House of Energy, Climate & Finance
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UNIVERSITÄT DUISBURG ESSEN

Offen im Denken

Internalizing local disamenities in onshore wind cost-potential curves: Evidence from Germany

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INREC Essen, 26.08.2026

Agenda

- Introduction
- Methods and data
- Results
- Takeaways

Onshore wind is cheap, but not costless locally

Standard energy-system models typically include

- Wind resources
- Land eligibility
- CAPEX / O&M
- Technical LCOE

But often omit local disamenities

- Visual impacts
- Property-value effects
- Local welfare losses
- Landscape sensitivity

Source: UBA

➢ **Ignoring local disamenities can bias investment/siting decisions**

Research question & contribution

How do local disamenity costs change onshore wind cost-potential curves and spatial siting?

Contribution

- Translate **empirical disamenity estimates** into model-ready LCOE adders or constraints
- Compare several disamenity representations in **one framework**
- Use a **hedonic property-price evidence** as preferred revealed-preference benchmark
- Quantify **cost premiums and spatial reallocation** for Germany

Empirical evidence behind the disamenity cost adders

- Social acceptance is not a binary phenomenon, but a multidimensional concept involving attitudes, behavior, perceived legitimacy, procedural fairness, local cost-benefit perceptions, etc.
  - How to quantify these effects?

Method	What it measures	Translation challenge
Stated preference	hypothetical WTP for avoiding turbine impacts	survey values → €/MWh adders
Revealed preference	property prices / life satisfaction	observed losses → spatial welfare costs
Planning proxies = Exclusion	Population density / scenicness / visibility	constraints → reduced feasible potential

Data and spatial framework

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Method and data

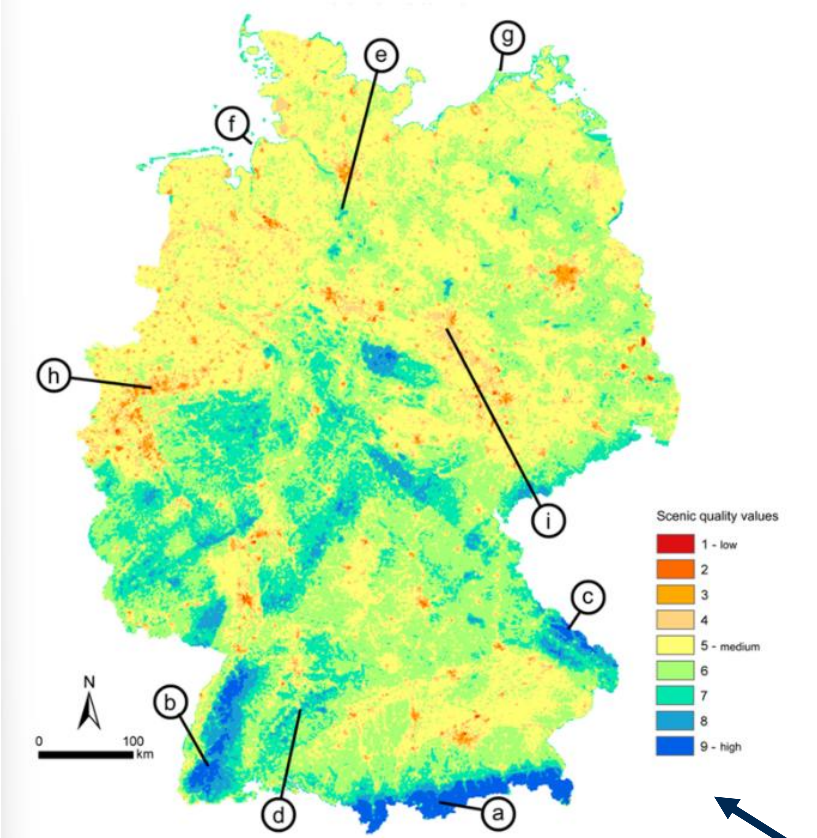

Fig. 1: Scenic beauty map of Germany, based on linear regression analysis with 17 regressors

Germany grid with approx. 360,000 raster cells. Each combines

Eligible wind area

JÜLICH Forschungszentrum – Jülich Systems Analysis

Geospatial Land Availability for Energy Systems (GLAES)

Wind resources

Programme of the European Union – Copernicus – ECMWF

Datasets › ERA5 hourly data on single levels from 1940 to present

ERA5 hourly data on single levels from 1940 to present

A novel approach to generate bias-corrected regional wind infeed timeseries based on reanalysis data

Yannik Pflugfelder, Hendrik Kramer, Christoph Weber

Representative turbine type

Turbine	*Hub height [m]*	*Rotor diameter [m]*	*Power [kW]*	*Type*[a]	*Capex [€/kW]*
6	150	140	4.000	Low speed	1.573
7	120	124	4.500	High speed	1.363

Existing wind capacity

Bundesnetzagentur

MaStR Marktstammdatenregister

Population and households

DESTATIS Statistisches Bundesamt

zensus 2022

Residential property values

rwi ImmoScout24

RWI-GEO-RED/REDC/REDX: REAL ESTATE DATA AND INDICES

Scenicness/landscape amenity

Landscape as an Area as Perceived by People: Empirically-based Nationwide Modelling of Scenic Landscape Quality in Germany

Michael Roth[1], Silvio Hildebrandt[2], Sina Röhner[2], Christian Tilk[3], Hans-Georg Schwarz von Raumer[4], Frank Roser[4], Milena Borsdorff[4]

