UNIVERSITÄT LEIPZIG

UFZ HELMHOLTZ Centre for Environmental Research

WIND POWER DEVELOPMENT IN GERMANY: INTERACTION AND TRADE-OFFS OF SPATIAL PLANNING INSTRUMENTS

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IEWT 2023

16th February 2023

OUTLINE

- **Motivation**
- Research questions & innovation
- Data and method
- Policy scenarios & analytical approach
- Preliminary results
- Conclusion

MOTIVATION

- Onshore **wind power** as **key technology** to decarbonize electricity production

- Negative **environmental effects** of wind turbines on people and nature (Zerrahn, 2017)

  Examples

  - Audio-visual disamenities for residents
  - Threat for wind power sensitive bird and bat species

- **Regulation of environmental effects** usually through **spatial planning policies**:

Exclusion of areas for wind power development

But multiple regulations can interact and imply trade-offs

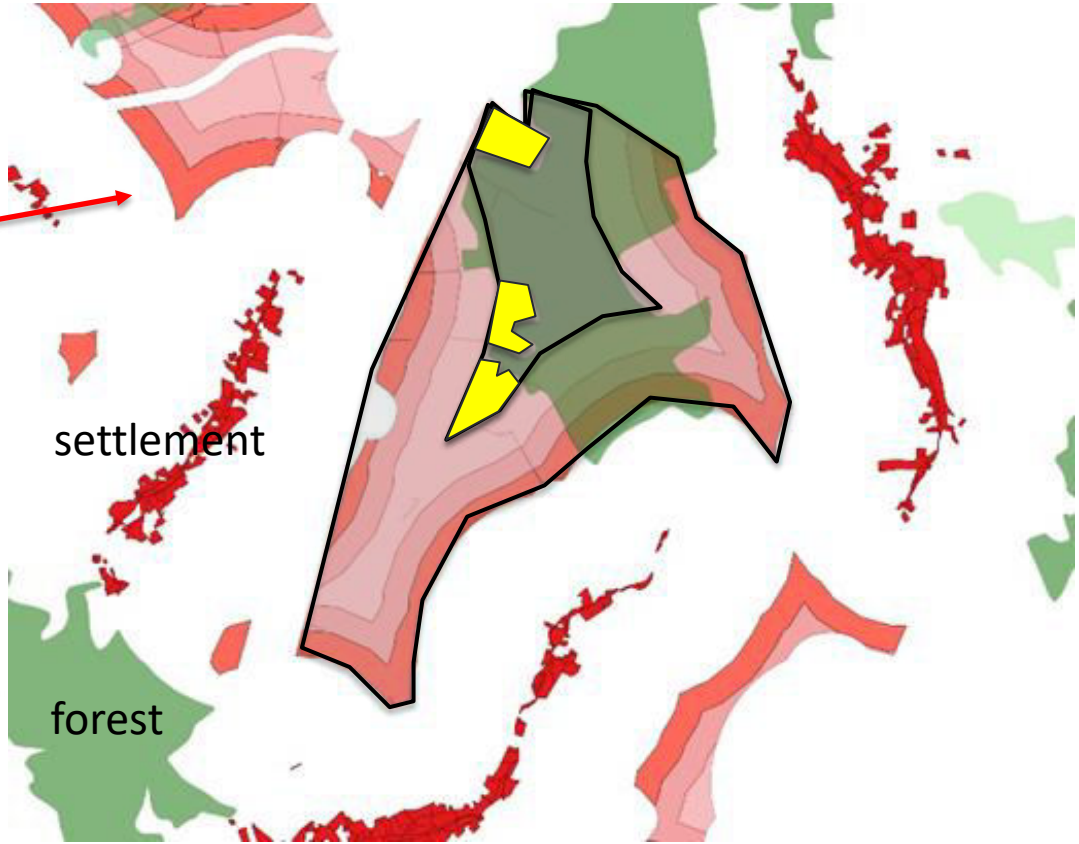
MOTIVATION

Exemplification of possible interaction:

setback distances
of potential sites to settlements

and

forest bans



MOTIVATION

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RESEARCH QUESTIONS

- Regulating individual negative environmental externalities from onshore wind power with **spatial planning policies** (area exclusions) increases **costs** caused by **other environmental externalities**
  → **Externality trade-offs**

- Regulating several negative environmental externalities with **several spatial planning policies** (multiple area exclusions) may **decrease the generation potential** from wind power considerably
  → **Generation potential trade-off**

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- Lessons to learn

DATA & METHOD I

Multicriteria GIS-based approach:

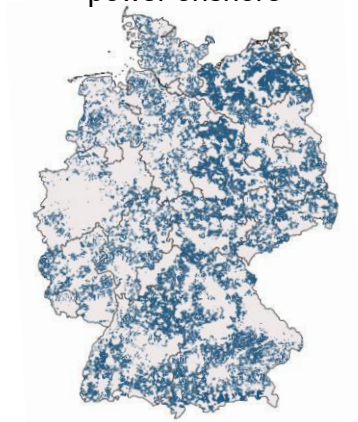
Step 1: Identification of potential areas for onshore wind power development

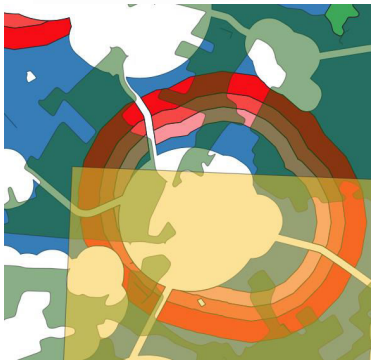
- naturally, technically and legally suitable areas for wind power production in **Germany** (Masurowski, 2016)
- three types of reference wind turbines IEC 61400 (4,2MW - 5,7MW)
- assumption power density: 20 MW/km² (Enevoldsen and Jacobson, 2021)

