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Trade-offs Associated with the Spatial Allocation of Future Onshore Wind Generation Capacity – a Case Study for Germany

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Agenda

- Background
- Trade-offs among sustainability criteria
- Model
- Preliminary results
- Conclusion

Background

- Expansion of renewable energy sources reduces negative environmental impacts / costs associated with fossile and nuclear energy production on a global scale (climate change, nuclear accidents, …)

- Renewable energy sources themself can have negative impacts / costs on the environment on a local to regional scale (noise, landscape, loss of natural habitats, …)

→ What is the scale of the possible trade-offs among relevant sustainability criteria and how does these trade-offs develop with the further expansion of renewables?

Sustainablility criteria

Possible sustainability criteria:

Local environmental protection:
Nature and species protection
Protection of residents
Soil and aquatic protection
Landscape protection
…

Techno-economic goals:
GHG-reductions. REN shares
Electricity generation costs
Security of supply
Distributive justice
…

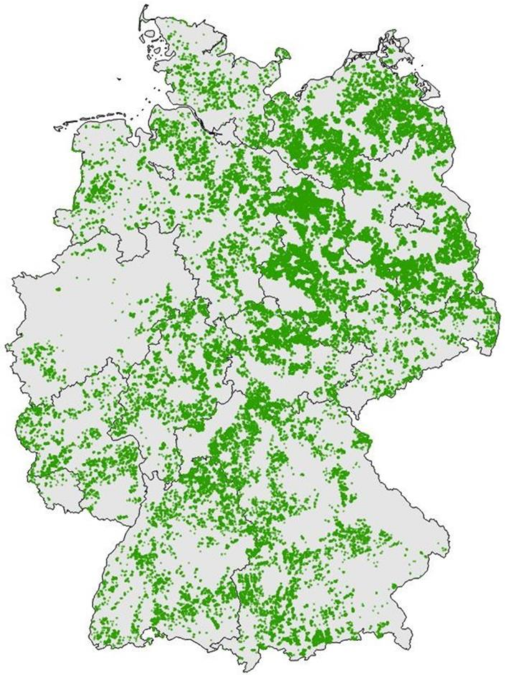
These two criteria will be investigated in an empirical case study for the onshore wind power expansion in Germany.

Model

Approach: optimizing the spatial allocation of wind turbines (WT) in a greenfiel approach

- Input data: technically and legally feasable potential sites for WT

  → 106.497 WT with a combined 778 TWh/a for a WT type E-101 (3 MW) at 135m hub height.

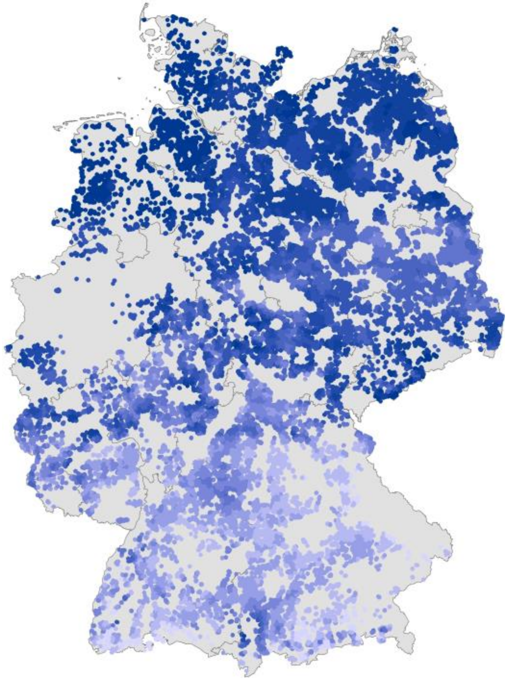


Literature:
Masurowski F. Eine deutschlandweite Potenzialanalyse für die Onshore-Windenergie mittels GIS einschließlich der Bewertung von Siedlungsdistanzenänderungen [Dissertation]. Osnabrück; 2016,