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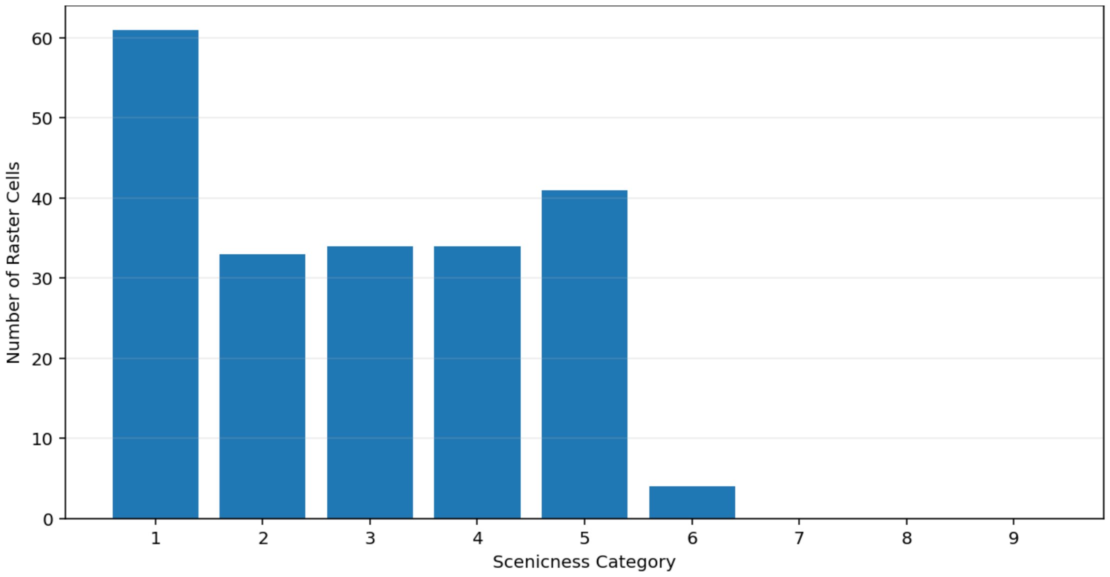
➢ Common raster allows heterogeneous evidence to be translated into one cost metric

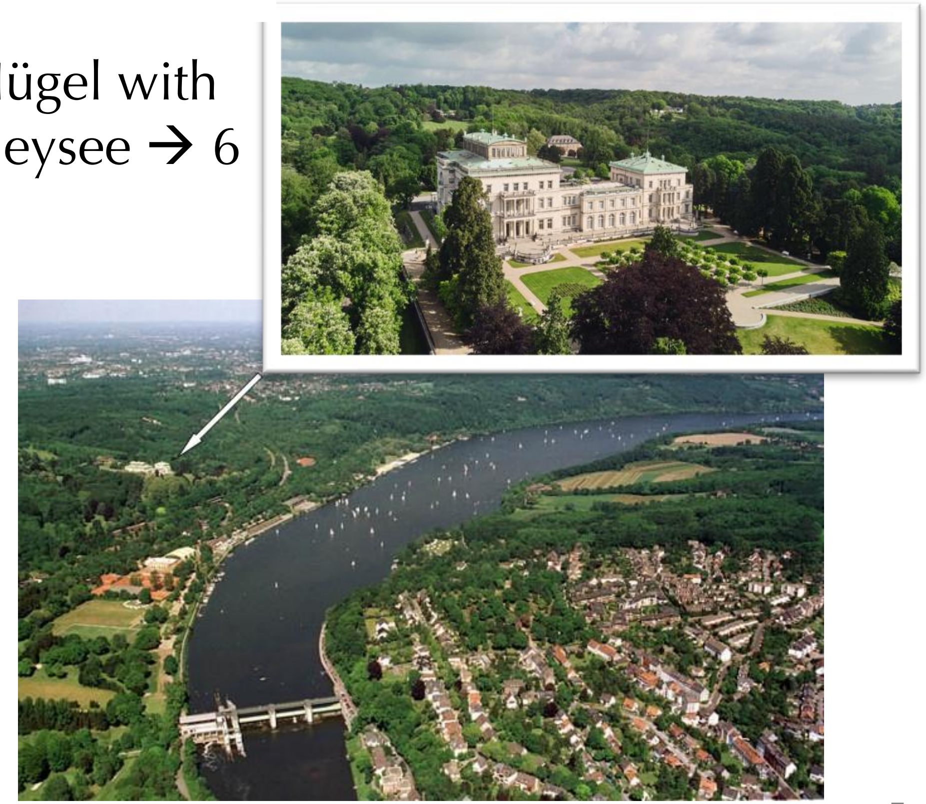
Scenicness in Essen

Side fact



- Altendorfer Str. → 1

- Villa Hügel with Baldeneysee → 6

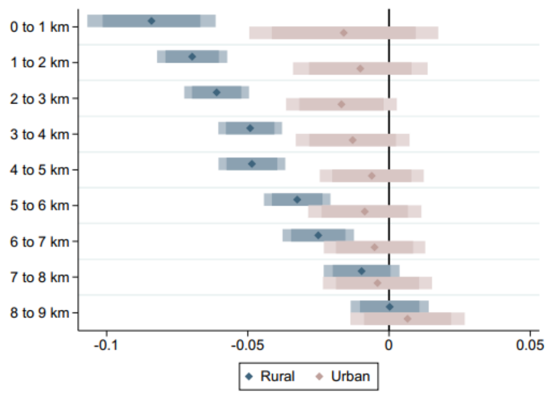


Five representations of local disamenities

Variant	Type	Characteristic
WTP-Low	Monetary	survey-based valuation → distance-decaying €/person/year exposure cost
WTP-High	Monetary	
HedPrice	Monetary	housing-market capitalization → property-value loss from nearest-turbine distance
LifeSat	Monetary	subjective well-being loss → monetized €/household within 4 km
ExclPop	Exclusion	social sensitivity proxy → exclude sites near dense population
ExclSce	Exclusion	landscape sensitivity proxy → exclude high-scenicness sites

$$C_i^{dis,HedPrice} = \sum_j V_j \cdot \max\left(0, \lambda(d_{i,j}) - \lambda(d_j^{old})\right)$$

