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Effects of the Technological Capacity Mix on Regional Market Values in Germany

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Offshore vs. Onshore Wind Energy

Agenda

1 **Motivation and Research Questions**

2 Fundamental Market Model Applied

3 Technological and Regional Driven Value Factor Development until 2035

4 Key Findings and Conclusion

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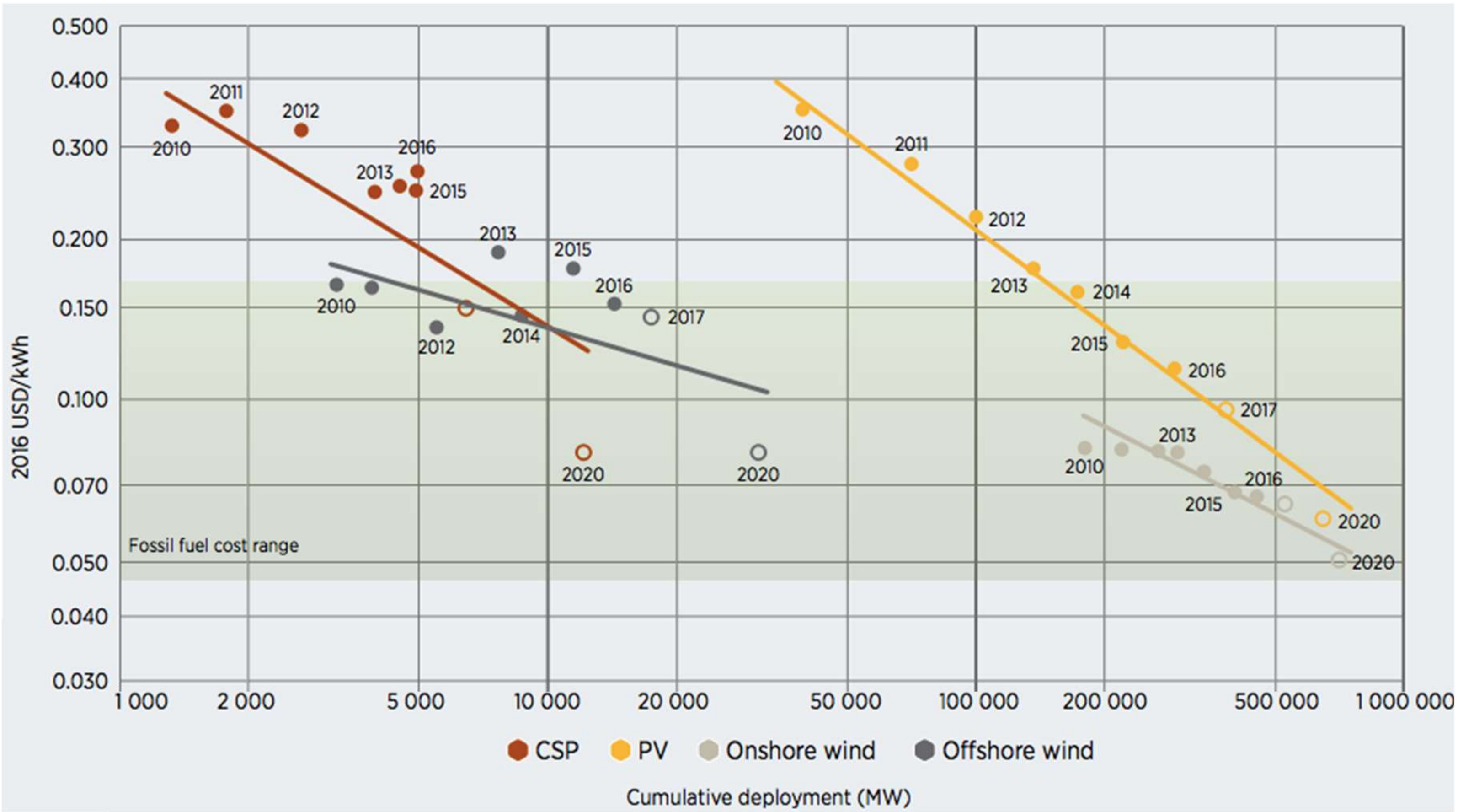
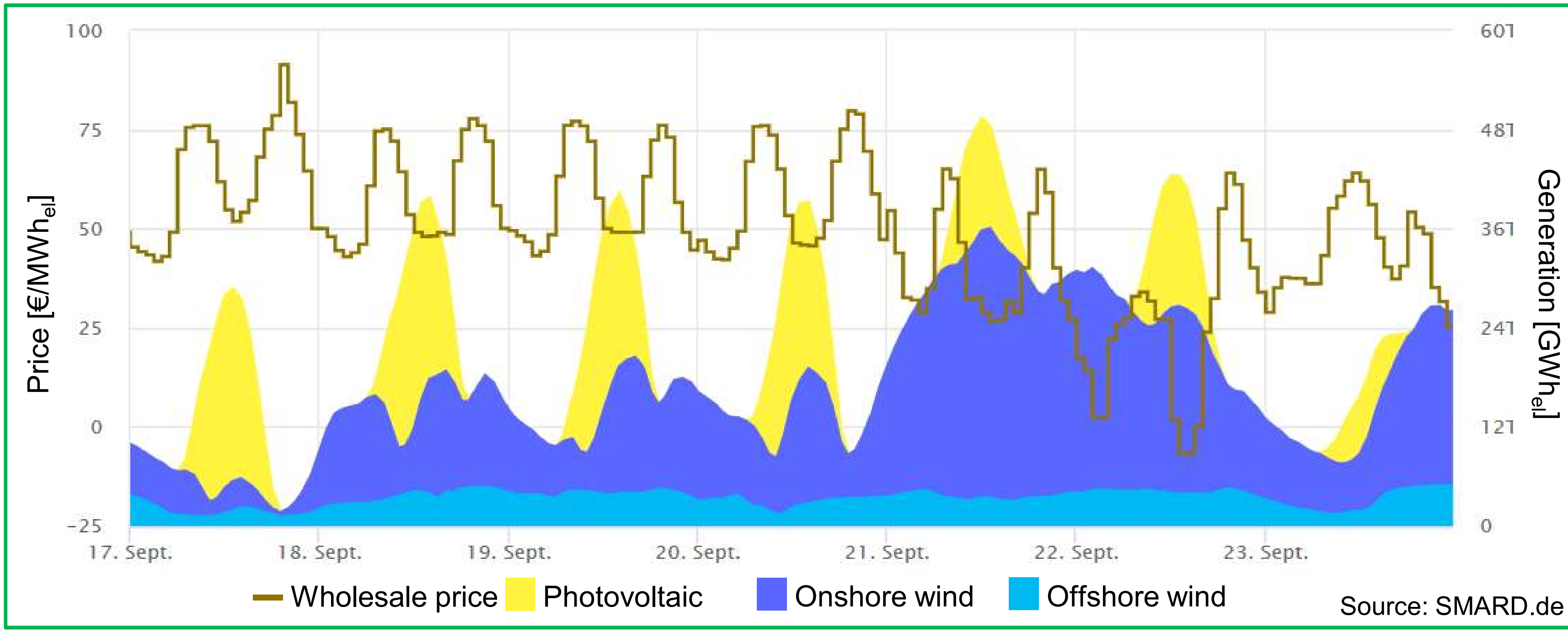
Levelized cost of electricity (LCOE) of renewables have massively decreased