Step 2: Assess potential areas with respect to **two** criteria

- **Forest** – data: Corine Land Cover
- **setback distances** – data: settlements from ATKIS
- (inclusion of further criteria (species protection) in progress)

Potential areas for wind power onshore





Potential areas assessed with respect to diverse criteria

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SPATIAL PLANNING SCENARIOS

Reference scenario: no area exclusions

- Forest ban (FB)
- Setback distances to settlements *
  - 1000m (SB1000)
  - 1500m (SB1500)
  - 2000m (SB2000)

Potential areas assessed with respect to criteria

- Combinations of these spatial planning instruments
  - E.g. Forest ban and setback distance 1000m (FB_SB1000)

* default minimum setback distance: 800m

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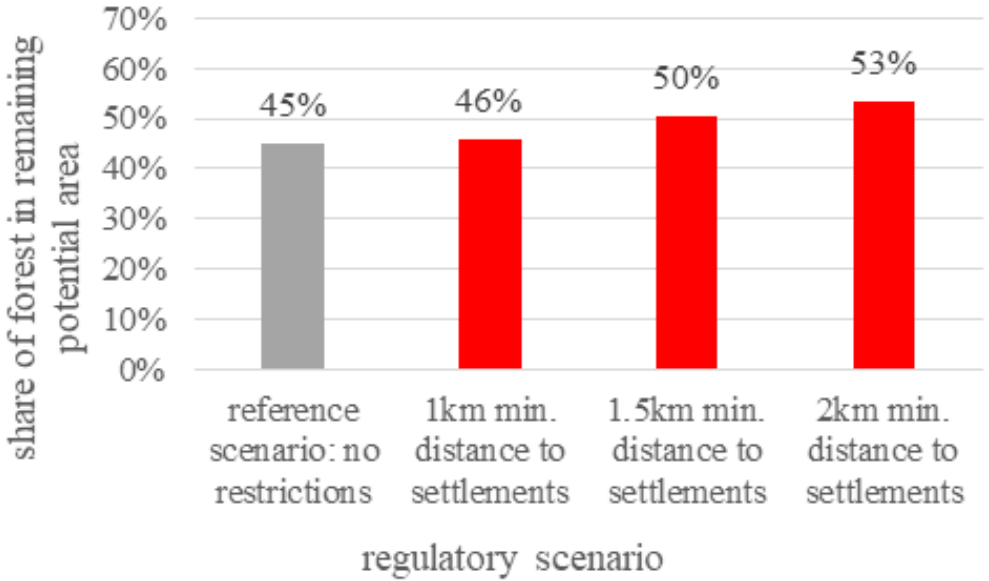
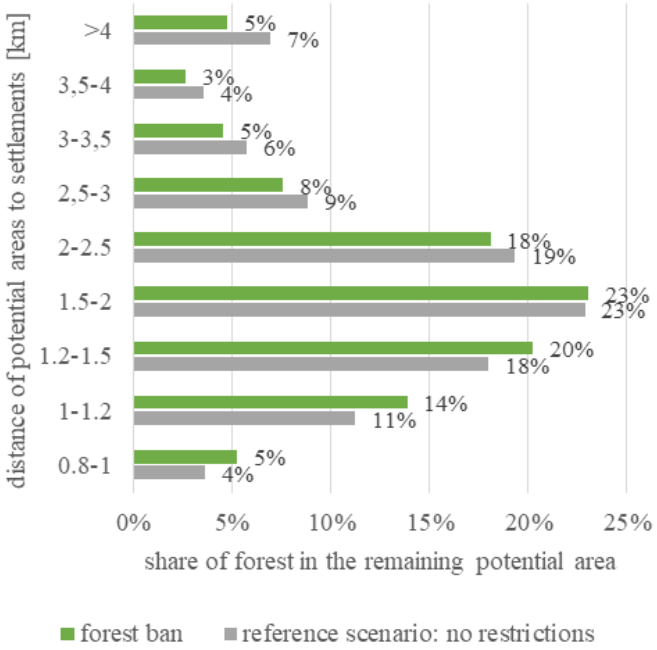
PRELIMINARY RESULTS I

- Indication of potential **Externality trade-off**
  - Increased setback distances from settlements increase the share of forest on the remaining potential areas - and vice versa - the exclusion of forests reduces the distance to settlements.