Model II

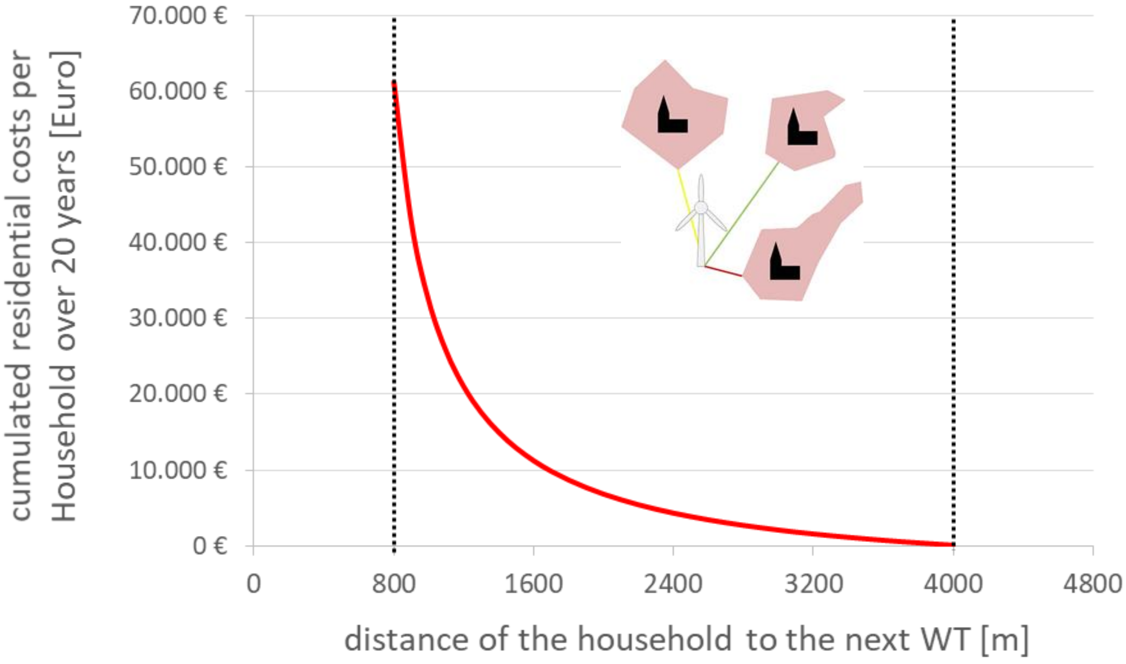
monetary cost for each WT derived from

- 1. electricity generation cost:
  - CAPEX/OPEX assumptions (Deutsche Wind Guard),
  - wind climate data (DWD),
  - WT power curve



Model III

2. residential cost as a function of the distance of a WT to the surrounding households



Literature:

- Meyerhoff, J., et.al., Landscape externalities from onshore wind power, Energy Policy, Volume 38, Issue 1, 2010

- Drechsler M., et. al., Combining spatial modeling and choice experiments for the optimal spatial allocation of wind-turbines, Energy Policy, Volume 39, Issue 6, 2011

- Wen, C., et. al., Valuing the visual impact of wind farms: A calculus method for synthesizing choice experiments studies. Sci. Total Environ. 637–638, 58–68 (2018)

Model IV

Model formulated and solved using General Algebraic Modelling System (GAMS)

Optimization - selection of WT out of the pool of WT on the potential sites – is targeting either

- minimal electricity generation cost
- minimal residential cost
- minimal combined cost of electricity generation and residential cost