Source: IRENA (2018): Renewable Power Generation Costs in 2017; Figure 2.14 Global weighted average CSP, solar PV, onshore and offshore wind project LCOE data to 2017 and auction price data to 2020, 2010-2020

Volatility of generation and prices

For economic assessment it matters when electricity is produced …



… but LCOE do not consider volatility of generation and prices over time

- Do not compare LCOE of different technologies without considering the time when electricity is produced
- Do not compare LCOE with average wholesale prices but its generation-weighted price, the ***market value***

Market value assessment becomes crucial while values decrease

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Historical evolution of wind market values

Year	Market value [€/MWh]	Average price [€/MWh]	Value factor
2001	23,33	24,06	0,97
2002	21,57	22,64	0,95
2003	26,82	29,47	0,91
…	…	…	…
2014	28,03	32,76	0,86
2015	26,80	31,63	0,85
2016	25,03	28,98	0,86
2017	27,95	34,19	0,82
2018	38,16 /	44,47 =	0,86

Calculation of market values and value factors

(1) Value factor: $VF^{Wind} = \frac{\bar{p}^{Wind}}{\bar{p}}$

(2) Market value: $\bar{p}^{Wind} = \frac{\sum_{t=1}^{T} g_t^{Wind} * p_t}{\sum_{t=1}^{T} g_t^{tech}}$

(3) Average wholesale price: $\bar{p} = \sum_{t=1}^{T} \frac{p_t}{T}$

p_t hourly wholesale price

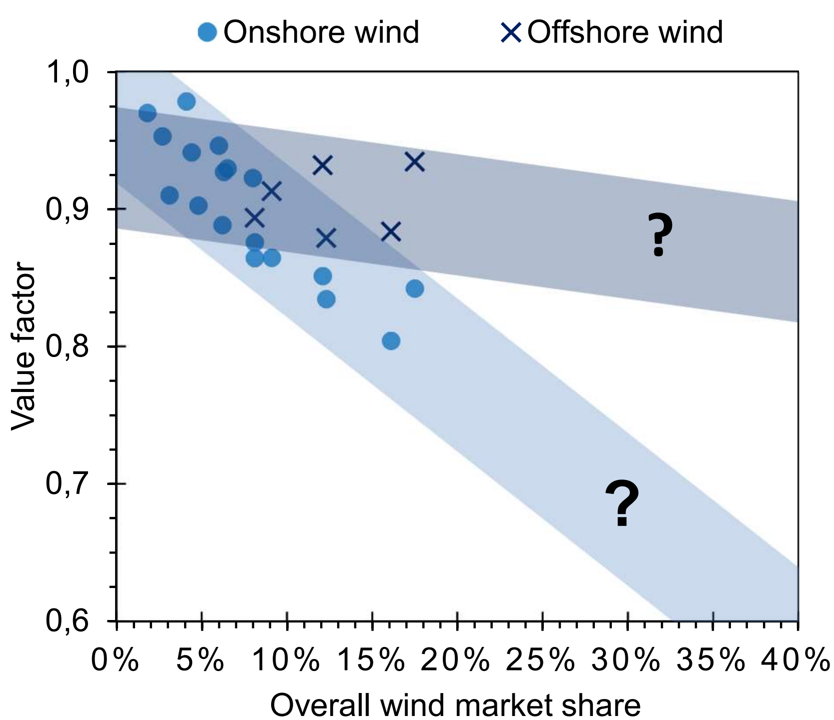
g_t^{Wind} hourly wind generation

- During hours of high wind feed-in prices depress (merit-order effect)
- Hence, the relative value of wind power drops as their market share increases

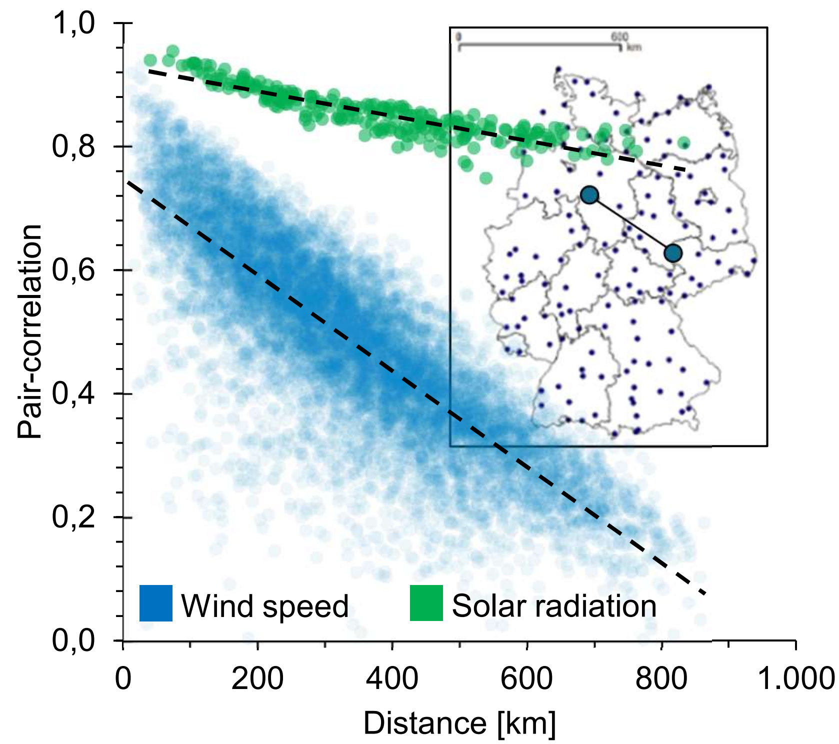
Source: Own calculation based on German day-ahead price data and feed-in time series