PRELIMINARY RESULTS II

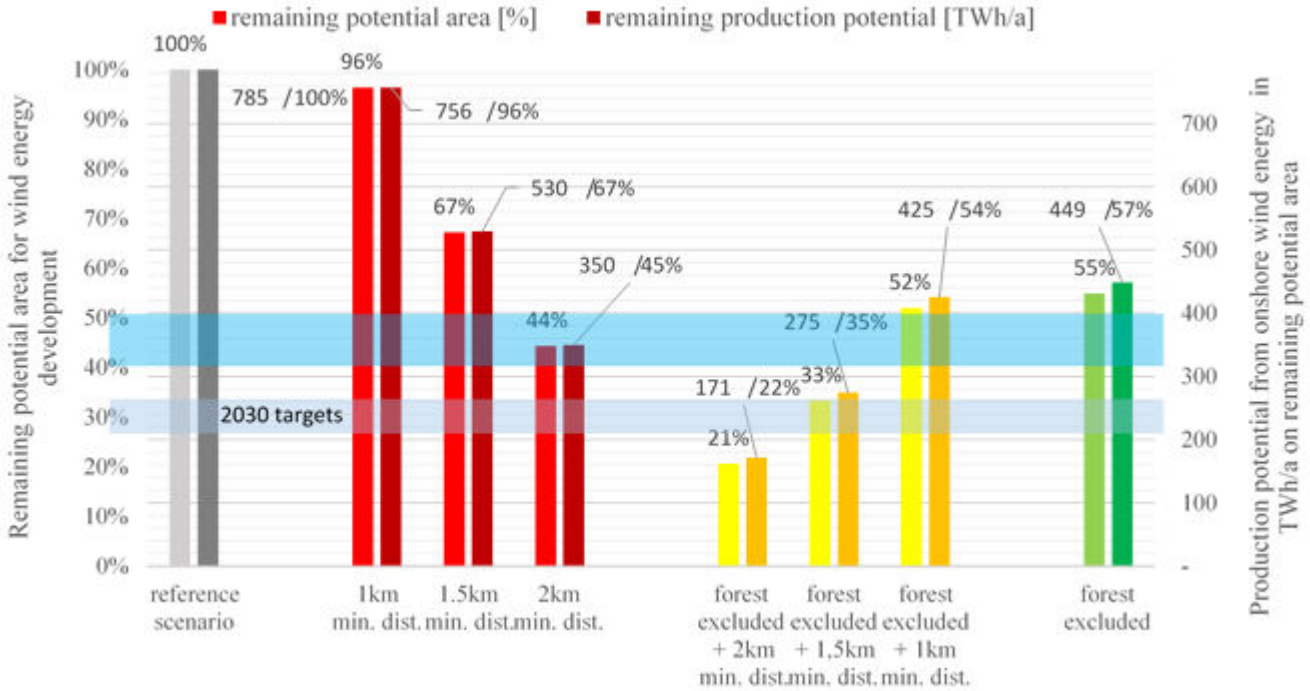
- Interdependancy of potential area characteristics
  - potential areas move closer to settlement areas if a forest ban is imposed



Regulatory scenario	Relative change in potential area	Relative change in area type			
		Forest area	*0.8-1km dist. to settlements*	*1-1.5km dist. to settlements*	*1.5-2km dist. to settlements*
Reference scenario	0%	0%	0%	0%	0%
Forest ban	-45%	- 100%	-20%	-36%	-45%
1km min. dist. to settlements	-4%	-2%	-100%	0%	0%
1.5km min. dist. To settlements	-33%	-25%	-100%	-100%	0%
2km min. dist. to settlements	-56%	-48%	-100%	-100%	-100%

PRELIMINARY RESULTS IV

Generation potential trade-off



Generation target for onshore wind: **200 TWh/a**

- Reachable for all singular spatial planning policies
- Some combinations of spatial planning policies do not allow to achieve the set generation targets!

OUTLINE

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CONCLUSION

Spatial planning policies to address environmental externalities from wind turbines can cause

- **Regulatory interactions and potential externality trade-offs**
  - Exclusion of forests reduces distances to settlements on average, while high setback distances from settlements increase the share of forest on the remaining potential areas.

- **Generation potential trade-off**
  - Generation target of 200 TWh/a and beyond for 2040 cannot be reached for all of the spatial planning policies that combine multiple restriction, even under optimistic circumstances (MW/km², land availability, local restrictions, etc.)

Policy makers must be aware of possible interactions and implications of commonly applied spatial planning policies

THANK YOU FOR YOUR ATTENTION!

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LEARN MORE about our reseach group

- Tafarte, P., Lehmann, P. (2021). “Trade-offs associated with the spatial allocation of future onshore wind generation capacity – A case study for Germany”. *UFZ Discussion Paper 2/2021*.
- Lehmann, P., Reutter, F., Tafarte, P. (2021). “Optimal siting of onshore wind turbines: Local disamenities matter”. *UFZ Discussion Paper 4/2021*.
- Lehmann, P. et al. (2021). „Managing spatial sustainability trade-offs: The case of wind power“. *Ecological Economics* 185, Article 107029.
- Reutter, F. et al. (2022). „Flächenziele für die Windenergie: Wie zielführend ist das neue Wind-an-Land-Gesetz?“. Wirtschaftsdienst, 2022, 102(9), 703-708

- Our serious game on allocating wind power in Germany can also be played online.
  Website: https://home.uni-leipzig.de/multiplee/index.php/home-en/

LESSON TO LEARN

Policy instruments and implementation should be checked to a much larger extent possible trade-offs:

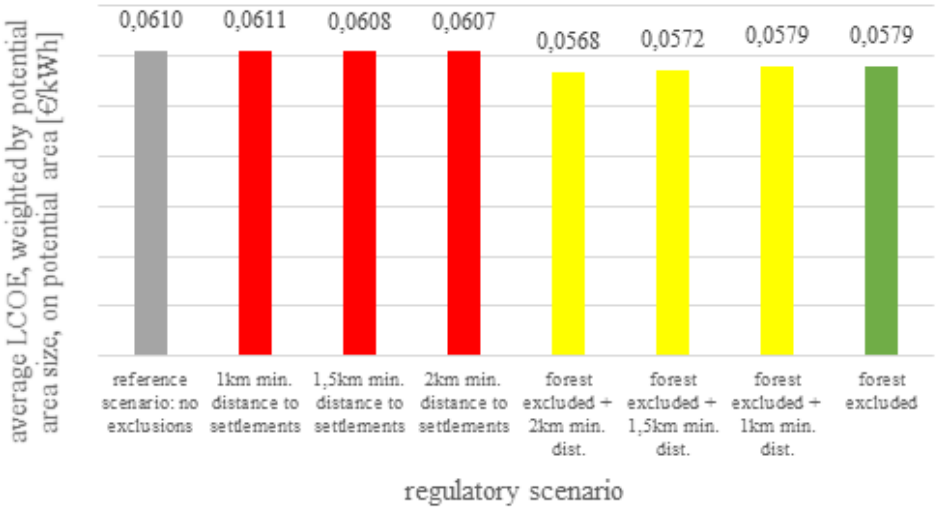
- How do policy instruments and their implementation interact with other policies across all relevant sectors (here protective goods for residents and nature protection in the presence of trade-offs)
- and across administrative levels (regional to state to national state levels)
- Effect overall policy goals (capacity expansion targets for renewables)

- For the case of Germany, many new legislative acts by the national government are now correcting strict regulations by the federal states with regard to spatial planning, forest bans and increased setback distances.
- However, it remains questionable if the increased expansion targets for 2030 can be met as many measures take years to result in new added capacities..
- Similar negative interferences among regulation in other fields:
  - prices caps and endogenious rationing for renewables auctions in the face of insufficient project volumes?

PRELIMINARY RESULTS III

Interdependancy of potential area characteristics

- average generation cost (LCOE) show minor variations, presumably due to regional variations in share of forests and spatial correlation with wind speeds.



→ no indication of significant interaction with least cost regulatory approch from tenders

DISCUSSION & NEXT STEPS

- Results may depend on
  - Assumptions regarding **production target** or **power density** of wind turbines (20 MW/km^2)
  - Further relevant restrictions (local hurdels for wind power (environmental/cultural heritage hurdles), land availability)

→ Next step:

- → Inclusion of zoning restrictions for wind power sensitive bird species
- → overall sensitivity analysis

Analytical approach

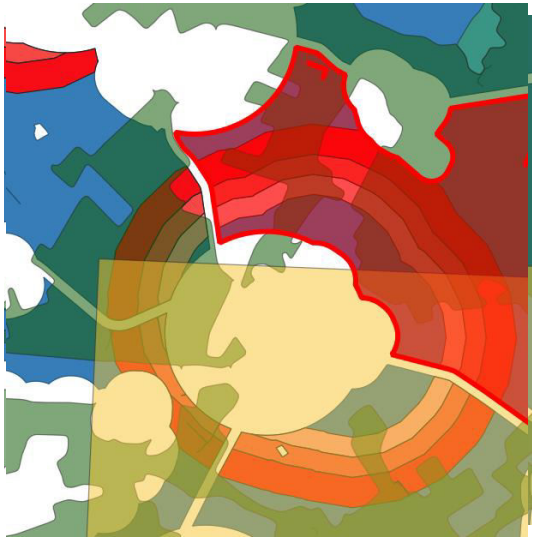
1. Generation target for onshore wind power development: **200 TWh/a**

2. Pick potential areas until the target is reached

- Picking process: **Minimization of generation costs** (LCOE)
  - Three types of reference wind turbines (4,2MW / 5,7MW / 5,5MW)
  - Assumption power density: 20 MW/km^2 (Enevoldsen and Jacobson, 2021)

3. Assess **picked potential** areas with respect to the four criteria

- **Identify trade-offs or synergies between the criteria for the different spatial planning scenarios**



Potential areas assessed with respect to criteria

DATA AND METHODS SUPPLEMENT

– modelled wind turbines types

Wind turbine types			
	Turbine Type	***Hub height***	***Nominal capacity***
IEC wind class I	Enercon E-115 4.2MW EP3 E4	92 m	4.2 MW
IEC wind class II	Nordex N149/5.7	125.4 m	5.7 MW
IEC wind class III	Enercon E-160 5.5MW EP5 E2	166 m	5.5 MW

Literature

CLC 2022 – CORINE Land Cover, European Commission – Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG-GROW). Available at: https://land.copernicus.eu/pan-european/corine-land-cover

Diffendorfer J. E., J. C. Stanton, J. A. Beston, W. E. Thogmartin, S. R. Loss, T. E. Katzner, D. H. Johnson, R. A. Erickson, M. D. Merrill, and M. D. Corum. 2021. Demographic and potential biological removal models identify raptor species sensitive to current and future wind energy. *Ecosphere*. 12(6):e03531.

Enevoldsen P. and Jacobson M. Z., 2021, Data investigation of installed and output power densities of onshore and offshore wind turbines worldwide, *Energy for Sustainable Development*, 60, 40-51.