Figure 4: Effects of Wind Turbines on logged House Prices in Rural and Urban Areas



Allocation logic: ex-post accounting vs. internalization

- Standard allocation
  - Rank sites by technical LCOE
  - Build technical least-cost path
  - Add disamenity costs ex post

Greedy:
select the lowest-cost feasible turbine site, update constraints

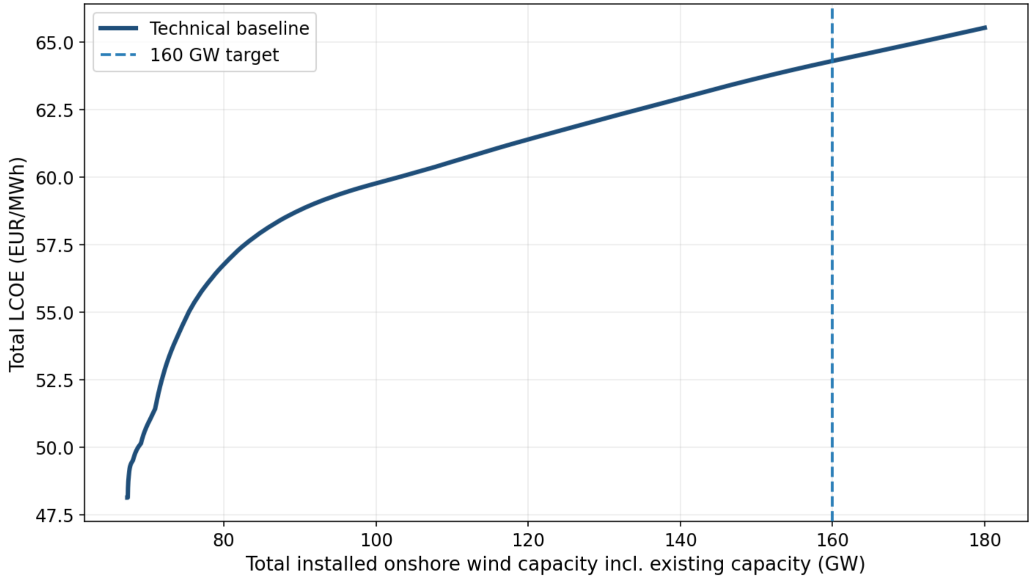
- Extended LCOE allocation
  - Rank sites by technical + disamenity costs
  - Avoid high-exposure sites if worthwhile
  - Build socially adjusted path

$$LCOE_q^{total} = \frac{\sum_{q=1}^{Q}\left(C_{i(q)}^{base} + C_{i(q)}^{dis}\right)}{\sum_{q=1}^{Q} G_{i(q)} \cdot AF(r,T)}$$

$AF_{r,T}$	Present-value factor for a constant annual stream	Discounted years
C_i^{base}	Present value of technical base costs for one turbine in cell i	EUR
C_i^{dis}	Present value of marginal disamenity costs caused by one additional turbine in cell i	EUR
G_i	Annual electricity generation of one turbine in cell i	MWh/year
q	Step in the **greedy** allocation sequence	Turbine-placement step
Q	Total number of turbine placements	Number of newly placed turbines

➢ If disamenities are internalized, the model can change where turbines are built

Technical benchmark: 160 GW target

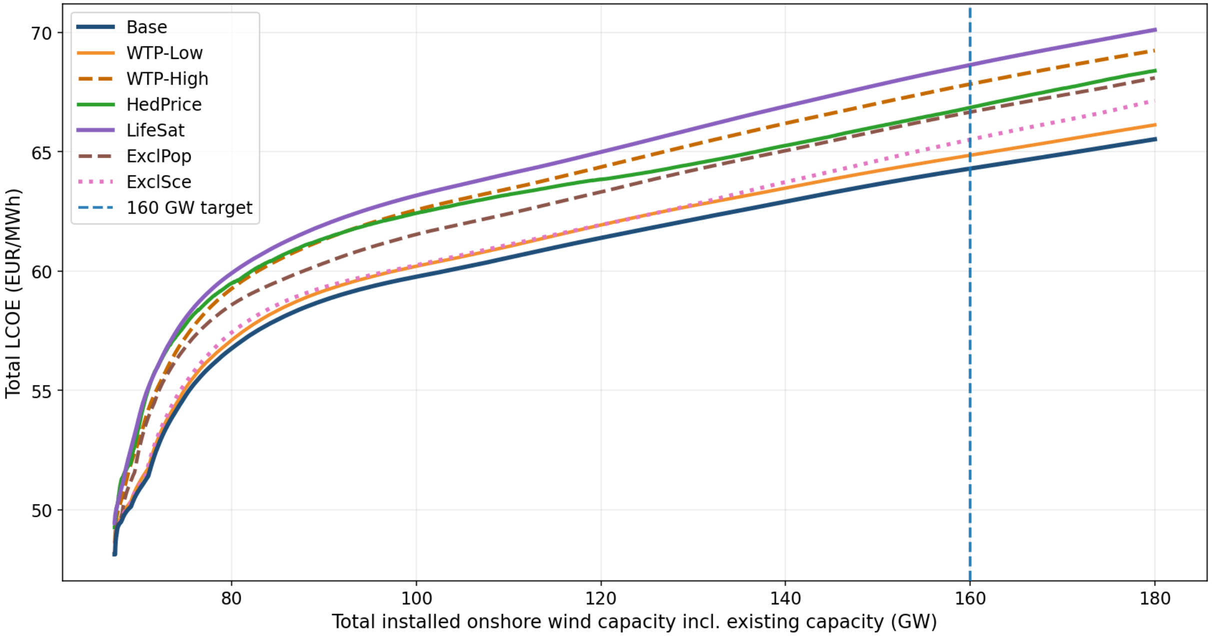


Technical baseline cost-potential curve

- Existing onshore wind capacity (01/26)
  67.3 GW
- Target (2040)
  160 GW
- Capacity needed
  92.7 GW
- Baseline total LCOE at target
  64.3 EUR/MWh
- Annual generation at target
  377.5 TWh/year
- Here: consider (with buffers) federal-state deployment corridors