Deriving two research questions

'Cannibalization effect' of increasing wind shares



Pair-wise correlation depending on site distance

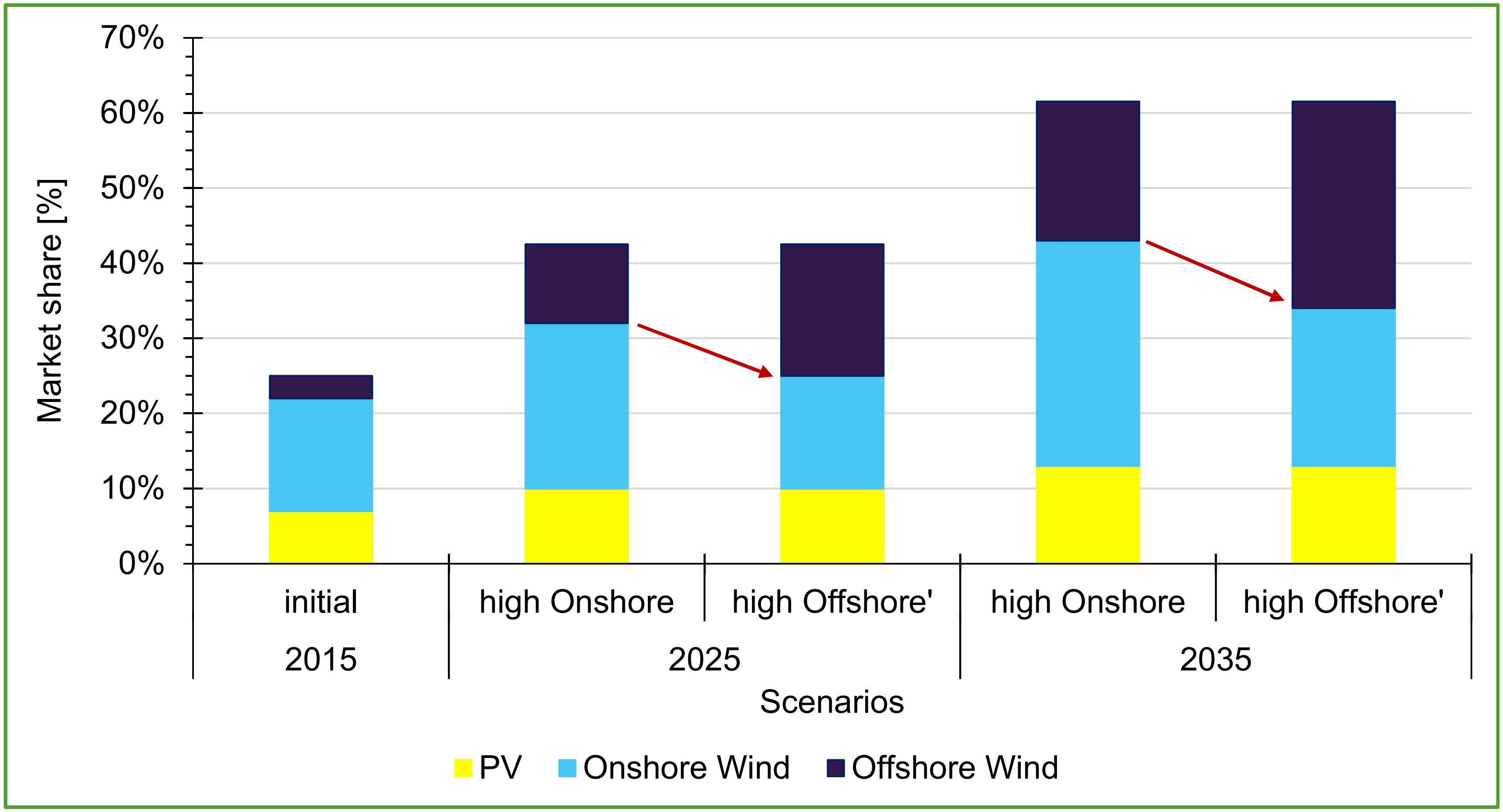


1 Which fundamental factors drive the market value development of onshore/offshore wind ?

2 How do regional wind pattern affect regional market values ?

Agenda

Scenario framework: Effects of the Technological Capacity Mix



ELTRAMOD calculates cost minimized power plant dispatch and market prices

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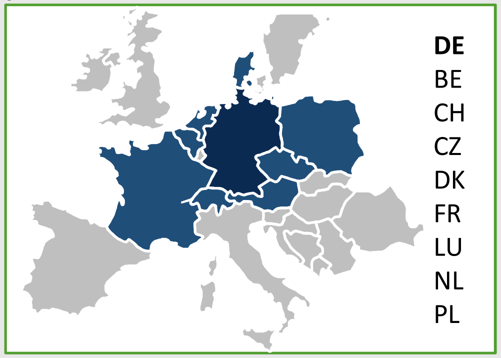
Effects of the **Technological Capacity Mix** on **Regional Market Values**

Dispatch model *ELTRAMOD*

Target function:

- Minimization of total system costs

Spatial resolution



Data input:

- Power plant characteristics
- Fuel and CO_2 allowances prices
- Load of demand and VRE feed-in of Germany's neighbours (8760h)

Restrictions:

- Electricity balance
- Must-run requirements for CHP
- Ramping constraints
- NTC restrictions