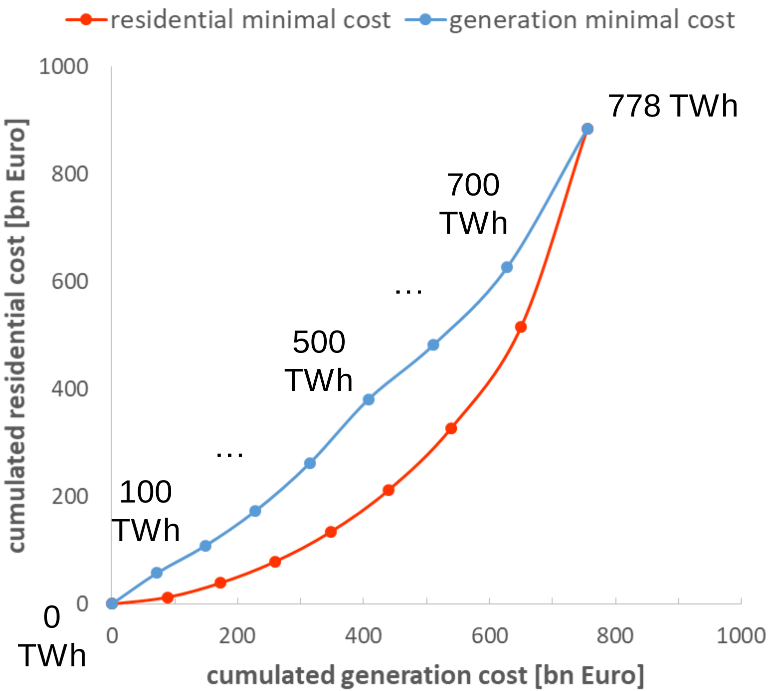
with set constraints for the expanding electricity production of onshore wind (TWh/a)

Results (preliminary) I

Graphical representation of the trade-off

- cumulated generation cost vs.

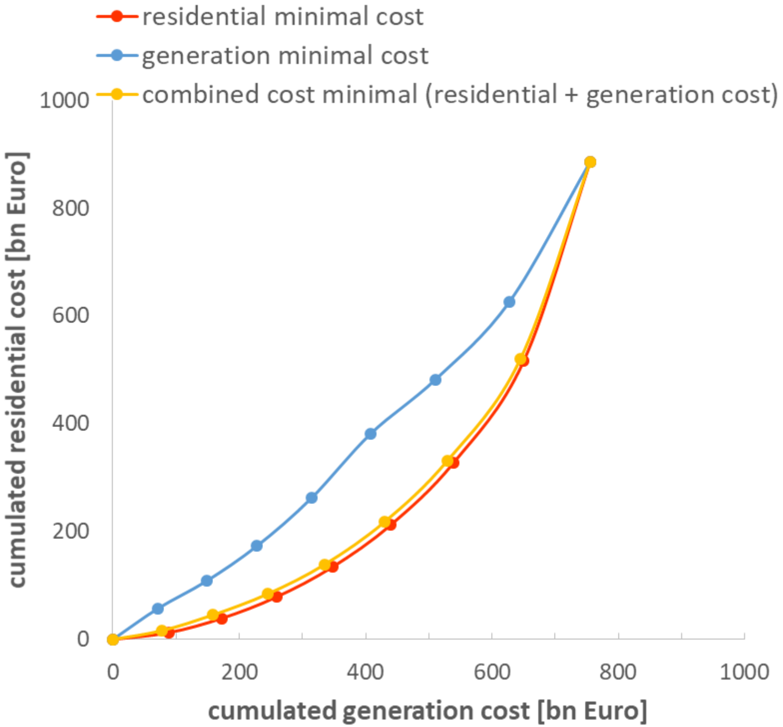
  cumulated residential cost



Results (preliminary) II

Graphical representation of the trade-off

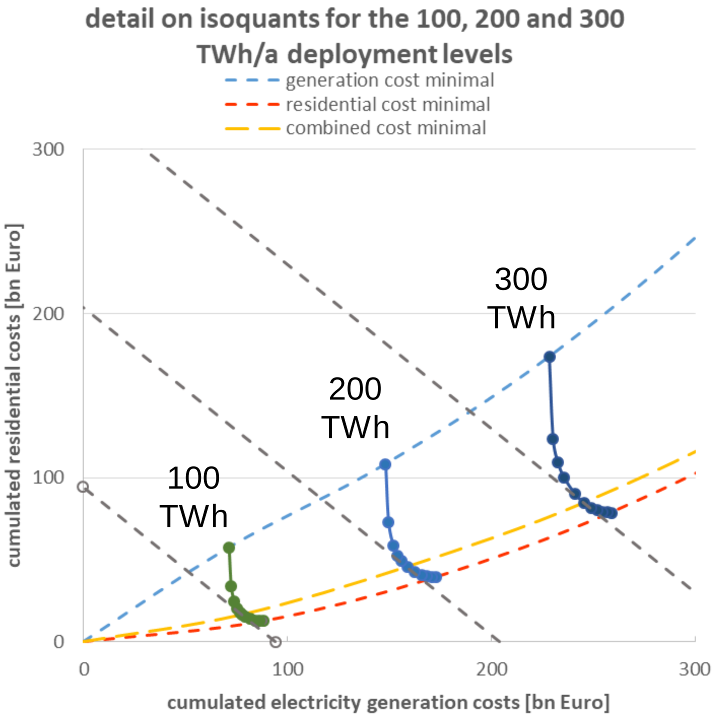
- cumulated generation cost vs.
  cumulated residential cost
- combined costs