Disamenity-aware siting raises cost potential curves

Results



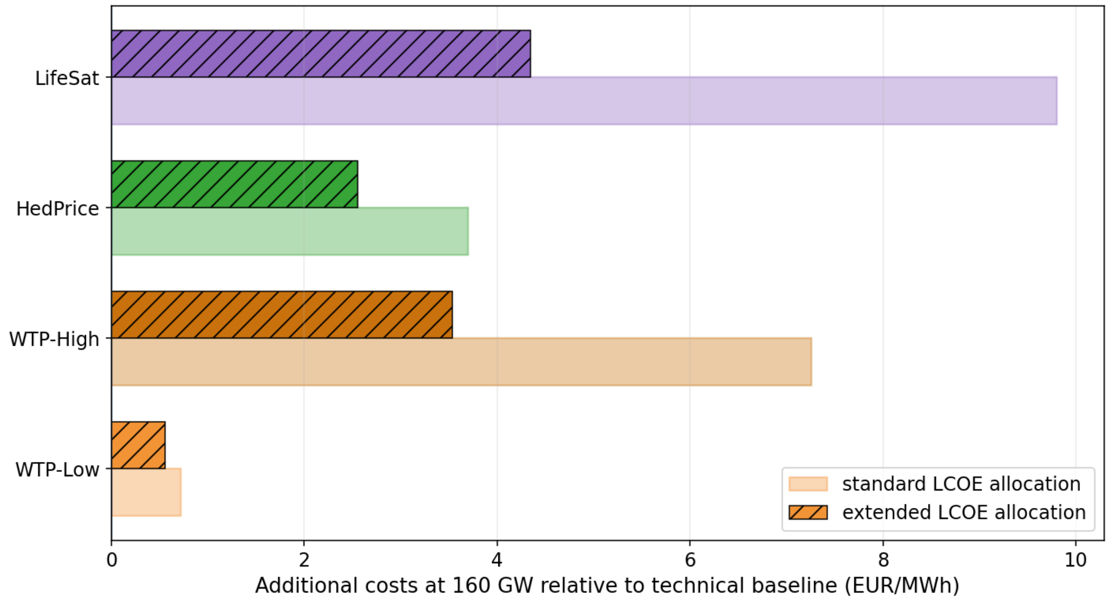
Total LCOE comparison under extended LCOE allocation

Model results at the 160 GW target under extended LCOE allocation. All LCOE values are in EUR/MWh and annual generation is in TWh/year

Model	Total LCOE	Premium vs. base	Relative Premium	Base component	Disamenity component	Annual generation
Base	64.3	0.0	0.0 %	64.3	0.0	377.5
WTP-Low	64.9	0.6	0.9 %	64.4	0.5	377.3
ExclSce	65.5	1.2	1.9 %	65.5	0.0	373.2
ExclPop	66.7	2.4	3.7 %	66.7	0.0	370.9
HedPrice	66.9	2.6	4.0 %	66.6	0.2	371.6
WTP-High	67.8	3.5	5.5 %	65.2	2.7	375.4
LifeSat	68.6	4.3	6.8 %	65.5	3.1	374.4

Internalizing disamenities lowers total LCOE

Results



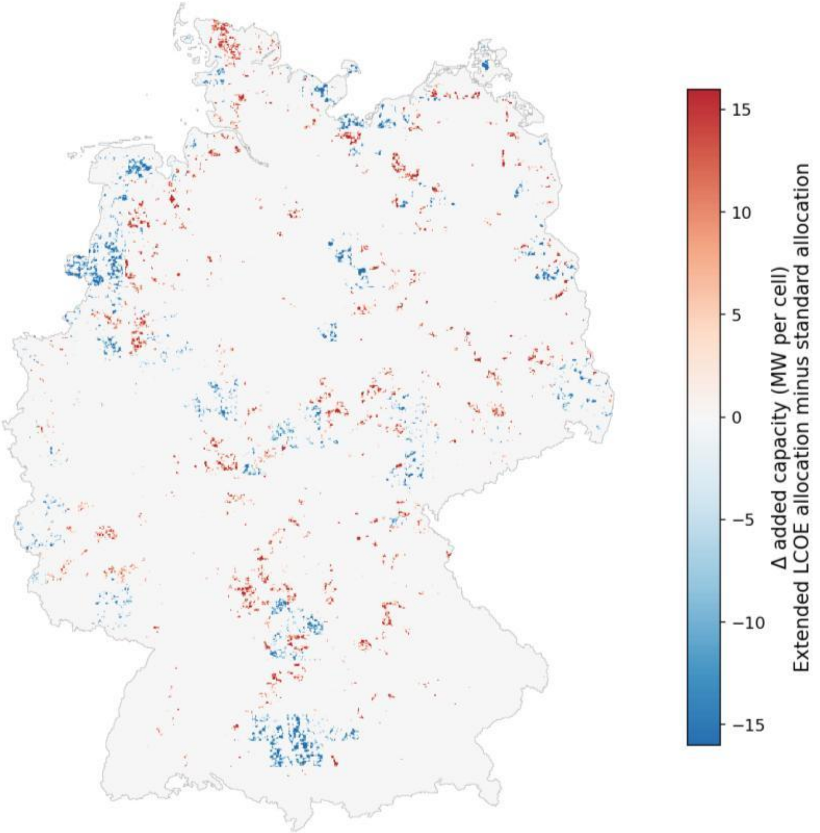
Allocation effects: Standard versus extended LCOE siting

