Identifying key elements for adequate simplifications of investment choices – The case of wind energy expansion

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Which key elements most strongly influence investment decisions?

- A social planner seeks to identify possible and profitable sites and turbine technologies to invest in under a given economical and technological setting.
- A modeler aims to support the social planner. She therefore aims to accurately model wind energy expansion under given constraints while using limited computational and time resources.
- ➢ Leads to the challenge of minimizing the error of aggregation in electricity market modeling

I. Definition of value components

II. Computation of value components

1. Choice of adequate scenarios
2. Define investment choices as objects for the clustering algorithm
3. Calculate value components for various scenarios

III. Aggregation of investment choices in limited number of clusters

4. Predefine cluster numbers using hierarchical clustering
5. Aggregation of investment choices

The value of an investment choice

Definition of value components

- Key parameter in decision-making process
- Considers multiple spatial and technological factors
- Sum of the contribution margin over time subtracted by the investment cost
- Interpreted as site (area) and unit (technology) specific excess profit per installed capacity

$$NPV_{a,i} = \sum_t e^{-rt} \theta_{t,a,i} K_{a,i} p_{t,a} - c_i K_{a,i}$$

Per-unit consideration:

$$Value_{a,i} = \sum_t e^{-rt} \theta_{t,a,i} p_t - c_i$$

Parameters

e^{-rt}	discounting factor
$\theta_{t,a,i}$	capacity factor
$K_{a,i}$	capacity
p_t	electricity price
c_i	investment cost

Indices

t	time
a	area
i	technology

Decomposition of the value of an investment choice

Definition of value components

- **Yield specific value component**
  - driven by the **site-specific full load hours** (at average technology mix)
- **Resource specific value component**
  - driven by the **market value factor** of wind
  - self destructive effect of high RE shares
- **Site specific value component** (spatial heterogeneity)
  - driven by **wind profile** of the selected site
  - site vs. overall averaged profile per time
- **Technology specific value component**
  - driven by the **selected turbine type**
  - individual vs. portfolio averaged profile
- **Grid specific value component**
  - considering the **network load** and resulting nodal price differences.

For further analysis summed up as **"net yield"** component

Exemplary value components (VC) for a future portfolio

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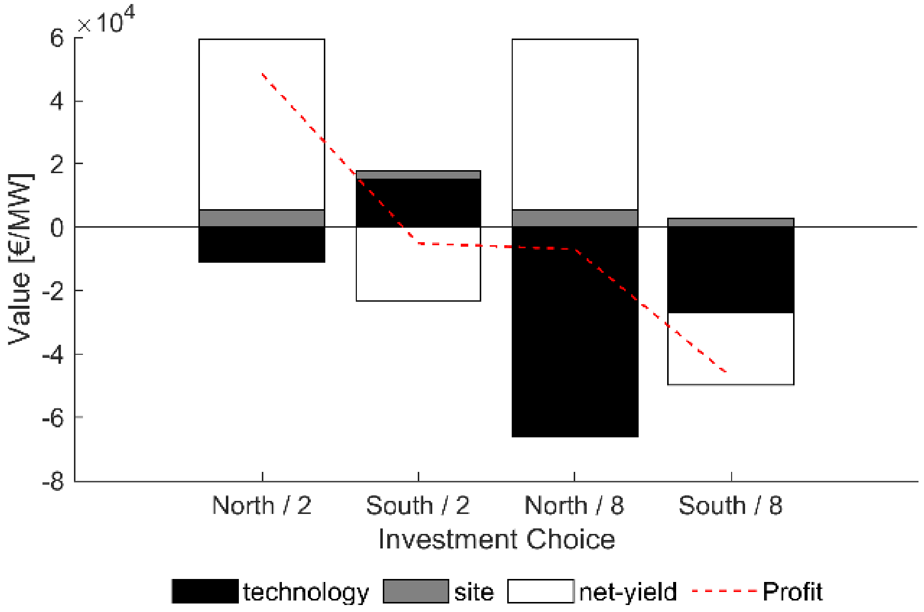
Definition of value components

- VC based on the result of an optimized future scenario
- Four investment choices (IC)
  as combinations of site and technology
  - sites: DE132 → South Germany
    DEF02 → North Germany
  - technologies: Turbine 2 → Onshore low speed
    Turbine 8 → Onshore high speed



➢ Net yield component positive in the north, negative in the south, reflective of FLH independent from technology

➢ Positive effect of the site component even at the exemplary southern site

➢ Highest variation in the technology component
  - Onshore high speed turbine is not beneficial at the Northern site
  - the additional revenues do not compensate the additional costs compared to the average portfolio (cf. also next slide)