Model Output

Hourly plant dispatch

Commercial flows

Curtailment

Welfare

Hourly power market prices

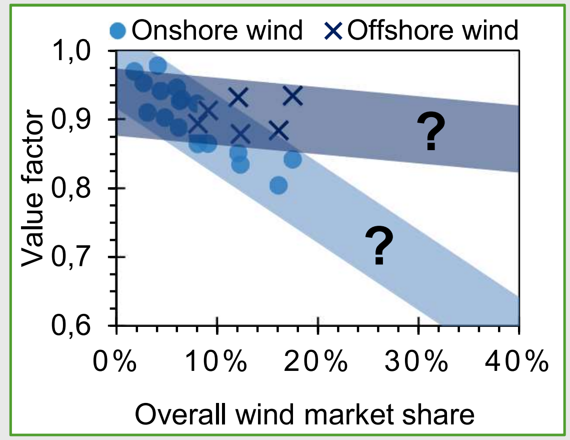
\+

Regional time series

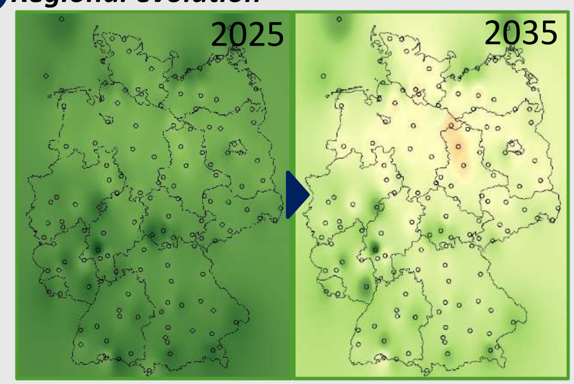
3 offshore sites + 140 onshore sites

Evolution of market values

1 ***Overall evolution***



2 ***Regional evolution***



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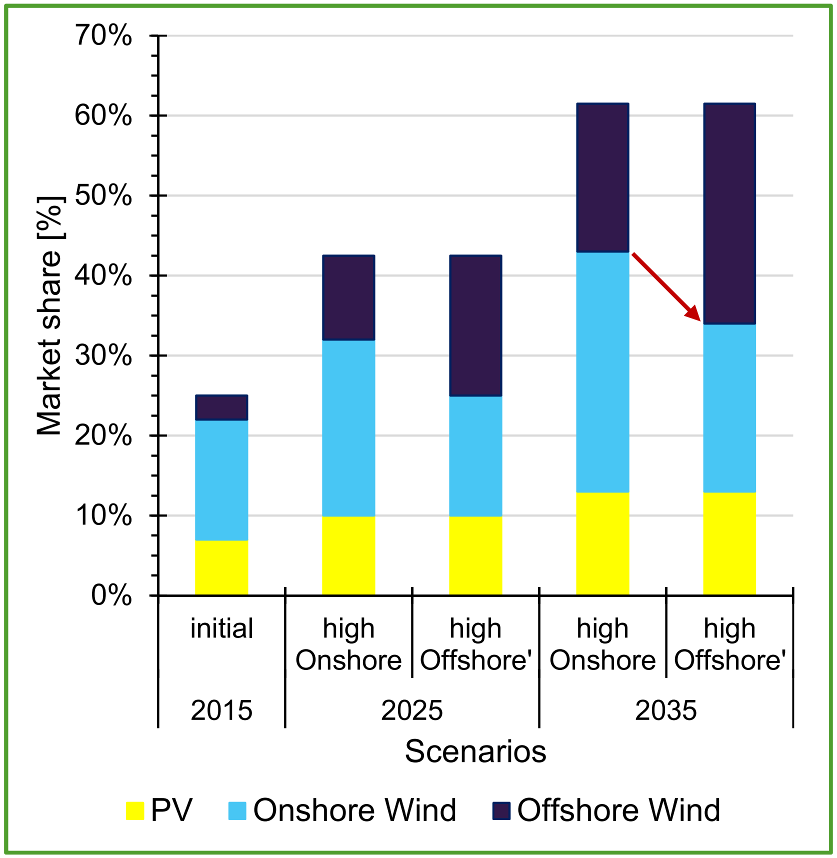
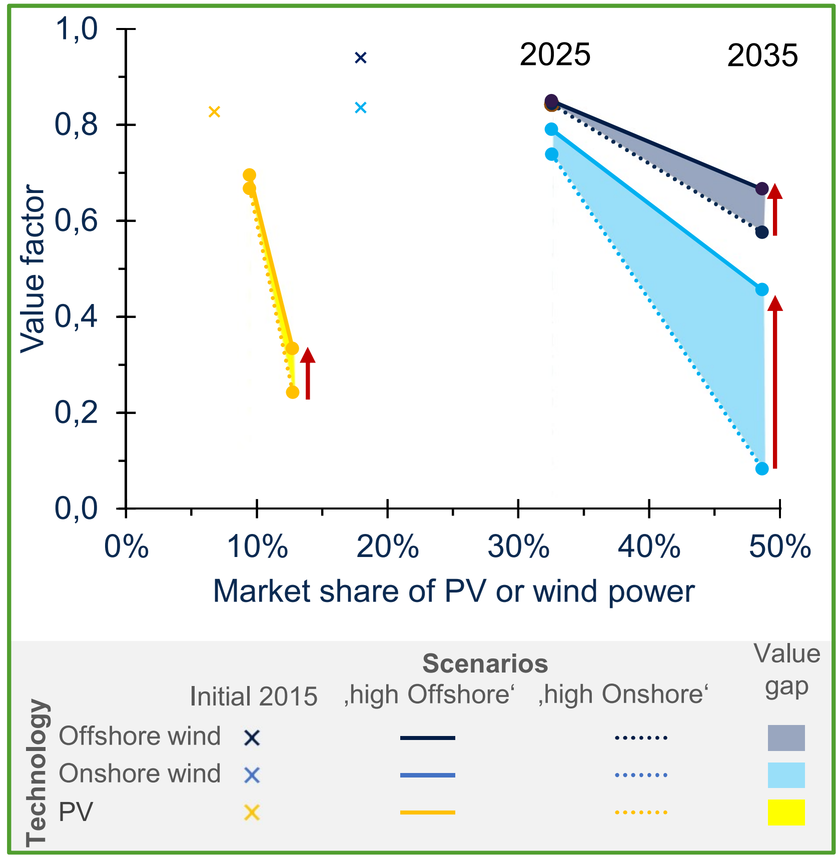
Capacity mix impacts value factors

Wind capacity mix and scenario framework



Development of value factors

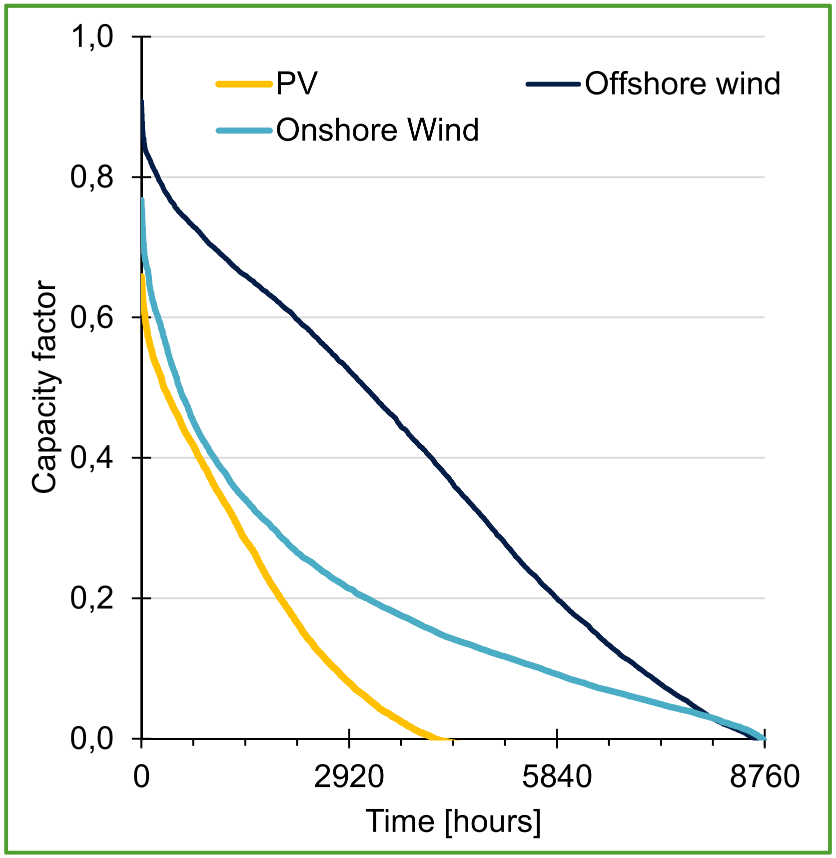


1. Higher offshore wind shares can reduce overall wind power volatility

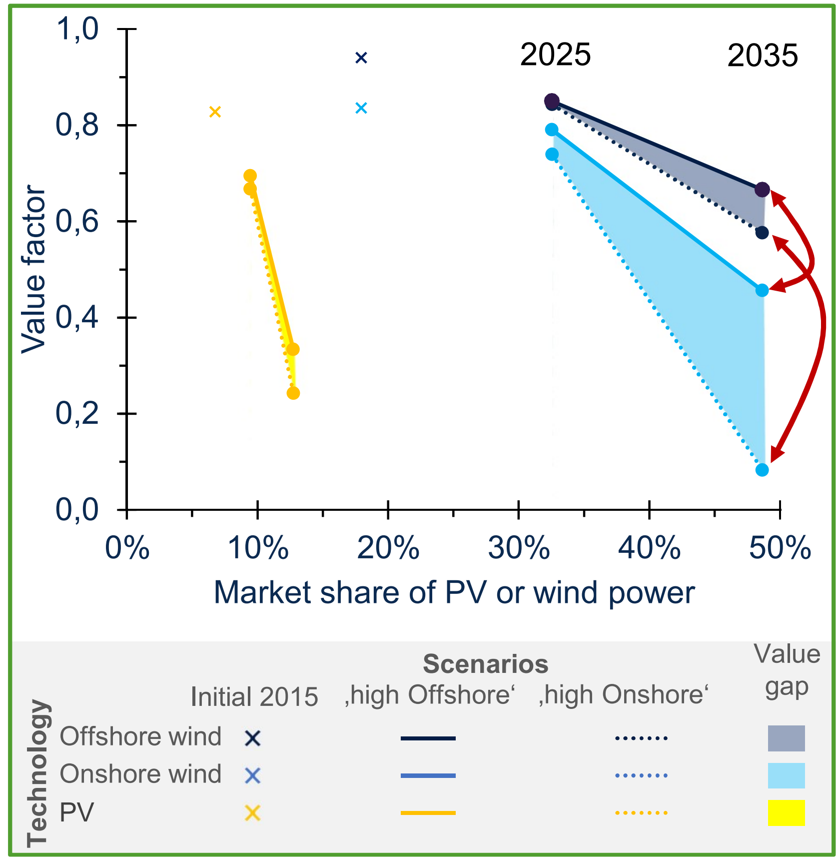
! This mitigates the value drop of offshore and onshore wind as well as PV