- Mechanism: the model does not just pay a surcharge. It reallocates turbines.
- Key example: Hedonic price model
  - Base-only: 68.0 EUR/MWh
  - Total-LCOE: 66.9 EUR/MWh
  - Disamenity component falls from 3.7 to 0.2 EUR/MWh

  But
  - Technical component increases

Disamenity-aware siting changes where turbines are built

Results

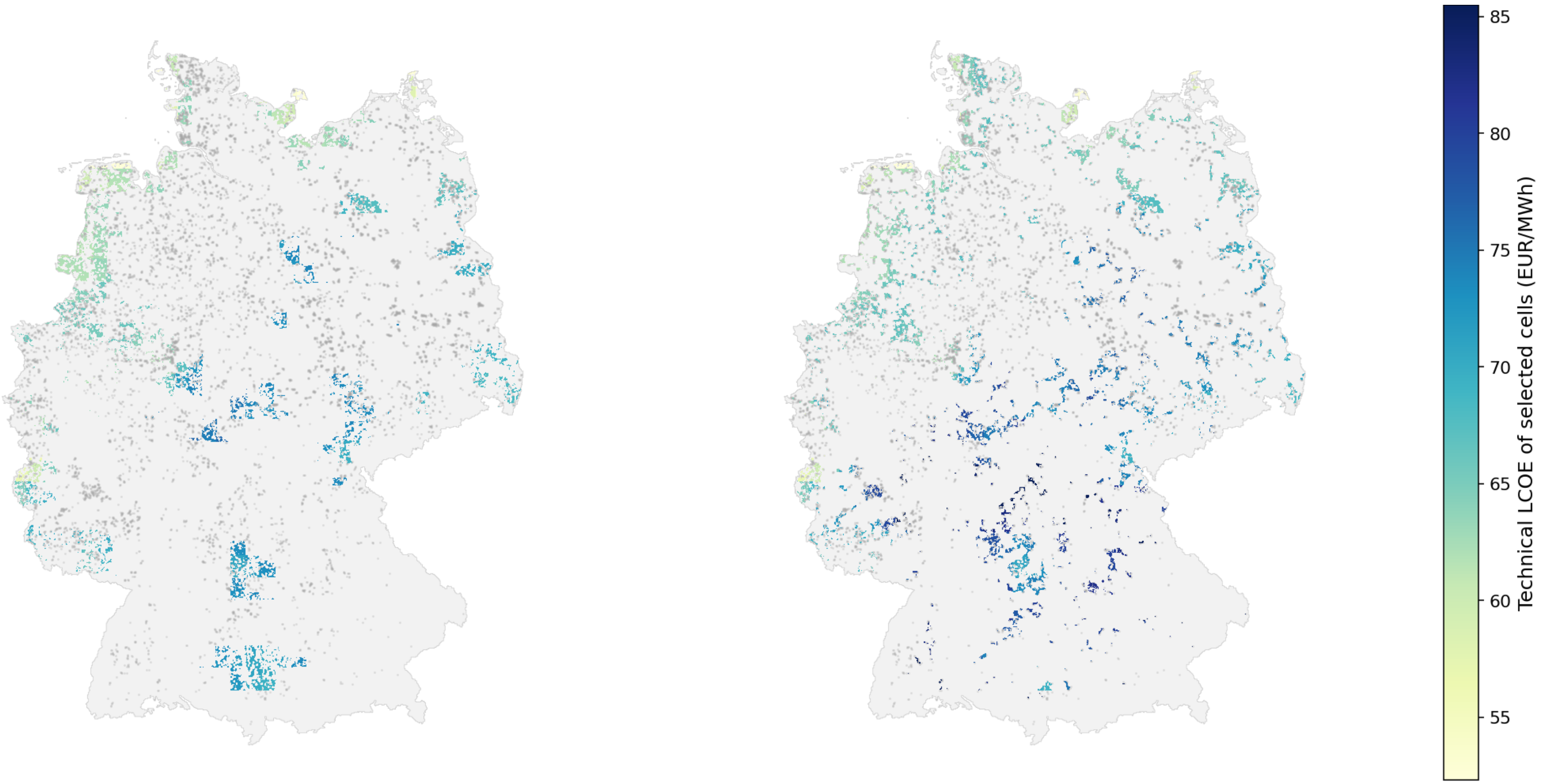


Cell-level difference in selected new-build capacity between HedPrice standard and extended allocation

- Blue: capacity avoided under disamenity-aware siting
- Red: substitute locations
- Same total deployment target
- Reallocation reduces property-value exposure

➢ The cost premium is not only a monetary adder, but also a spatial reallocation of the buildout path

Lower exposure comes with a technical cost penalty



Technical site-level LCOE of selected new-build locations under baseline (left) and disamenity-aware (hedonic property-price, right) siting. Grey dots symbolize existing wind turbines

- Reduced local exposure is achieved by accepting moderately higher technical site costs

Implications for energy-system models

Takeaways

1. Standard technical wind cost curves understate disamenity costs
2. Exclusion rules capture social acceptance only indirectly
3. Monetary disamenity adders allow siting trade-offs to be represented explicitly
4. Total-LCOE (“extended”) allocation is more relevant than pure ex-post accounting

Empirical disamenity evidence

↓

”model-ready“ cost adders/constraints

↓

Disamenity adjusted cost curves

↓

Capacity-expansion models

Conclusion

Takeaways

1. Local disamenities matter
   - At 160 GW, premiums range from 0.6 to 4.3 EUR/MWh
   - Ruhnau et al. (2022):„Disamenity costs are not a game changer“ (?)
2. Hedonic property-price model provides a central benchmark
   - Premium of 2.6 EUR/MWh, between low stated-preference and stronger welfare-cost estimates
   - Plausible model since it is based on empirical parameters (revealed preferences)
3. Siting changes the result
   - Internalizing disamenities reduces exposure but increases technical site costs

➢ **Onshore wind remains cost-effective, but its cost curve is steeper than a purely technical curve suggests**

Next steps

- Calculate own parameters, similar to Frondel et al. (2019) with more focus on
  - Recent Immoscout & turbine data
  - Higher differentiation between rural and urban areas (RegioStar classification)
  - Incorporating view axis (Sichtachsen)

Thank you for your attention!