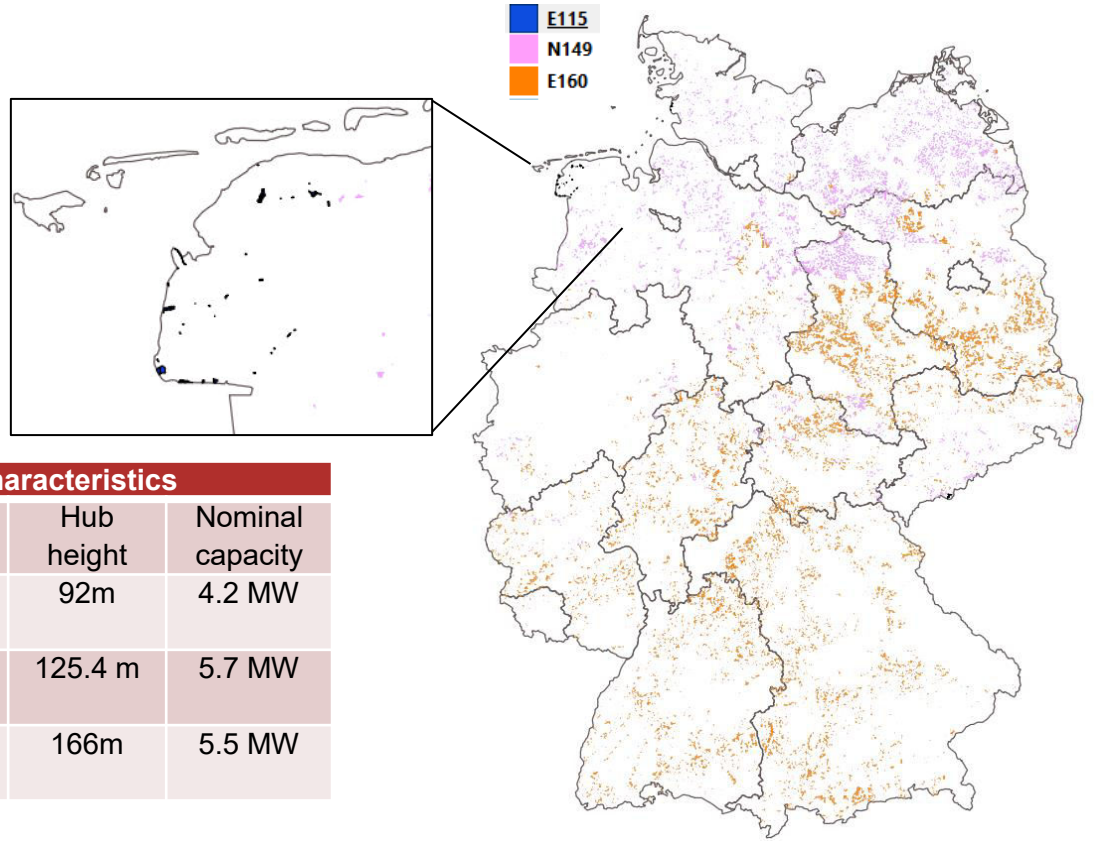
Masurowski, Frank. 2016. Eine deutschlandweite Potenzialanalyse für die Onshore – Windenergie mittels GIS einschließlich der Bewertung von Siedlungsdistanzenänderungen.

Nagel H., Nicolai B., Mammen U., Fischer S., Kolbe M. 2018. Verantwortungsart Rotmilan – Ermittlung von Dichtezentren des Greifvogels in Sachsen-Anhalt. *Naturschutz und Landschaftsplanung*. 51(1). 14-19.

Zerrahn A., 2017, Wind Power and Externalities, *Ecological Economics*, 141, 245-260.

WIND TURBINES TYPES

- turbine types attributed to the potential areas based on IEC wind climate classification



IEC wind classification	Wind turbine characteristics		
	Turbine type	Hub height	Nominal capacity
class I	Enercon E-115 4.2MW EP3 E4	92m	4.2 MW
class II	Nordex N 149/5.7	125.4 m	5.7 MW
class III	Enercon E-160 5.5MW EP5 E2	166m	5.5 MW

PAPER 2: SPECIES PROTECTION CRITERION

Wind power sensitive species selected for the species protection indicator

- Black kite
- Black stork
- Lesser spotted eagle
- Marsh harrier
- Montagu‘s harrier
- Osprey
- Pern
- Red kite
- White-tailed eagle

- Additions for sensitivity analysis
  - Eagle owl
  - Tree falcon
  - White stork

- List based on Reichenbach and Aussieker (2021)
  - All species with a mortality-endangerment-index I or II (Bernotat and Dierschke, 2016)
  - + black stork

DENSITY AREAS APPROACH

Density threshold: 150% of average population density

Species	averge population density [BP/TK]	150% average population density [BP/TK]	ADEBAR-TK selection [min. BP/TK]	population ratio in density areas [% of BP]
black kite	3,44	5,16	5	**43**
black stork	1,37	2,05	2	**50**
eagle owl	1,94	2,90	3	**39**
lesser spotted eagle	1,81	2,72	3	**27**
marsh harrier	4,07	6,11	8	**52**
Montagu's harrier	2	3	3	**46**
osprey	2,11	3,16	3	**44**
pern	2,27	3,4	3	**46**
red kite	5,23	7,93	8	**67**
tree falcon	2,35	3,53	3	**50**
white stork	3,23	4,85	8	**40**
white-tailed eagle	1,49	2,23	2	**54**