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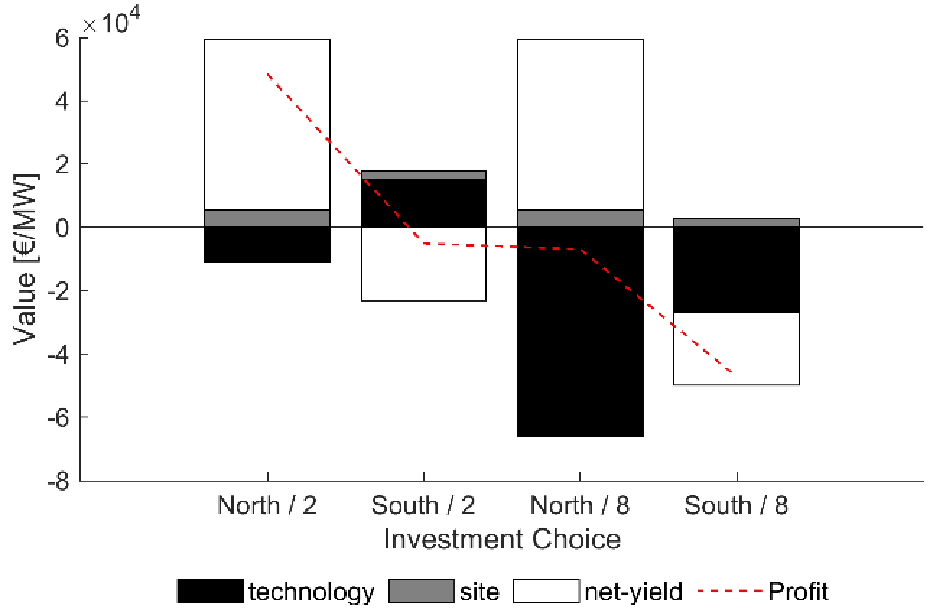

Note: In the optimized future portfolio
- If at one site no technology has positive profit, the site remains unused
- If there is at least one profitable technology at one site, the technology with the highest profit is built up to the site capacity limit

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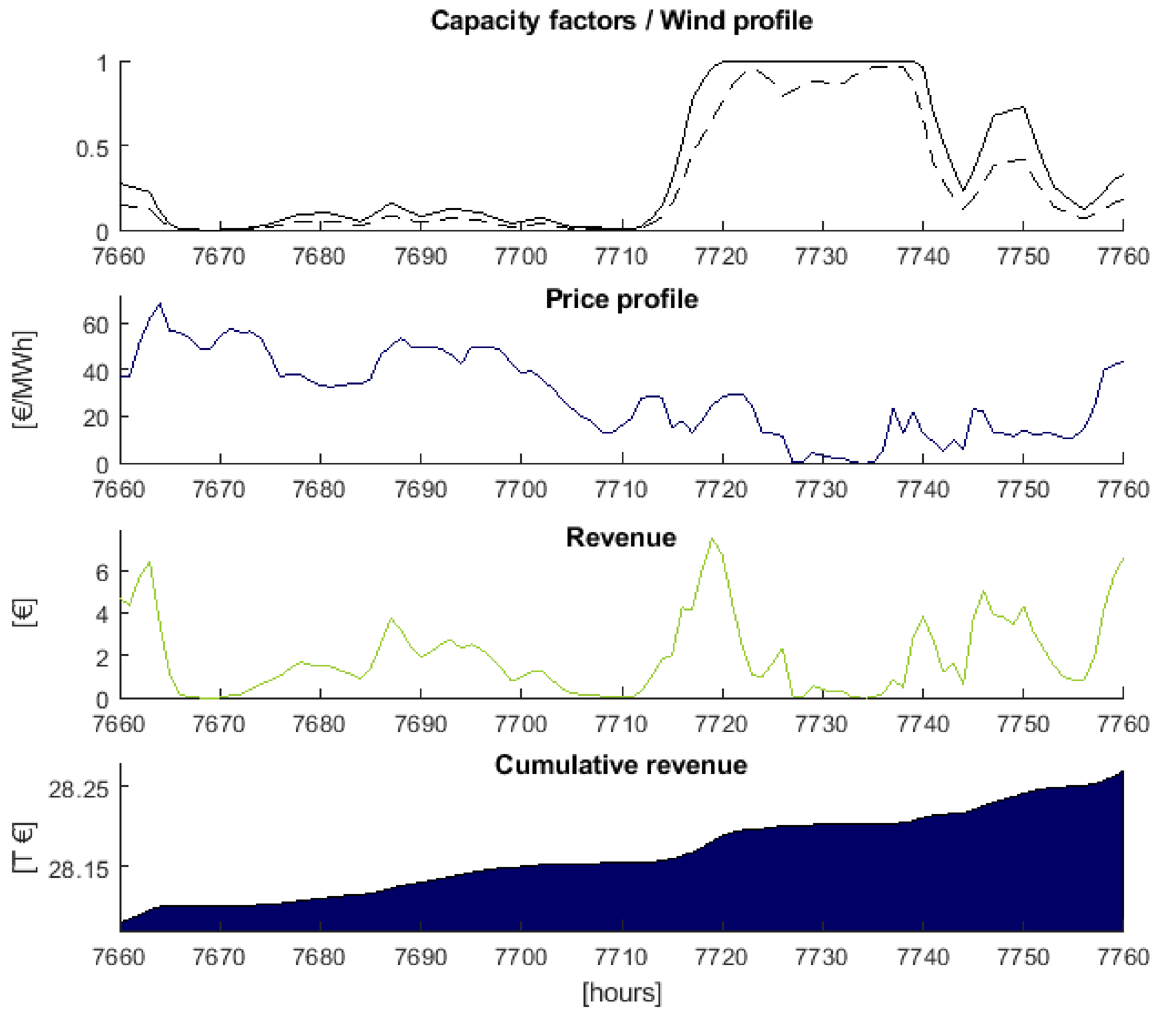
Exemplary analysis of the technology component