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Backup A: LCOE and disamenity cost calculation

$$N_i^{\max} = \left\lfloor \frac{\max\left(\rho A_i^{pot} - K_i^{exist}, 0\right)}{P_i} \right\rfloor$$

$$D_i^{dis,WTP} = \sum_{j:d_{ij}<4} Pop_j \cdot \theta \cdot 3.6 \cdot \ln\left(\frac{4}{\max\left(d_{ij}, d_{min}\right)}\right)$$

$$AF(r,T) = \frac{1-(1+r)^{-T}}{r}$$

$$C_i^{dis,HedPrice} = \sum_j V_j \cdot \max\left(0, \lambda\left(d_{i,j}\right) - \lambda\left(d_j^{old}\right)\right)$$

$$C_i^{dis,LifeSat} = \sum_{j:d_{ij}<4} \kappa \cdot HH_j$$

$$LCOE_i^{base} = \frac{I_i + OM_i \cdot AF(r,T)}{G_i \cdot AF(r,T)}$$

$$LCOE_i^{tot} = \frac{C_i^{base} + C_i^{dis}}{G_i \cdot AF(r,T)}$$

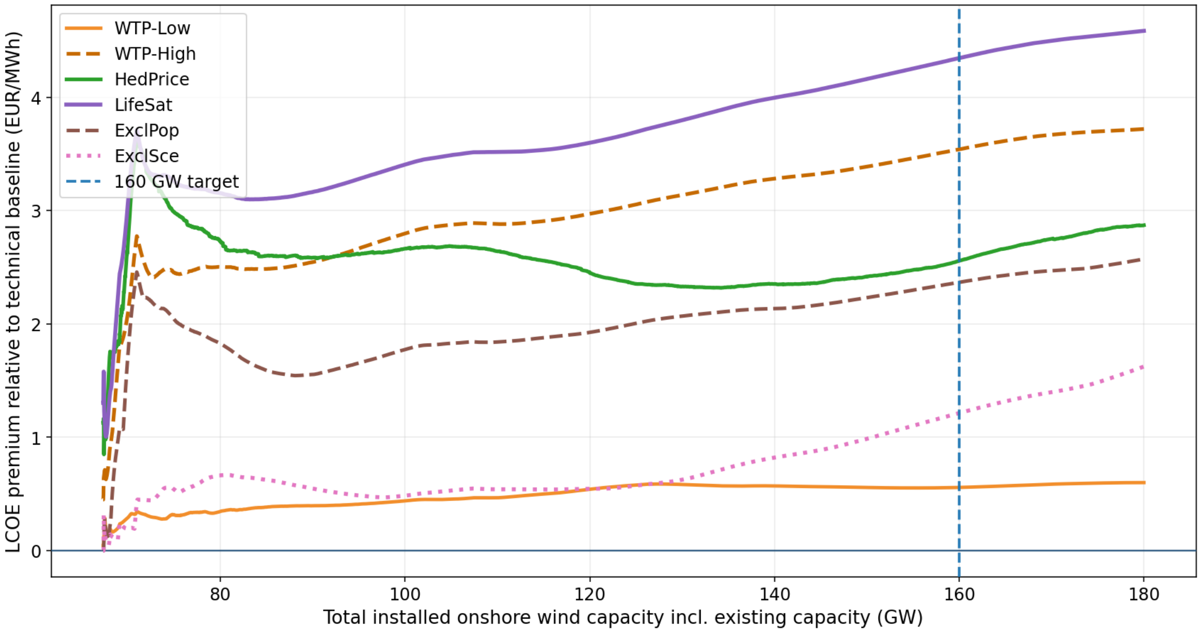
$$LCOE_q^{total} = \frac{\sum_{q=1}^{Q}\left(C_{i(q)}^{base} + C_{i(q)}^{dis}\right)}{\sum_{q=1}^{Q} G_{i(q)} \cdot AF(r,T)}$$

Backup B: Model specifications

Parameter	Symbol	Value	Role in the model
Spatial resolution	-	1 km × 1 km	Basic unit for turbine allocation and population/property exposure
Maximum wind capacity density	ρ	25 MW/km²	Converts eligible land area into gross technical potential
Existing turbine proxy	-	2.5 MW/turbine	Used where existing turbine counts must be approximated
Project lifetime	T	20 years	Used for present-value cost and generation calculations
Discount rate / WACC	r	6 %	Used to discount annual costs and generation
Fixed O&M	OM_i	2.5 % of I_i per year	Annual fixed operating cost assumption
Investment costs	I_i	Capacity (low-wind: 4,000 kW, high-wind: 4,500 kW) x CAPEX (low-wind: 1,573 EUR/kW and high-wind 1,363 EUR/kW)	Determines turbine investment costs
Total onshore wind target	-	160 GW	Target total capacity including existing capacity
State target corridot	-	+50 % upper corridor	Allows discrete turbine allocation around federal-state targets
Allocation unit	-	One turbine	Greedy algorithm places turbines discretely

