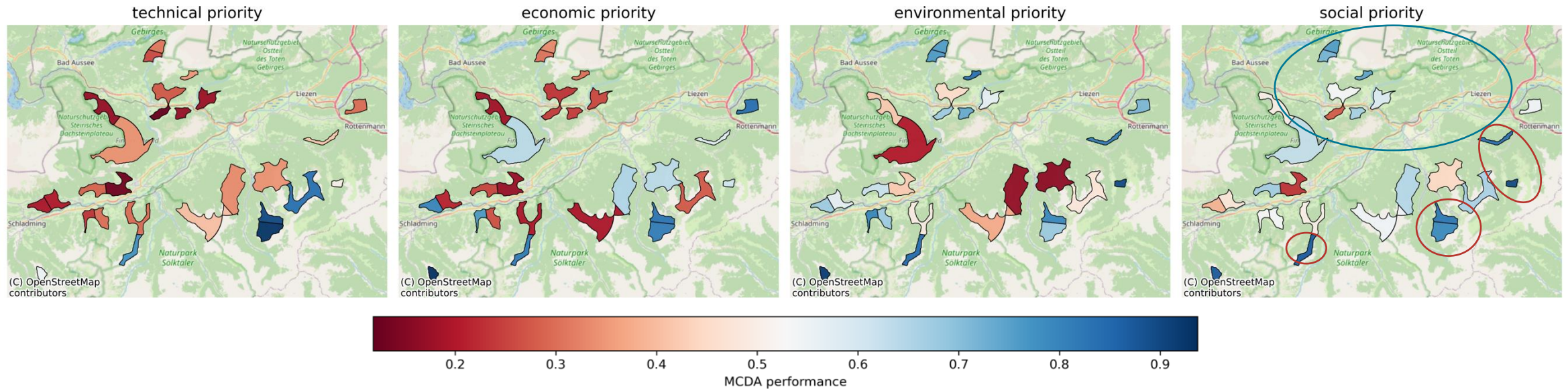
# Sensitivity on criteria weighting



- Final score difference using equal, entropy or hybrid criteria weights
- Below zero: **equal weighting** tends to give a **more generous** score (less penalizing of extreme scores)
- Close to the 1:1 line: both entropy-based and entropy-survey hybrid weighting schemes give **almost identical** scores, despite the different focuses on **noise and shadow flicker**

# Sensitivity analysis – custom prioritization weights

Wind farm MCDA performance under each pillar priority (weight = 0.7)



- Increase one pillar's weight to 0.7 while keeping others at 0.1
- Small wind farms (< 10 turbines) north of valley more sensitive & worse techno-economic performance (unbalanced pillar performance)
- Southernmost farms stay high performance due to good wind resources and low impacts (balanced)
- Robustness of scores is spatially dependent

# Summary and limitations

## Summary

- Holistic MCDA for wind farm sites with socio-environmental impact assessment
- Attribute calculation, 3 criteria weighting schemes, correlation and sensitivity analysis
- Entropy-based weights have similar structure to survey weights
- Trade-off between landscape and other criteria
- Small farms away from settlements have lower impacts, but more sensitive to pillar weight changes

## Limitations

- Lack of data (resolution and spatial coverage)
- Limited stakeholder inputs (only residents)
- Simplified assumptions
  - Economic benefits not considered
  - Uncertainty not included

## Outlook

- Gather more data through: data mining, crowd sourcing, survey, interview, etc.
- Economic benefits approximation
- Uncertainty quantification

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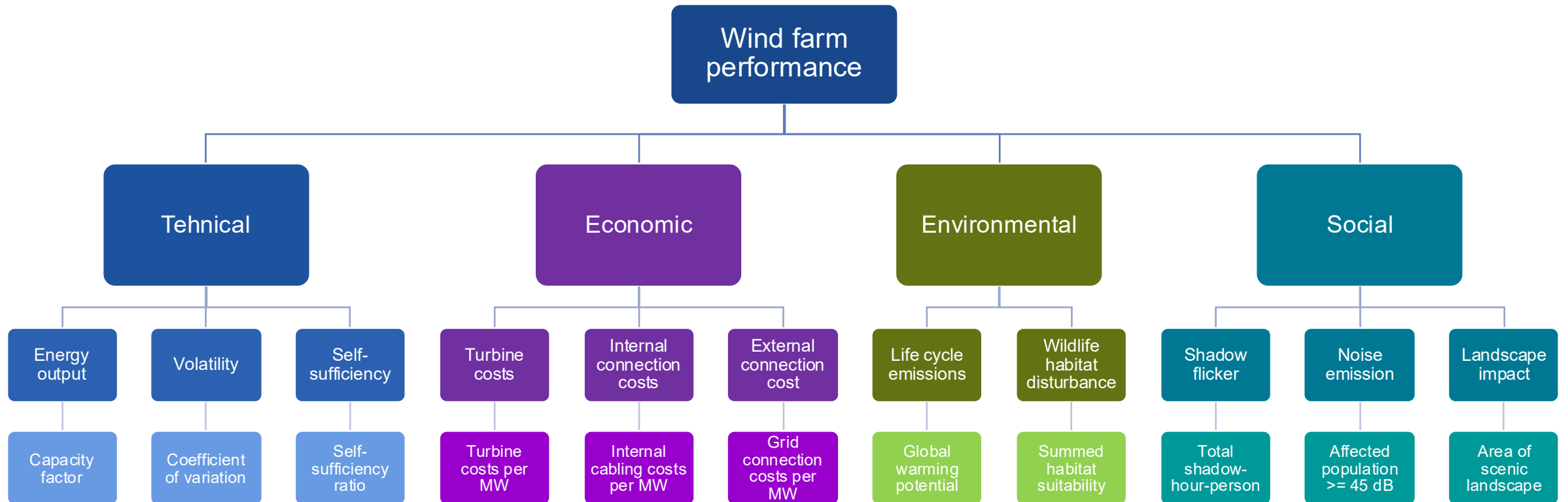
Thank you for your attention!

Looking forward to your questions

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# Objective hierarchy



Each attribute is min-max normalized into  $[0,1]$  with 5<sup>th</sup> and 95<sup>th</sup> percentile