- VC based 2017 scenario
- Investment choice South (DE132) / WEA 2

$$VC_{a,i}^{technology} = \sum_t \underbrace{(\theta_{t,a,i} - \bar{\theta}_{t,a,\cdot})}_{\text{Difference in capacity factors}} p_t - \underbrace{(c_i - c_\cdot)}_{\text{Cost difference}}$$

- Cumulated yearly
  - revenue 33,191.00 €
  - cost difference 39,806.00 €
  - technology component -6,615.00 €



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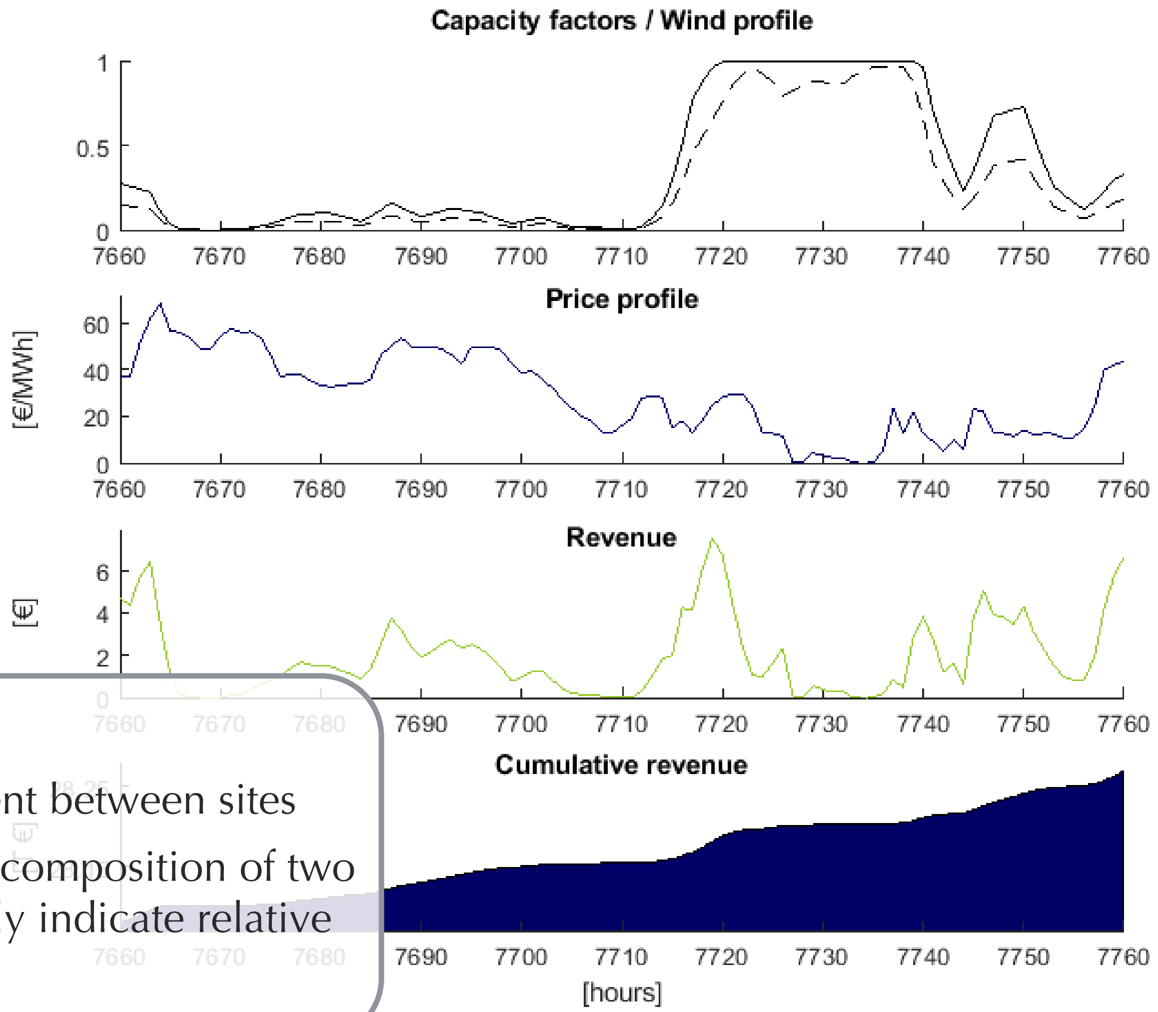
Note: For the technology component

- the average capacity factor is different between sites
- hence, the comparison of the value composition of two different investment choices can only indicate relative differences