Backup C: LCOE-premiums relative to technical baseline

Backup

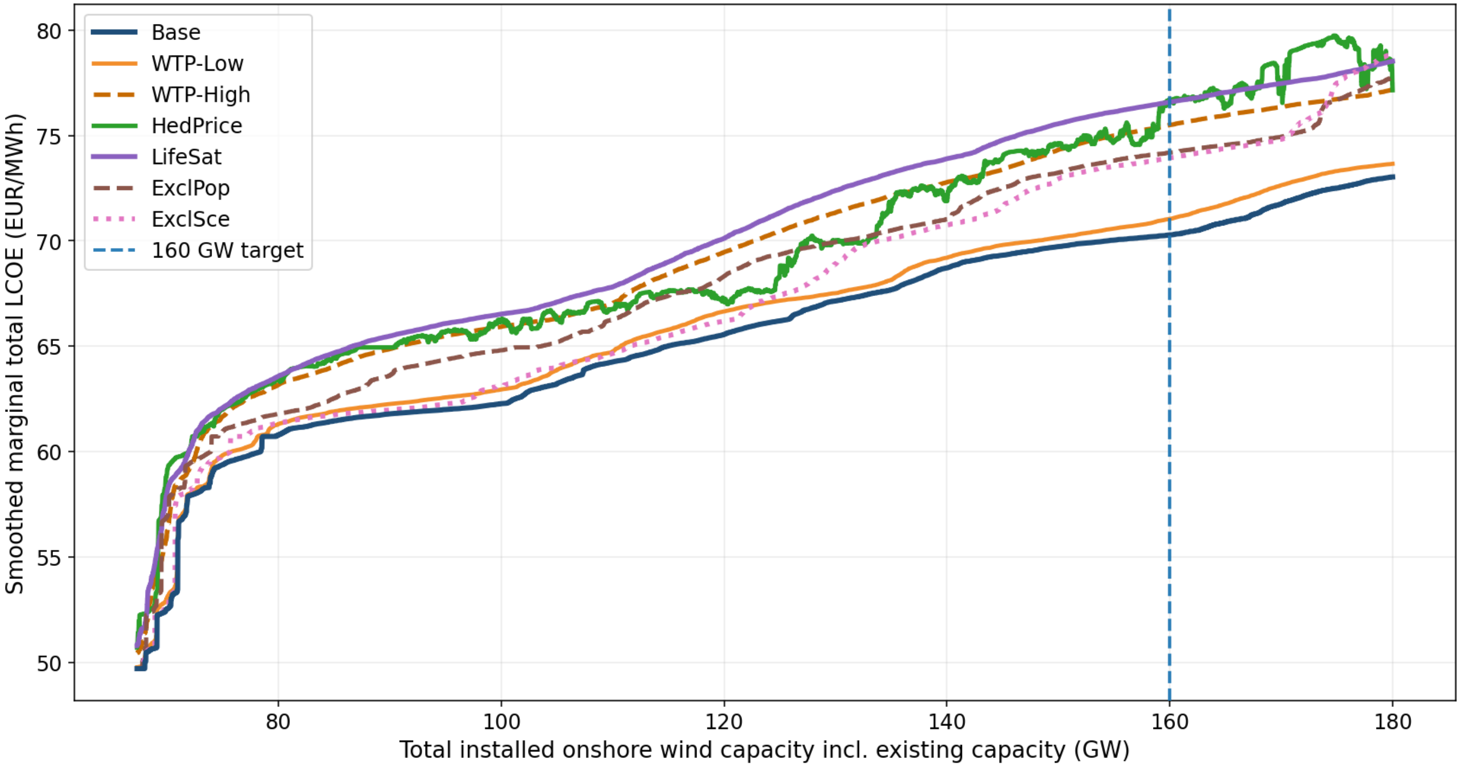


Disamenity cost LCOE-premium relative to the technical baseline

- „Jumps“
  - The premium is a cumulative average relative to the baseline, not a marginal cost measure
  - Early in the buildout, only few new turbines are included, so single placements can strongly affect the average
  - Turbine placement is discrete and spatially lumpy: one site may affect many residents, high-value properties, or nearest-turbine exposure
  - Total-LCOE allocation minimizes the absolute total cost of each candidate, not the premium relative to the technical baseline
  - Federal-state deployment corridors can amplify early variation by restricting where capacity is initially placed
  - These spikes should therefore not be overinterpreted; the main comparison is the 160 GW target

Backup D: Marginal cost dynamics

Backup



Marginal cost dynamics under total-LCOE allocation

Backup E: Federal-state targets

Gesetz zur Festlegung von Flächenbedarfen und zur Genehmigungserleichterung für Windenergieanlagen an Land und für Anlagen zur Speicherung vom Strom oder Wärme aus erneuerbaren Energien in bestimmten Gebieten (Windenergieflächenbedarfsgesetz - WindBG)
Anlage (zu § 3 Absatz 1)
Flächenbeitragswerte

(Fundstelle: BGBl. I 2022, 1356)