Generation intermittency drops value factors

Power duration curves



Development of value factors

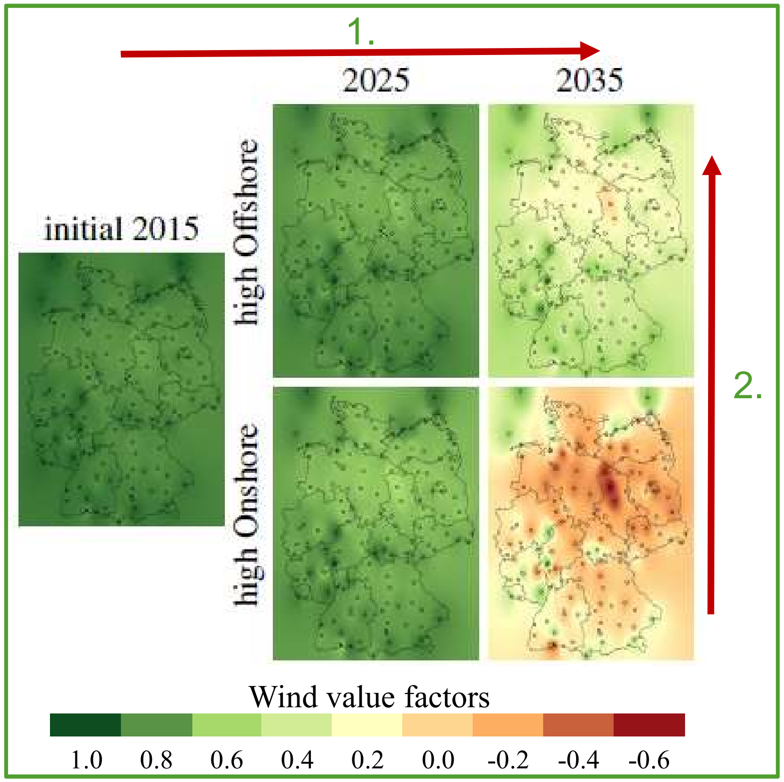


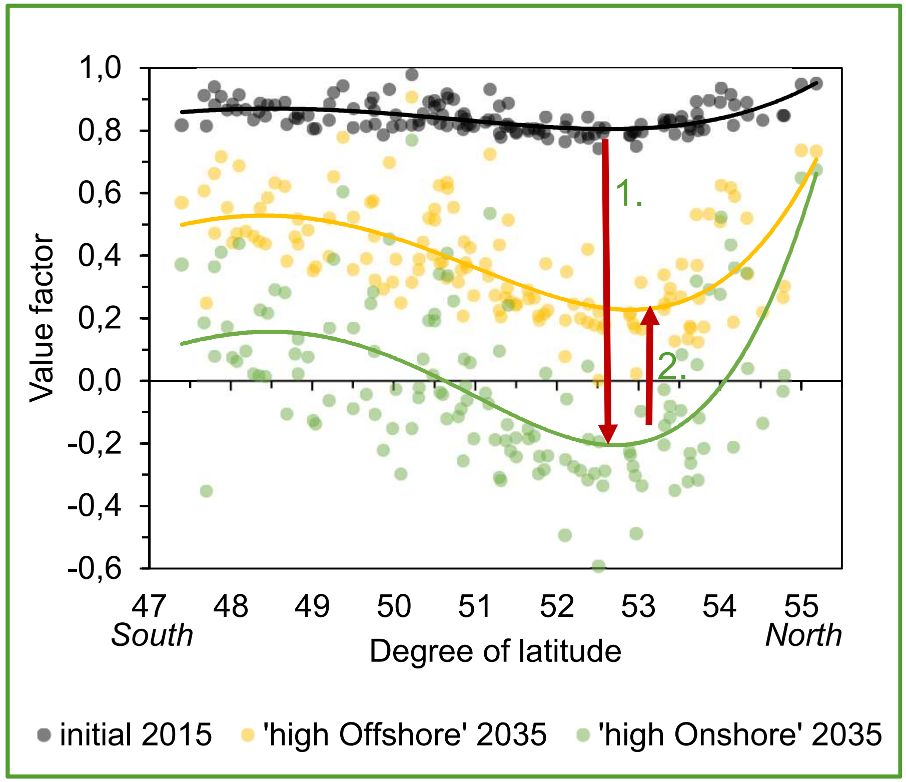
2. PV and onshore wind are more volatile than offshore wind