The case of wind energy in Germany

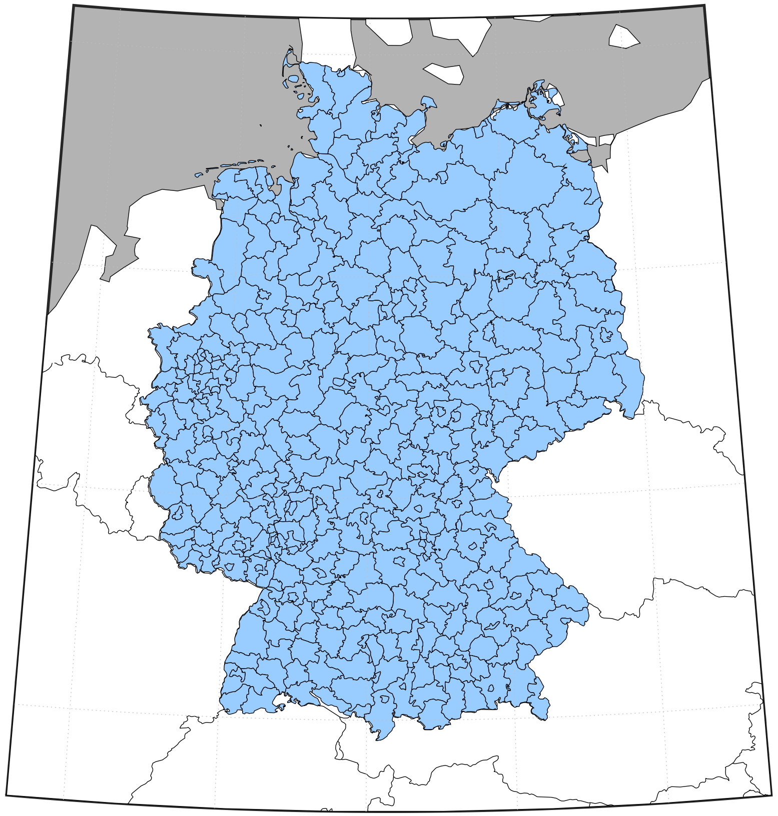
Step 1
Choice of adequate scenarios

Step 2
Define investment choices

Step 3
Calculate value components

Step 4
Predefine cluster

Step 5
Aggregation of investment choices



1. Choice of adequate scenarios

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- Scenario A or “2017”
  - real capacities of wind power 2017
  - historical day-ahead spot prices
- Scenario B or “2020 nodal”
  - ensure the consideration of congestion effects
  - scaled capacities of 2017
  - approximated prices for 2020 adopted from Felling and Weber (2018)
- Scenario C or “future”
  - result of a simplified electricity market model optimization
  - greenfield approach with one conventional backup technology and three renewable sources
  - low-emission scenario with a renewable share of about 65 %
  - demand held constant from 2017

2. Define investment choices

The case of wind energy in Germany

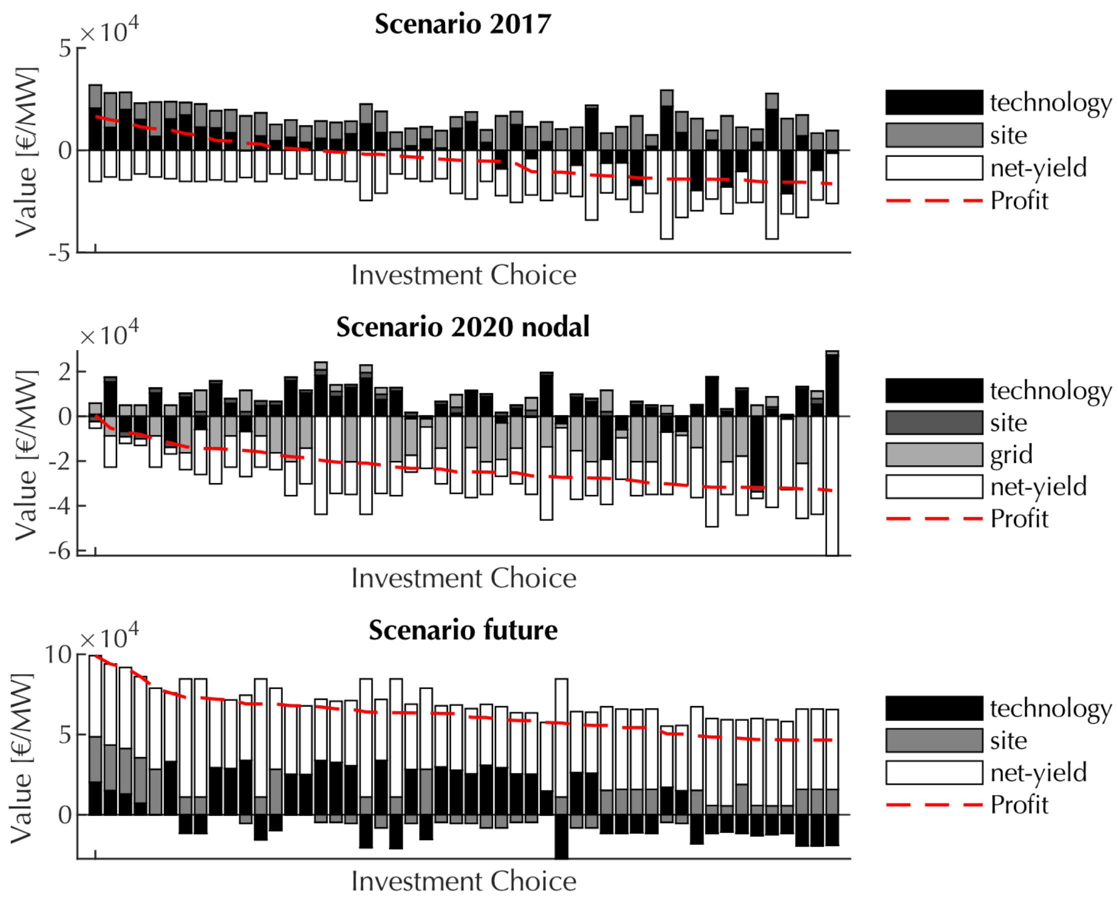
- Combination of site and technology type:
  - spatial resolution: 402 NUTS3 regions in Germany
  - level of technological detail: 8 wind turbines representing the variety of wind turbines in Germany
- 402 sites and 8 technology types lead to an overall of 3216 investment choices (cluster objects)