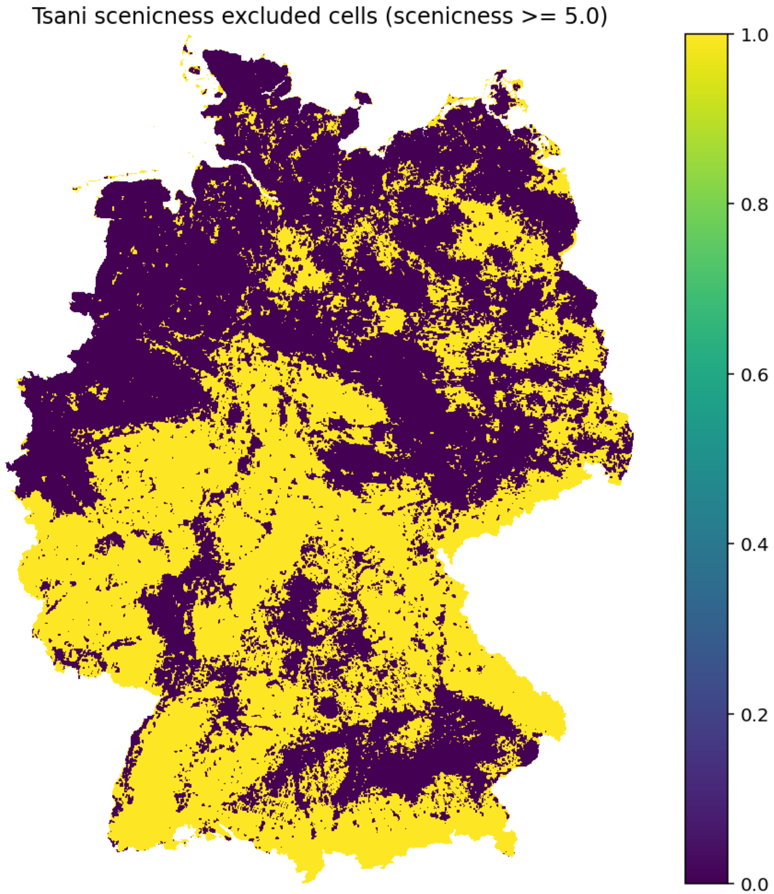
Bundesland	Spalte 1: Flächenbeitragswert, der bis zum 31. Dezember 2027 zu erreichen ist (Anteil der Landesfläche in Prozent)[1]	Spalte 2: Flächenbeitragswert, der bis zum 31. Dezember 2032 zu erreichen ist (Anteil der Landesfläche in Prozent)[1]	Spalte 3: Landesflächen (in km^2)[2]
Baden-Württemberg	1,1	1,8	35 747,82
Bayern	1,1	1,8	70 541,57
Berlin	0,25	0,50	891,12
Brandenburg	1,8	2,2	29 654,35
Bremen	0,25	0,50	419,62
Hamburg	0,25	0,50	755,09
Hessen	1,8	2,2	21 115,64
Mecklenburg-Vorpommern	1,4	2,1	23 295,45
Niedersachsen	1,7	2,2	47 709,82
Nordrhein-Westfalen	1,1	1,8	34 112,44
Rheinland-Pfalz	1,4	2,2	19 858,00
Saarland	1,1	1,8	2 571,11
Sachsen	1,3	2,0	18 449,93
Sachsen-Anhalt	1,8	2,2	20 459,12
Schleswig-Holstein	1,3	2,0	15 804,30
Thüringen	1,8	2,2	16 202,39

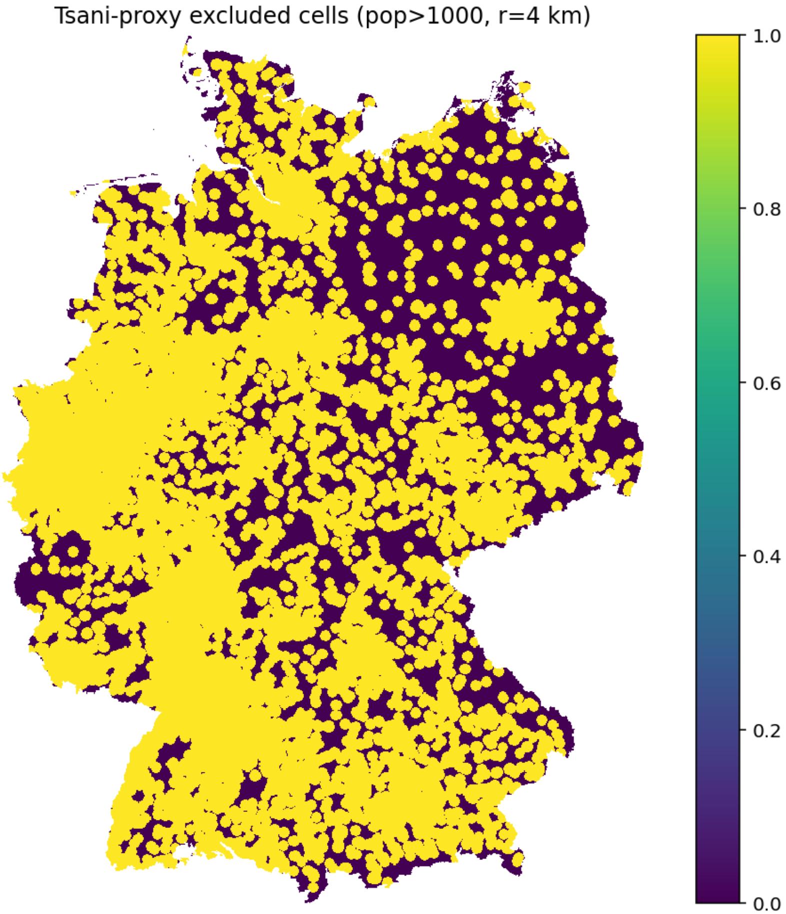
1 In den Fällen des § 3 Absatz 4 ersetzen die durch Landesrecht erhöhten Flächenbeitragswerte und vorgezogenen Stichtage die entsprechenden in den Spalten 1 und 2 genannten Flächenbeitragswerte und Stichtage.

2 Quelle: Statistisches Bundesamt, Daten aus dem Gemeindeverzeichnis: Bundesländer mit Hauptstädten nach Fläche, Bevölkerung und Bevölkerungsdichte, Gebietsstand: 31.12.2020, Erscheinungsmonat: September 2021.

Backup F: Map of exclusion criteria

Backup





Backup G: Turbine specifications

Backup

- The model uses a mix of a low-wind turbine and a strong-wind turbine following Pöstges and Weber (2023). The turbine mix is assigned based on local wind conditions, with interpolation between the lower and upper wind-speed thresholds used in the model.

Parameter	Low-wind turbine	Strong-wind turbine
Turbine type	turbineType6	turbineType7
Wind class	low	strong
Hub height	150 m	120 m
Rotor diameter	140 m	124 m
Rated capacity	4.0 MW	4.5 MW
CAPEX	1,573 EUR/kW	1,363 EUR/kW