! Offshore wind value factors resist more against increasing market shares

Analysing spatial wind generation patterns becomes crucial

Regional distribution of wind value factors

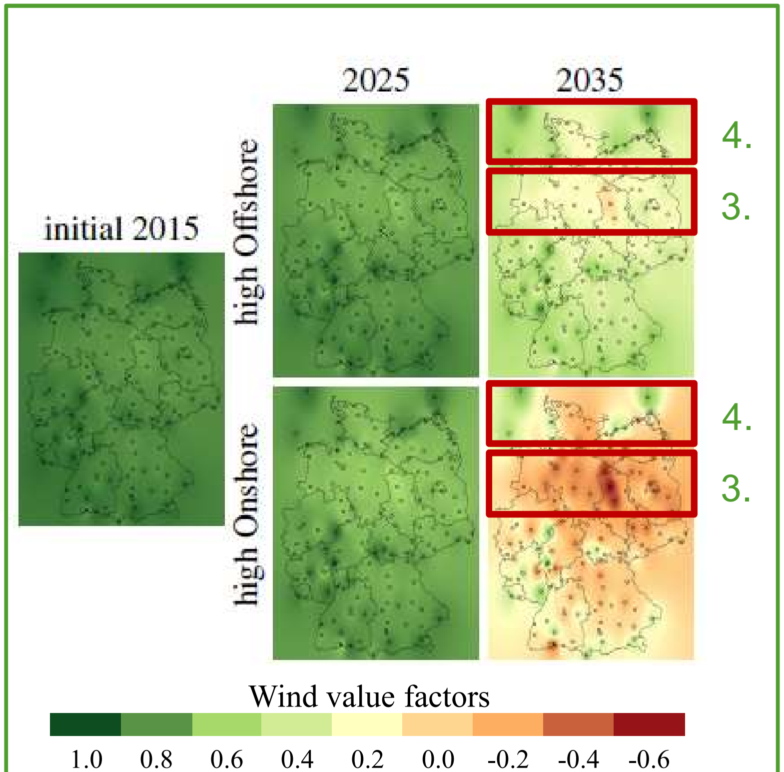


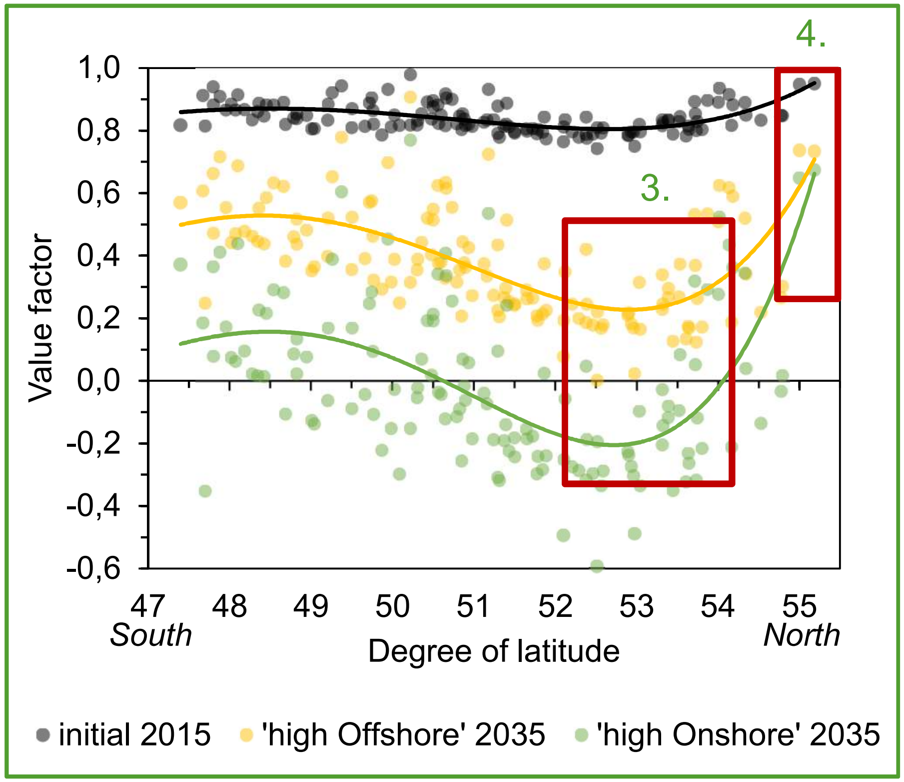


1. Increasing spatial spread until 2035
2. Higher shares of offshore wind power reduces spatial differences
3. High wind power density in the coastal hinterland
4. Steadier feed-in at offshore and nearshore locations

Analysing spatial wind generation patterns becomes crucial

Regional distribution of wind value factors





1. Increasing spatial spread until 2035
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Key Findings and Conclusion

1. Onshore vs. Offshore wind capacity mix:
   - High shares of offshore wind in the capacity mix seem to be beneficial for both, the market value of onshore as well as offshore wind generation.
2. Cannibalization effect:
   - Due to stronger feed-in intermittency onshore wind value factors decrease stronger then offshore wind.
3. Evolution of regional market values:
   - Increasing wind market shares foster differences between regional value factors throughout Germany.

Analysing site-specific (regional) market values becomes significantly more important for system planners as well as wind farm operators

Thank you…

Contact

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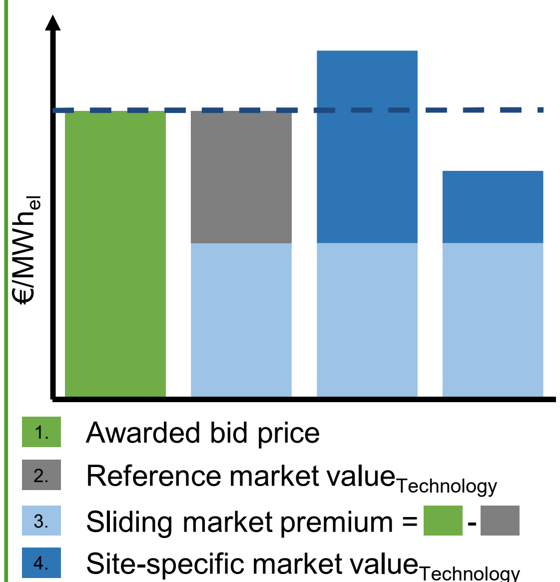
Need for market value assessment

Three perspectives

1. Investors perspective:

Where to invest and which plant design to choose?

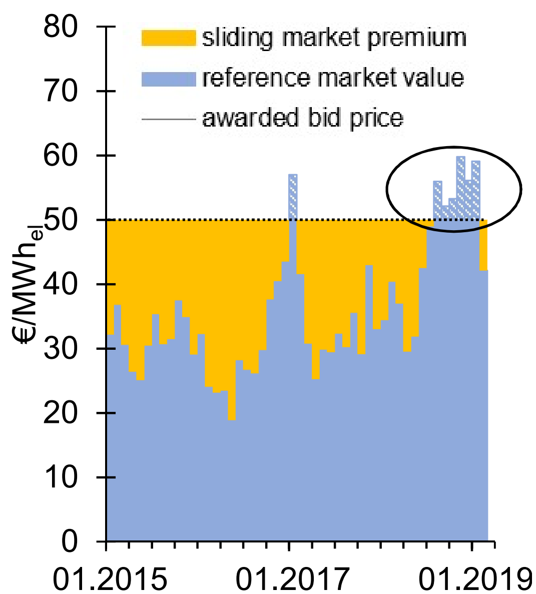
Achieve additional profits from site over-performance



2. Auction bidder:

Which auction price to bid?

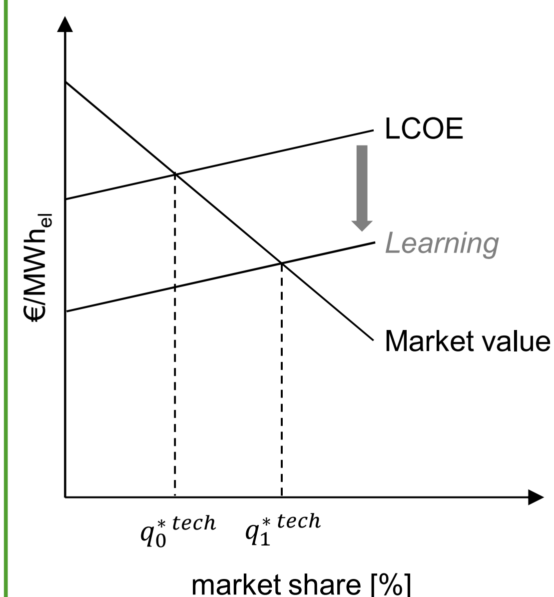
Anticipate adequate upward risks within the bid price



3. Central planer:

How to integrate high shares of volatile renewables energies?