Turbine Type	Hub height [m]	Rotor Diameter [m]	Power [kW]	Type	Capex [€/kW]
WEA 1	72	53	800	High speed	1.047
WEA 2	139	121	2.530	Low speed	1.571
WEA 3	109	92	2.350	High speed	1.155
WEA 4	142	114	3.170	Low speed	1.290
WEA 5	110	109	3.000	Low speed	1.169
WEA 6	150	140	4.000	Low speed	1.573
WEA 7	120	124	4.500	High speed	1.363
WEA 8	120	140	6.000	High speed	1.483

3. Calculate value components for three scenarios

The case of wind energy in Germany

- Shown results: 50 most profitable investment choices (ICs) of each scenario in descending order
- Observations:
  - Number of ICs with positive profit: 15 - 1 - 245
  - Number of ICs with a strictly positive realized capacity: 991 - 927 – 52
  - Strong changes in profitable investment choices and in capacities greater zero between 2017/2020 nodal and future
    → fundamental difference prices and capacities
  - reduction in overall profitability from 2017 to 2020 nodal
    → price influence of grid congestion
  - high profitability in future
    → positive contributions of the net-yield component



4./5. Cluster analysis

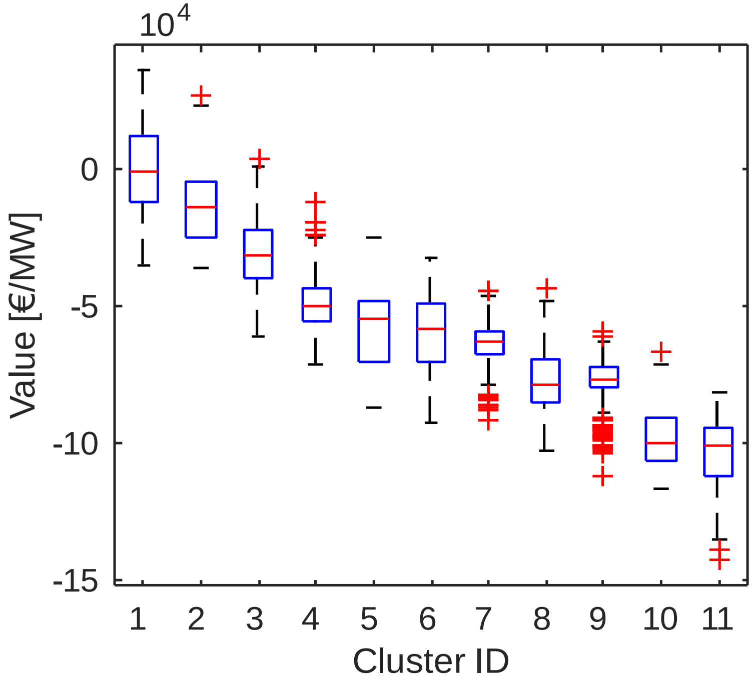
The case of wind energy in Germany

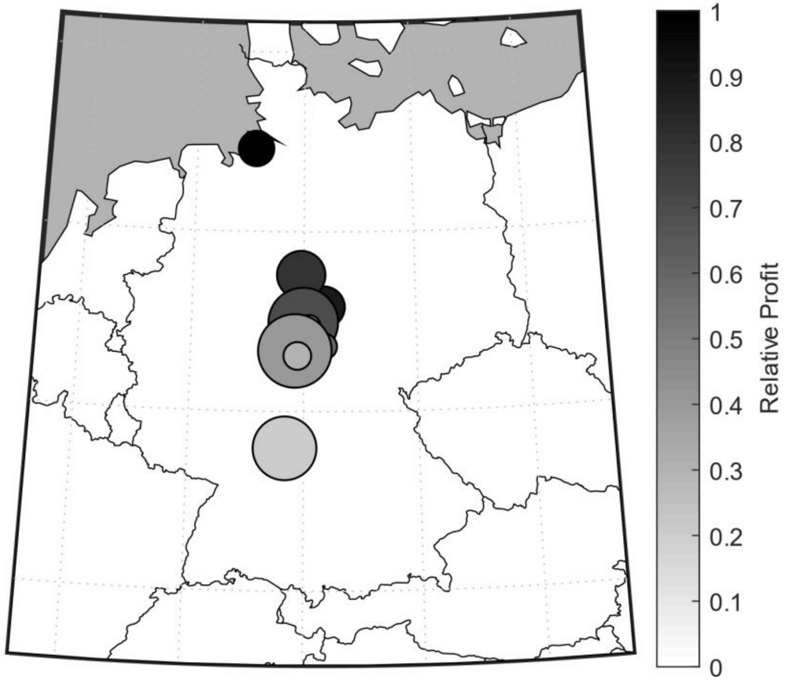
- Using:
  - k-means clustering
  - predefined number of clusters using hierarchical clustering
  - squared Euclidean Distance
- Done for:
  - 402 sites (NUTS3 regions)
  - 8 technologies
  - ➢ 3216 investment choices
- Based on:
  - 4 to 5 value components in
  - 3 scenarios → indicating that aggregation of decision alternatives is robust under different scenario settings
  - ➢ 13 attributes
  - ➢ 11 clusters