Results (preliminary) III

Graphical representation of the trade-off

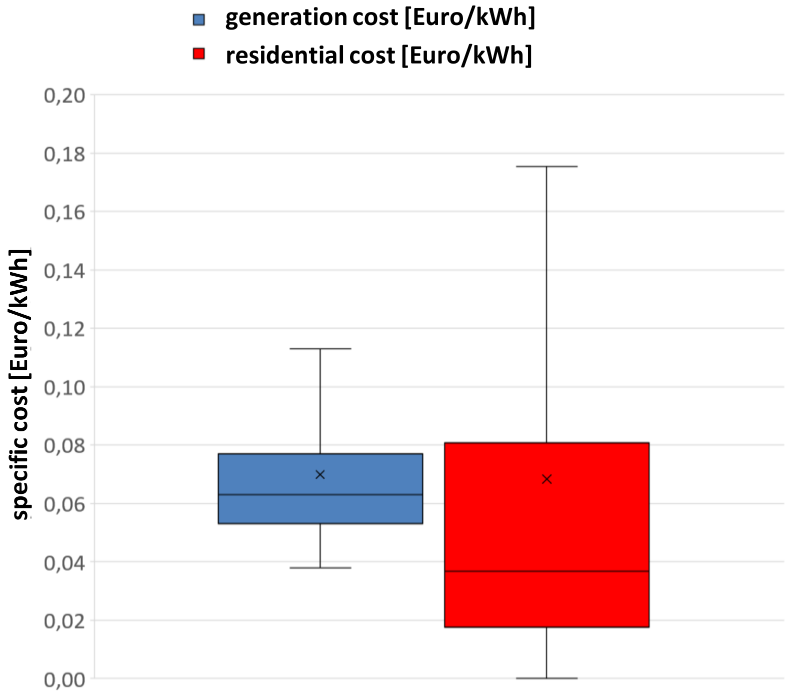
- cumulated generation cost vs. cumulated residential cost
- combined costs
- isoquants for set generation targets



Results (preliminary) IV

Graphical representation of the trade-off

- cumulated generation cost vs. cumulated residential cost
- combined costs
- isoquants for set generation targets
- descriptive statistics as an explanation

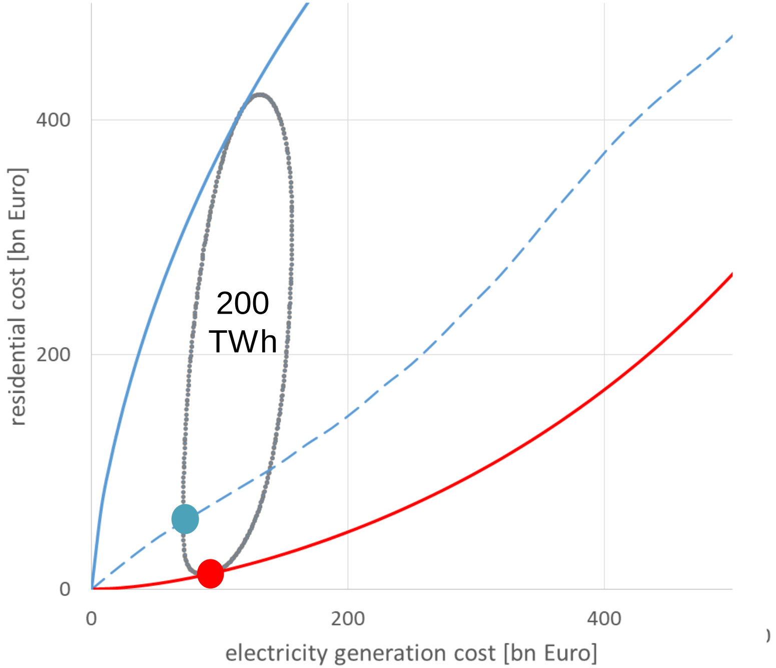


Results (preliminary) V

Pareto-frontiers for the 200 TWh case:

Determining the solution space: the enclosed pareto frontier marks the boundaries of the overall solution space for the allocation problem.

→ Potential trade-off can be much higher than expected when considering the overall potential solution space instead of the cost minimal solutions only.

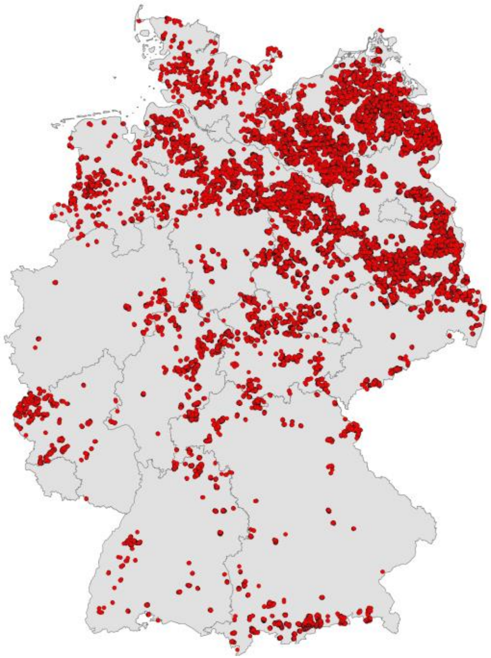


Results (preliminary) VI

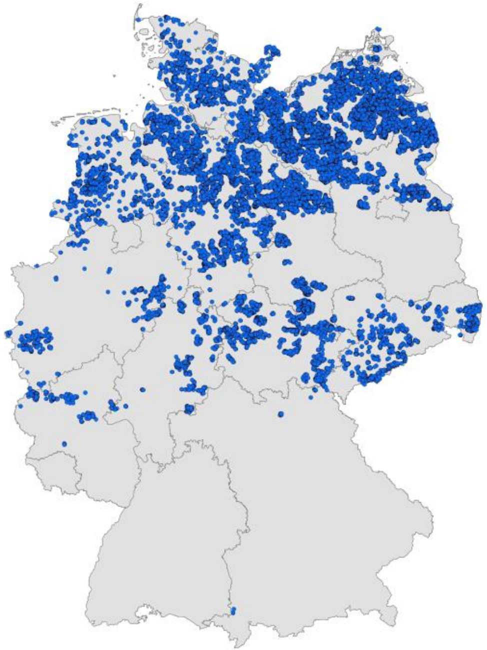
Spatial allocation mapping

Generation target 100 TWh/a
200 TWh/a
300 TWh/a
400 TWh/a

residential minimal allocation



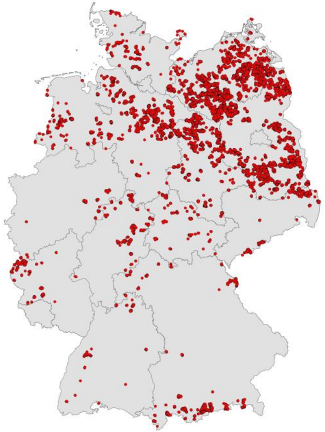
generation cost minimal allocation



Results (preliminary) VII

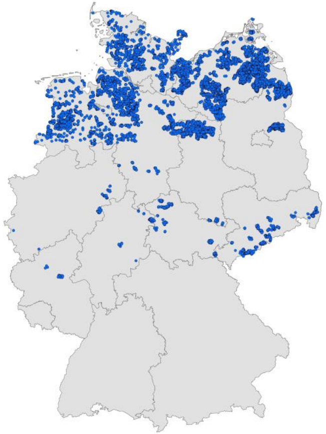
Spatial representation of the trade-off:

residential minimal allocation



$\wedge$

generation cost minimal allocation



≈ 74 TWh

Potential sites selected for both optimization criteria for the 200 TWh generation target (overlap), that can be regarded as „no regret“ potential sites, amount to only 74 TWh.