Increase the optimal share of renewable energies

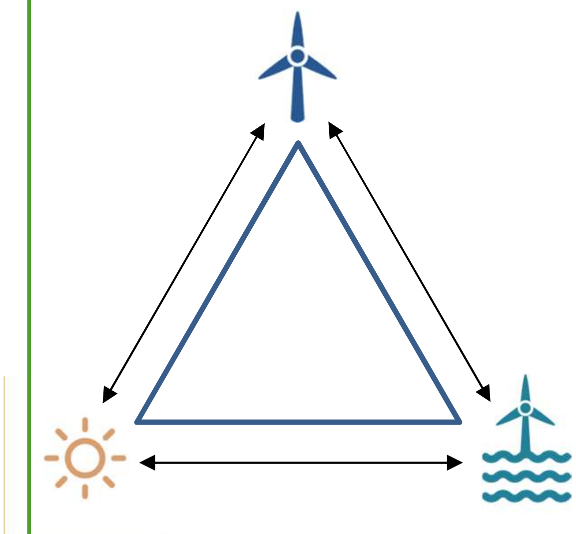


Three deployment strategies to stabilize market values

Level out VRE feed-in fluctuation to mitigate the value drop

1. Technological diversity

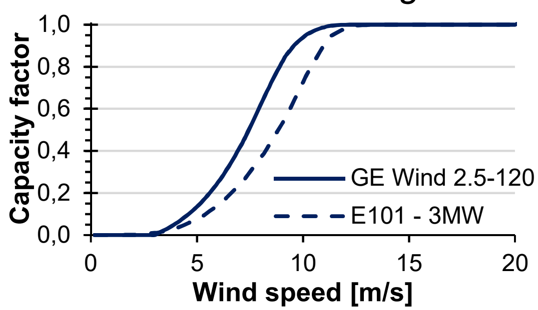
Deployment diversification



- Optimised portfolios can flatten the aggregated VRE feed-in

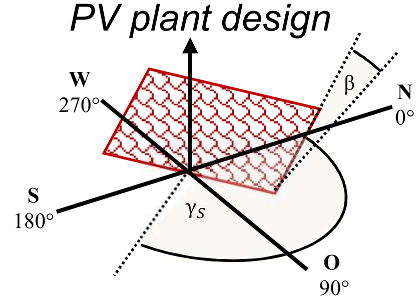
2. Technological design

Wind turbine design



- Higher hub heights and advanced power curves

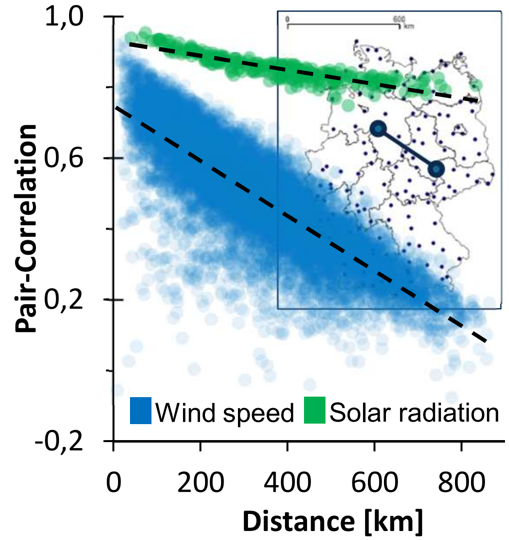
PV plant design



- Feed-in pattern depends on tilt, orientation and tracking

3. Geographical diversity

Geographically distributed VRE generation



- Promising potential especially for wind energy due to decreasing pair correlation of generation over distance

Source: Own visualization, calculation of pair-correlations over distances based on data from DWD (German Meteorological Office)

Literature research

Deployment strategies

1. Technological diversity

- Optimised portfolios can flatten the aggregated VRE-feed-in
- Deployment diversification between offshore and onshore wind as well as PV and other VRE

2. Technological design

- Higher **hub heights** and **advanced performance curves** stabilize wind power generation
- **Tilt angle** and **east-to-west orientation** impact the PV feed-in

3. Geographical diversity

- Geographically distributed VRE generation
- Promising potential especially for wind energy due to decreasing pair correlation of generation over the distance

Strategy application in dispatch models

Author	***1.***	***2.***		***3.***
		PV	***Wind***	
Obersteiner and Saguan (2011)	x			x
Höfling (2013)	x			
Schaber (2014)	x			
Gerlach and Pape (2014)		x		
Fernahl et al. (2015)	x			
Hartner et al. (2015)	x	x		
Winkler et al. (2016a)	x			
Lamont (2008)	x			
Mills and Wiser (2012)	x			
Nicolosi (2012)	x			
Hirth (2013)	x			
Winkler et al. (2015)	x			
Hirth (2015)	x		x	
Mills and Wiser (2015)	x			x
Hirth and Müller (2016)			x	
Hirth (2016)	x			
Simshauser (2018)	x			
Johansson and Thorson (2016)			x	
Dalla Riva (2016)			x	
May (2017)			x	

Research gap: Impact of the wind capacity mix on overall as well as regional market values

Capacity development

Germany

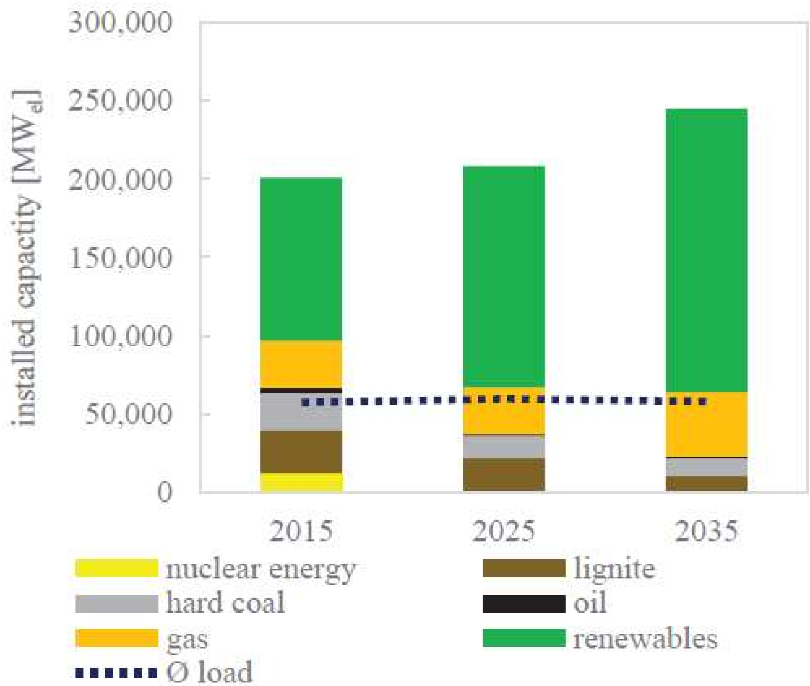


Figure A.20: Capacity development in Germany, according to ENTSO-E (2016b) and Bundesnetzagentur (2016a,b)