Aggregation of investment choices

The case of wind energy in Germany

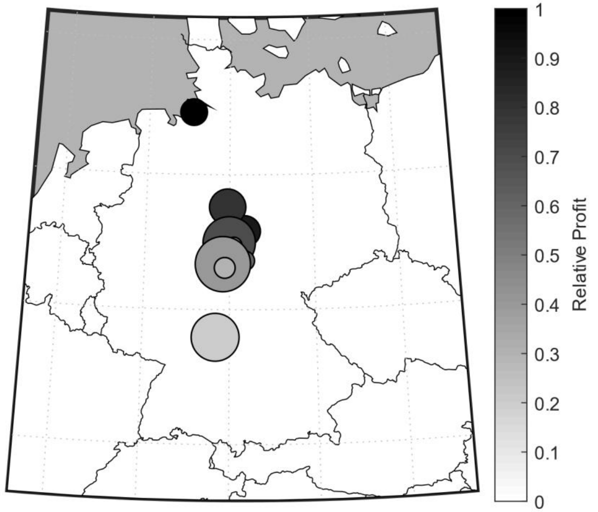
- Two key aspects of interest
  - the geographical and technological diversification within the clusters
  - general characteristics of cluster specific value components

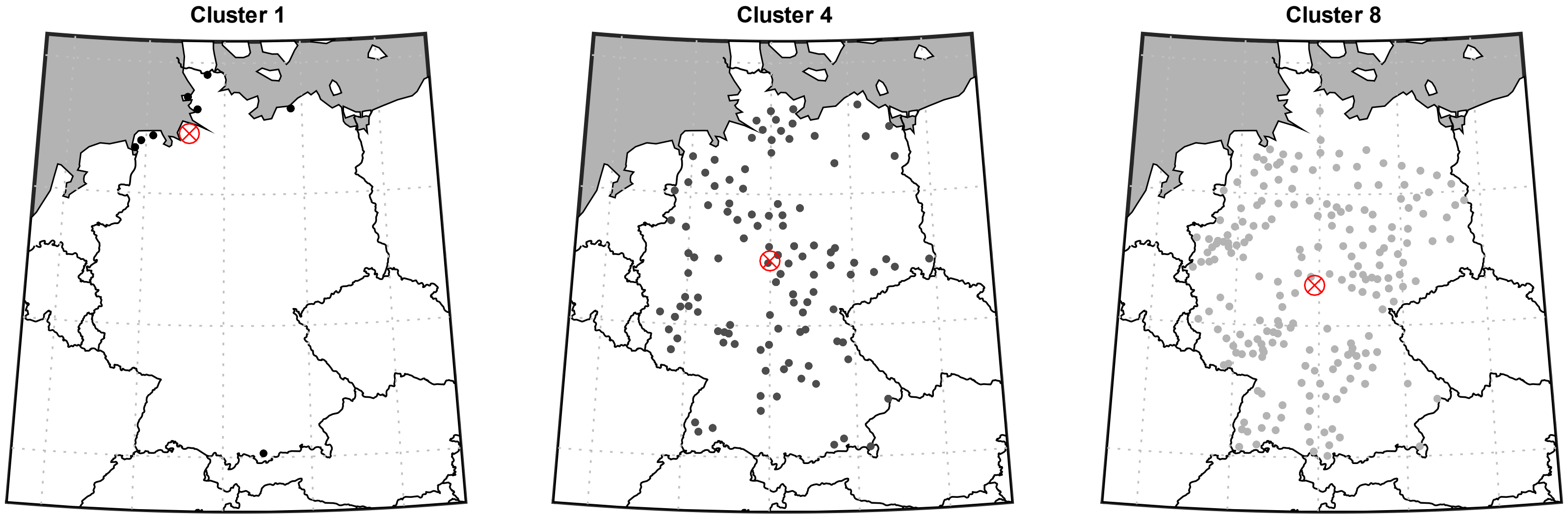




Geographical diversification

- Separation in two types of clusters
  - small, generally profitable clusters
  - large less profitable clusters
- Most profitable centroids (black) in North Germany or at mountain sites
- No obvious split between East and West clusters
  - spatial heterogeneity in that dimension not too important