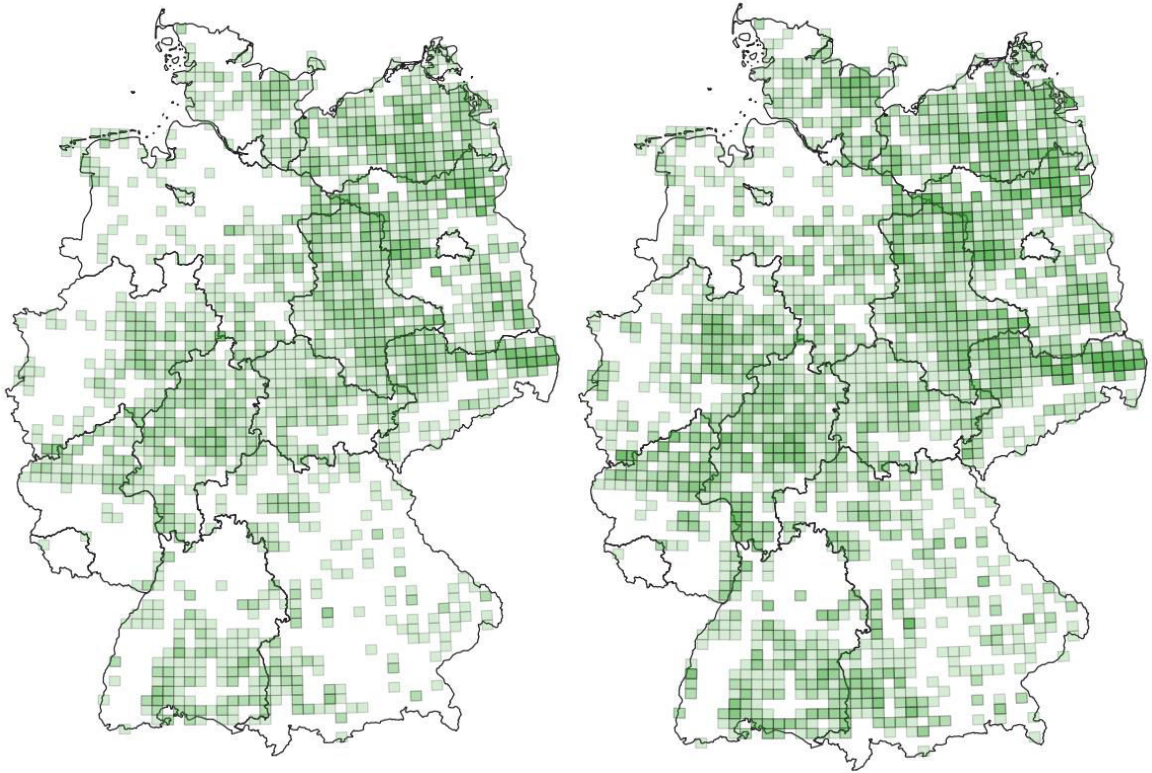
– Weak points of the approach

ADEBAR data only classified available → actual threshold cannot be implemented for some species

Heterogeneous spatia prevalence of species results in high differences between protected population ratios
→ Approach may not be suitable for all types of species

SENSITIVITY ANALYSIS FOR DENSITY AREAS APPROACH – MAPS 9 AND 12 SPECIES

Density areas approach 1 for 9 selected species
- 47% area of Germany
- 59% of potential areas



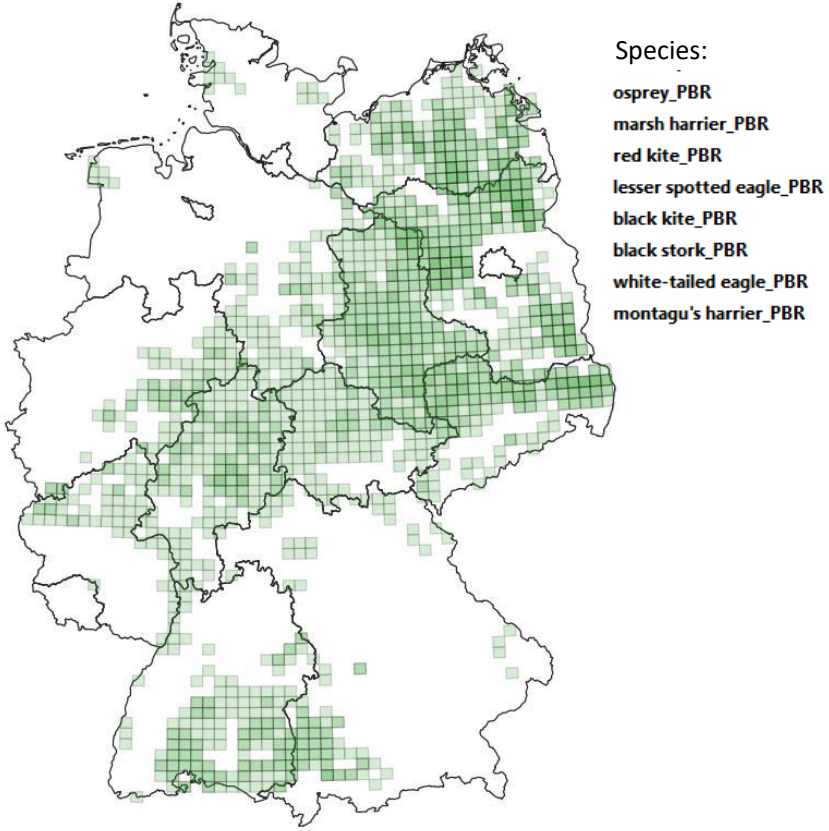
Density areas approach 1 for 12 selected species
- 55% area of Germany
- 66% of potential areas

DENSITY AREAS: APPROACH 2

- Goal: Protection of density areas guarantee **healthy source population**

- Density threshold:
  - select areas until x% of population within density area
  - x is **species specific**, e.g. black stork min. 22% in density areas
  - Based on Diffendorfer et al. (2021)

- Approach used in Thuringia for different species (x=20%)



Density areas for 8 species (=39% area of Germany)

DENSITY AREAS: APPROACH 2

Specific ratio of population (x%) protected in density areas

- Based on „potential biological removal (PBR)“ approach
  - PBR represents „take limit“ to secure an optimal population size
  - Remainder of the population needs to be protected from anthropogenic mortality
  - Reduced by population ration of special protection areas (SPAs)
  - Reduced by fixed population ratio