→ only a minority of the potential sites of either optimization are simultaniously selected

Summary

- Residential cost are comparable in scale to generation cost according to the modelling
- Trade-Off first increases (until 500 TWh) before it decreases due to diminishing degree of freedom when approaching the maximum generation potential of 778 TWh
- Minmizing the overall cost (residential + generation cost) requires the inclusion of residential costs due to the observed trade-off
- Overall potential trade-off can be very significant as shown using the pareto frontiers

Outlook: checking obtained results by sensitivity analysis, modelling additional (non-monetary) criteria like landscape aesthetics and nature protection

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THANK YOU FOR YOUR ATTENTION

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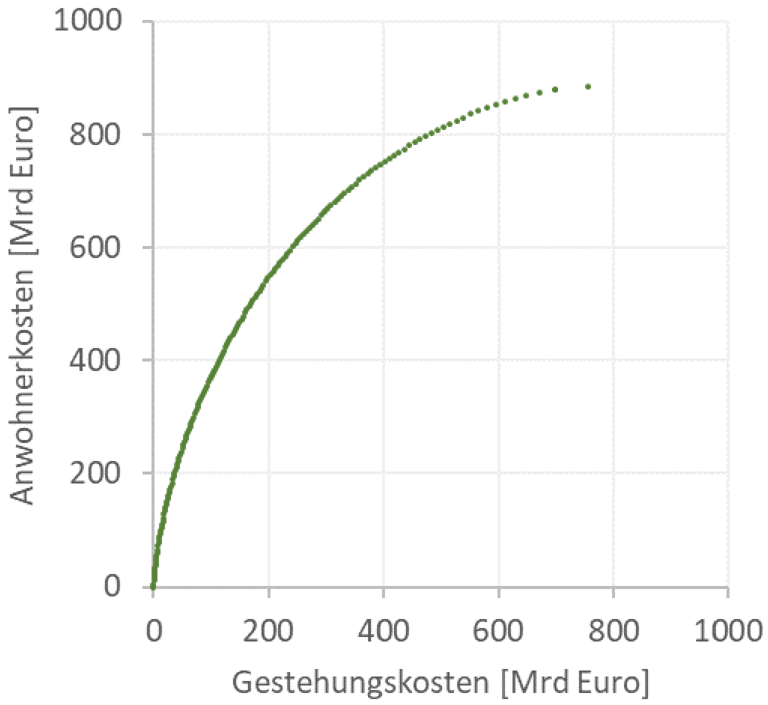
Erste Ergebnisse I

Zielkonflikte in der grafischen Darstellung

- Paretofront



Nachwuchsforschungsgruppe MultiplEE

Nachwuchsforschungsgruppe „**Nachhaltiger Ausbau erneuerbarer Energien mit multiplen Umweltwirkungen – Politikstrategien zur Bewältigung ökologischer Zielkonflikte bei der Energiewende (MultiplEE)**“

MultiplEE
Multiple Umweltwirkungen Erneuerbarer Energien

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Praxispartner:

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Summary

- Anwohnerkosten in relevanter Größe im Vergleich zu Gestehungskosten
- Anwohnerkosten variieren stärker als Gestehungskosten

  → Gesamtkosten aus Gestehungskosten und Anwohnerkosten lassen sich am besten durch eine Berücksichtigung der Anwohnerkosten reduzieren.
- Trade-Offs nehmen zunächst zu, reduzieren sich dann aufgrund der fehlenden Freiheitsgrade bei der Auswahl an WEA wieder bei Ausschöpfung des gesamten Energiepotenzials.

Ausblick: Ergebnisse durch Sensitivitätsanalysen absichern, zusätzliche (nichtmonetäre) Nachhaltigkeitskriterien wie Landschaftsbild, ökolog. Kriterien, … integrieren.