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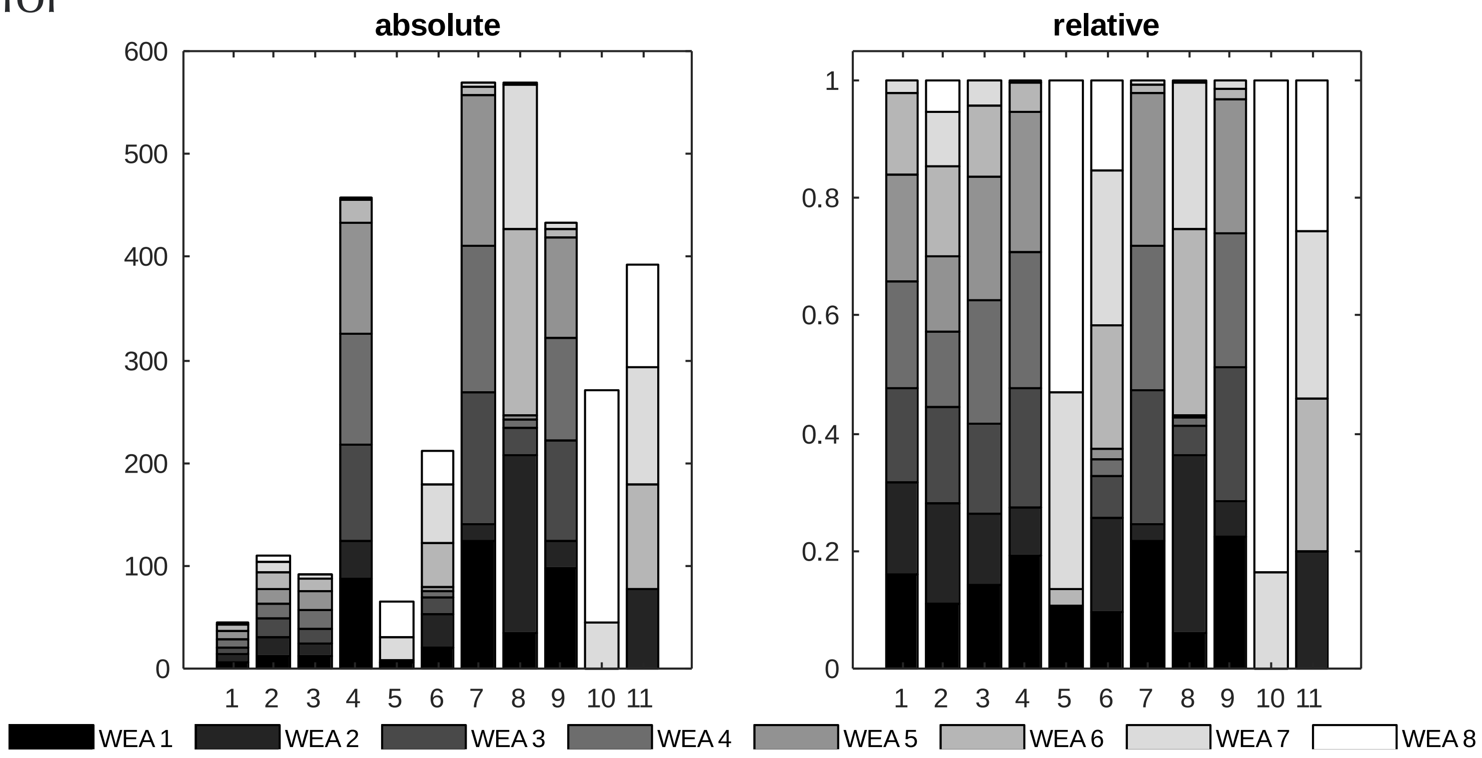
Technological diversification

The case of wind energy in Germany - Aggregation of investment choices

- Turbine type is similarly distributed for the four most profitable clusters
- Clusters five and ten are quite specialized on high speed wind turbines



Obtained clusters: Profitability across scenarios

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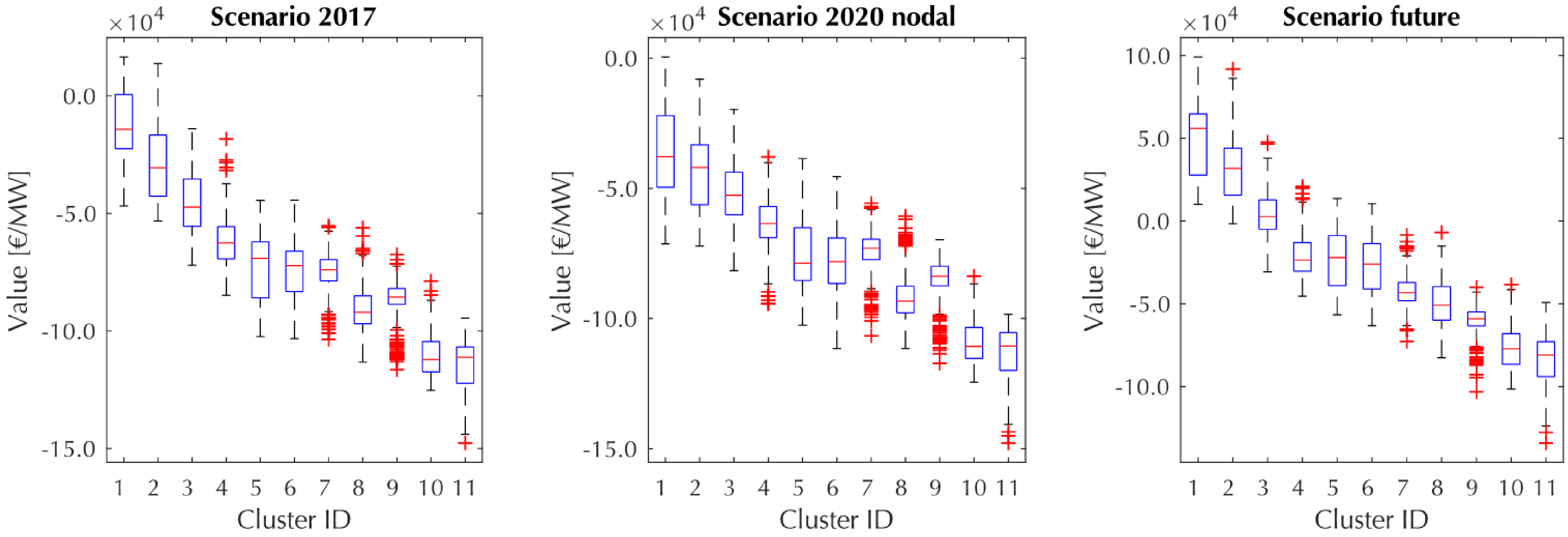
Evaltuation of cluster statistics