- Not all individuals outside of density areas are subject to collisions with wind turbines
- Other causes for anthropogenic mortality than wind turbines

Difficulties of the approach

- Data availability regarding parameters for PBR calculation
- Spatial resolution: 11x11 km^2

DENSITY AREAS: APPROACH 2

PBR values and ratio of species protected in density areas (x%):

Species	Potential biological removal (PBR)	Percentage outside of special protection areas (SPAs)	Percentage of population protected in density areas
Baumfalke	80	NA	NA
Fischadler	105,5	62,5	22%
Rohrweihe	106	75	26%
Rotmilan	95	77	27%
Schreiadler	92,5	19,5	7%
Schwarzmilan	96	69	24%
Schwarzstorch	86	62	22%
Seeadler	59	20	7%
Uhu	69	53	19%
Weissstorch	0	-27	-9%
Wespenbussard	130	NA	NA
Wiesenweihe	81,5	23,5	8%

SELECTION OF POTENTIAL AREAS (MASUROWSKI 2016) – BASIC AREAS

Tab. 3.2: Ausgewählte Landschaftsflächentypen als Grundlage für die Potenzialflächenberechnung.

Flächentyp[1]	Inhalte[2]
Halde, Aufschüttung	Flächen auf der aufgeschüttetes Material langfristig gelagert wird
Ackerland	Flächen für den Anbau von Feldfrüchten
Grünland	Gras- und Rasenflächen die gemäht oder beweidet werden
Heide	meist sandige Flächen mit typischen Sträuchern, Gräsern und geringwertigen Baumbestand
Wald, Forst	Flächen die mit Forstpflanzen (Waldbäume und Waldsträucher) bestockt sind
Gehölz	Flächen die mit einzelnen Bäumen, Baumgruppen, Büschen, Hecken und Sträuchern bestockt sind
vegetationslose Flächen	Flächen ohne nennenswerten Bewuchs aufgrund besonderer Bodenbeschaffenheit (z.B. aus dem Geländerelief herausragende Felspartien, Sand- oder Eisflächen)

[1] Quelle: ATKIS Basis-DLM (Tabelle: 3.1) [2] Quelle: [AdV-Arbeitsgruppe ATKIS 2003]

SELECTION OF POTENTIAL AREAS (MASUROWSKI 2016) – RESTRICTED AREAS AND BUFFER ZONES

Ausschlusselement[1]	Inhalt[2]	Regelquelle	Regelung[3]	Maßnahme[4]
Wohnbaufläche	reine Wohngebiete, Wohngebiete/Kleinsiedlungsanlagen, Versorgung der Fläche dienende Läden, nicht störende Handwerksbetriebe, Einrichtungen für kirchliche, kulturelle, soziale und gesundheitliche Zwecke	TA Lärm[5] Abschn. 6	35 db(A) (nachts)	1000 m Abstand
Industrie- und Gewerbeflächen	Gewerbe- und Industriebetriebe, Einkaufszentren, Lager/Depots, Ver- und Entsorgungsbetriebe, Messeeinrichtungen	TA Lärm Abschn. 6	50 db(A) (nachts)	180 m Abstand
Flächen gemischter Nutzung	Mischgebiete ohne eine klare Zuordnung zu einem bestimmten Flächentyp	TA Lärm Abschn. 6	45 dB(A) (nachts)	320 m Abstand
Flächen besonderer funktionaler Prägung	Verwaltung, Gesundheit und Soziales, Bildung, Forschung, Kultur, Sicherheit und Ordnung, Wochenend- und Ferienhausbebauung, Landesverteidigung	TA Lärm Abschn. 6	35 dB(A) (nachts)	1000 m Abstand
Siedlungsfreiflächen	Flächen die hauptsächlich der Erholung und sportlichen Betätigung dienen (z.B. Grünanlagen, Sportplätzen, Schwimmbädern, Freizeitparks, Friedhöfe u.s.w.)	keine	keine	Tabufläche
Talsperren	Anlagen zur Anhebung des Wasserspiegels	keine	keine	Tabufläche
Uferbefestigungen	Anlagen zum Schutze des Ufers	keine	keine	Tabufläche
Boden-bewegungsgebiet	Gebiete in denen sich die oberen Erdschichten auf Grund verschiedener Einflüsse lage- oder höhenmäßig verändern	keine	keine	Tabufläche
Bruchfeld	durch Bergbau unterhöhltes Gebiet, das teilweise bereits eingebrochen ist oder sich in Absenkung befindet	keine	keine	Tabufläche
Truppenübungsplatz	Gelände zur militärischen Ausbildung	keine	keine	Tabufläche
Testgelände	Gebiete zur Erprobung technischer Produkte	keine	keine	Tabufläche
ehem. militär. Sperrgebiete	keine Definition	keine	keine	Tabufläche
Denkmäler und archäologische Fundstätten[6]	Orte oder Bauwerke die eine kulturgeschichtliche Bedeutung aufweisen	keine	5 m Sicher-heitsab-stand	5 m Abstand
Rohrleitungen und Bandstraßen[7]	Bauwerke zum Transport von Flüssigkeiten, Gasen und sonstigen Gütern	keine	4 m Sicher-heitsab-stand	4 m Abstand

Results: Externality trade-offs – forest ban (FB)