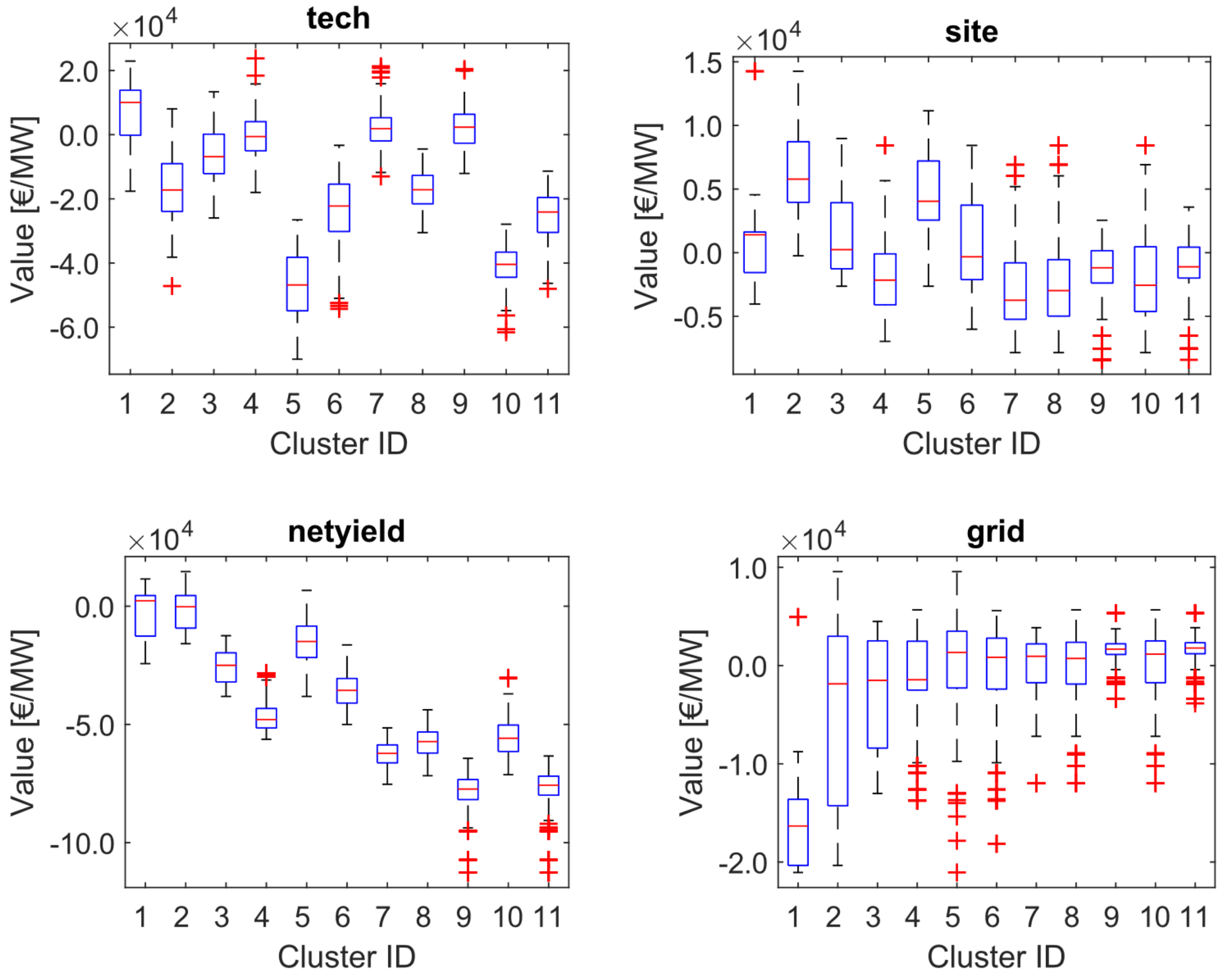
- Similar ranking of clusters in all scenarios
- Indication of limited changes in relative market value



Obtained clusters: The four value components in comparison

Evaltuation of cluster statistics

- Technology and net-yield component
  - in absolute terms the highest
  - considerable divergences between clusters
- Net-yield component
  - Most important driver for the overall profit
- Site component
  - smallest influence
  - lower variability
- Grid component
  - negative due to scarce transfer capacities in times of high renewable infeed



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Conclusion and further research

- ✓ Methodology enables robust clustering of investment choices in view of use in aggregate models
- ✓ Net-yield component is a key influencing factor for cluster formation
- ✓ Diversity in sites does not impact clustering as much
- ✓ The profitability ranking of the obtained centroids is rather robust against changes in portfolio mix and price

- ➢ Test robustness of clusters against further scenarios (e.g. varying carbon caps or solar penetration)
- ➢ Test of developed aggregation in an optimization environment

Thank you for your attention!

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