200 TWh/a; 20 MW/km2

Criteria		reference scenario		forest ban (FB)	
		absolute criteria potential area [km2]	absolute criteria area used to reach target [km2]	absolute criteria area used to reach target [km2]	change in criteria area used to reach target relative to criteria area used in the reference scenario [%]
forest		6.752	823	-	-100%
density area 1.9		8.842	1.855	2.041	**10%**
distance to settlements [km]	0.8-1	535	140	173	**23%**
	1-1.2	1.681	324	382	**18%**
	1.2-1.5	2.693	512	567	**11%**
	1.5-2	3.428	710	699	**-2%**
	2-2.5	2.893	623	600	**-4%**
	2.5-3	1.315	292	283	**-3%**
	3-3.5	853	199	186	**-6%**
	3.5-4	529	130	117	**-10%**
	>4	1.037	258	227	**-12%**
average LCOE [€/kWh]			0,0488	0,0494	**1,26%**

Trade-offs between excluding forest areas and the selection of

- Density areas for wind power sensitive bird species (+10%)
- Distance of selected potential areas to settlements

No considerable change in average generation costs.

Results: Externality trade-offs – exclusion of density areas

200 TWh/a; 20 MW/km2

Criteria		reference scenario		density areas 1.9 excluded	
		absolute criteria potential area [km2]	absolute criteria area used to reach target [km2]	absolute criteria area used to reach target [km2]	change in criteria area used to reach target relative to criteria area used in the reference scenario [%]
forest		6.752	823	1.521	**85%**
density area 1,9		8.842	1.855	-	-100%
distance to settlements [km]	0.8-1	535	140	108	**-23%**
	1-1.2	1.681	324	361	**11%**
	1.2-1.5	2.693	512	586	**15%**
	1.5-2	3.428	710	765	**8%**
	2-2.5	2.893	623	651	**4%**
	2.5-3	1.315	292	313	**7%**
	3-3.5	853	289	204	**-29%**
	3.5-4	529	130	147	**13%**
	>4	1.037	258	295	**14%**
average LCOE [€/kWh]			0,0488	0,0526	**7,93%**

Trade-off between excluding density areas and the selection of

- Forest areas (+85%)

No unambiguous result for distance of selected potential areas to settlements.

Increase in average generation costs (~ + 8%).

Results: Externality trade-offs – 1500m setback distance

200 TWh/a; 20 MW/km2

Criteria		reference scenario		setback 1500m (SB1500)	
		absolute criteria potential area [km2]	absolute criteria area used to reach target [km2]	absolute criteria area used to reach target [km2]	change in criteria area used to reach target relative to criteria area used in the reference scenario [%]
forest		6.752	823	1.186	**44%**
density area 1.9		8.842	1.855	2.001	**8%**
distance to settlements [km]	0.8-1	535	140	-	-100%
	1-1.2	1.681	324	-	-100%
	1.2-1.5	2.693	512	-	-100%
	1.5-2	3.428	710	998	41%
	2-2.5	2.893	623	882	42%
	2.5-3	1.315	292	442	52%
	3-3.5	853	199	309	55%
	3.5-4	529	130	208	60%
	>4	1.037	258	414	60%
average LCOE [€/kWh]			0,0488	0,0496	**1,73%**

Trade-off between excluding areas within 1500m to settlements and

- Forest areas (+44%)
- Density areas (+8%)

No considerable change in average LCOE.

Results: Externality trade-offs – forest ban and 1500m setback distance

200 TWh/a; 20 MW/km2					
Criteria		reference scenario		forest ban and setback 1500 (FB_SB1500)	
		absolute criteria potential area [km2]	absolute criteria area used to reach target [km2]	absolute criteria area used to reach target [km2]	change in criteria area used to reach target relative to criteria area used in the reference scenario [%]
forest		6.752	823	-	-100%
density area 1.9		8.842	1.855	2.059	**11%**
distance to settlements [km]	0.8-1	535	140	-	-100%
	1-1.2	1.681	324	-	-100%
	1.2-1.5	2.693	512	-	-100%
	1.5-2	3.428	710	1.214	71%
	2-2.5	2.893	623	989	59%
	2.5-3	1.315	292	430	47%
	3-3.5	853	199	271	36%
	3.5-4	529	130	161	24%
	>4	1.037	258	302	17%
average LCOE [€/kWh]			0,0488	0,0516	**5,70%**

Trade-off between excluding in forests *and* areas within 1500m to settlements and

- Density areas (+11%)

Slight increase in average generation costs (~ +6%).

Results: Externality trade-off – exclusion of density areas and setback 1500m

200 TWh/a; 20 MW/km2

Criteria		reference scenario		s 1.9 excluded and setback 1500m (DAex	
		absolute criteria potential area [km2]	absolute criteria area used to reach target [km2]	absolute criteria area used to reach target [km2]	change in criteria area used to reach target relative to criteria area used in the reference scenario [%]
forest		6.752	823	2.153	**162%**
density area 1,9		8.842	1.855	-	-100%
distance to settlements [km]	0.8-1	535	140	-	-100%
	1-1.2	1.681	324	-	-100%
	1.2-1.5	2.693	512	-	-100%
	1.5-2	3.428	710	1.273	79%
	2-2.5	2.893	623	1.092	75%
	2.5-3	1.315	292	508	74%
	3-3.5	853	199	325	63%
	3.5-4	529	130	216	67%
	>4	1.037	258	408	58%
average LCOE [€/kWh]			0,0488	0,0588	**20,59%**

Trade-off between excluding density areas *and* areas within 1500m to settlements and

- Forest areas (+162%)

Strong increase in average generation costs (~ +20%).