Neighbouring Countries

Figure A.21: Capacity development in neighbouring countries, according to ENTSO-E (2016b,a)

Fuel and CO2 prices

Table A.4: Fuel [EUR/MW_{th}] and CO_2 [EUR/t] prices

Fuel	2012	2015	2025	2035
Lignite	3.10	3.10	3.10	3.10
Gas	25.28	20.07	29.82	31.00
Oil	53.42	28.00	55.75	60.19
Coal	13.30	9.14	9.37	10.20
Uranium	2.50	2.50	2.50	2.50
CO_2	7.51	7.65	21.09	32.00

Schubert (2016), energate (2016) and Bundesnetzagentur (2016b)

Generation duration curves

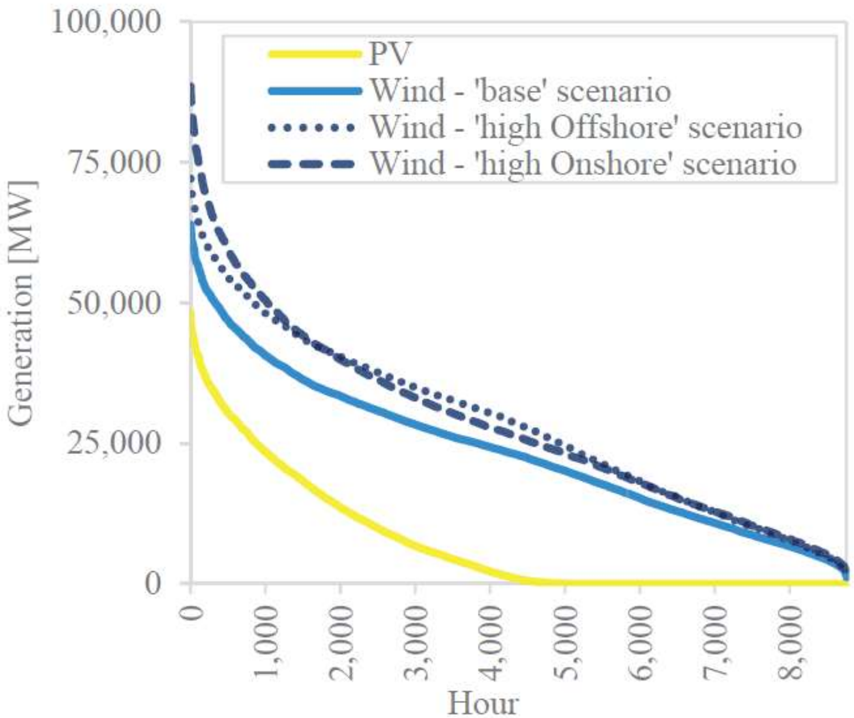


Figure 8: Power duration curve

Historical data

German value factors

	Market share			
Year	Wind	Onshore wind	Offshore wind	PV
2000	1,60%	1,60%		0,00%
2001	1,80%	1,80%		0,00%
2002	2,70%	2,70%		0,00%
2003	3,10%	3,10%		0,10%
2004	4,10%	4,10%		0,10%
2005	4,40%	4,40%		0,20%
2006	4,80%	4,80%		0,30%
2007	6,20%	6,20%		0,50%
2008	6,30%	6,30%		0,70%
2009	6,50%	6,50%		1,10%
2010	6,00%	6,00%		1,90%
2011	8,00%	8,00%		3,20%
2012	8,10%	8,10%		4,20%
2013	8,10%	8,00%	0,10%	4,90%
2014	9,10%	8,90%	0,20%	5,70%
2015	12,30%	11,00%	1,30%	6,00%
2016	12,10%	10,20%	1,90%	5,90%
2017	16,10%	13,40%	2,70%	6,00%
2018	17,50%	14,50%	3,00%	7,10%

	Value factor			
Year	Wind	Onshore wind	Offshore wind	PV
2000				
2001	0,97	0,97		1,21
2002	0,95	0,95		1,35
2003	0,91	0,91		1,33
2004	0,98	0,98		1,22
2005	0,94	0,94		1,18
2006	0,90	0,90		1,30
2007	0,89	0,89		1,18
2008	0,93	0,93		1,25
2009	0,93	0,93		1,16
2010	0,95	0,95		1,11
2011	0,92	0,92		1,11
2012	0,88	0,88		1,04
2013	0,85	0,86	0,89	0,98
2014	0,86	0,86	0,91	0,98
2015	0,85	0,83	0,88	0,98
2016	0,86	0,85	0,93	0,93
2017	0,82	0,80	0,88	0,93
2018	0,86	0,84	0,93	0,98

ELTRAMOD calculates cost minimized power plant dispatch and market prices

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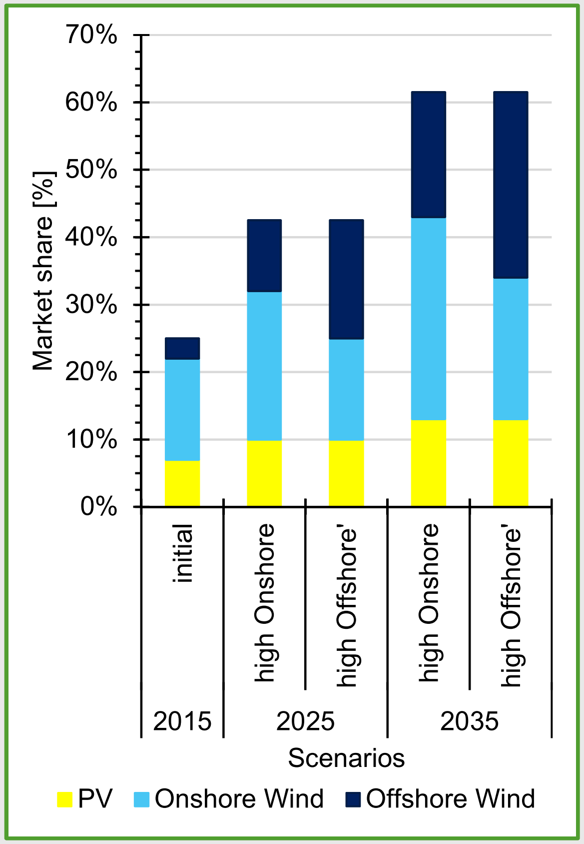
Effects of the **Technological Capacity Mix** on Regional Market Values

Scenario framework



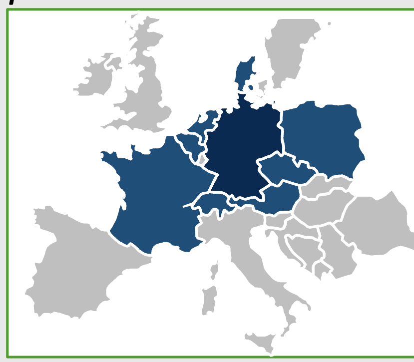
Aggregation of total German **VRE feed-in**

Dispatch model *ELTRAMOD*

Target function:

- Minimization of total system costs

Spatial resolution



Data input:

- Power plant characteristics
- Fuel and CO_2 allowances prices
- Load of demand and VRE feed-in of Germany's neighbours (8760h)

Restrictions:

- Electricity balance
- Must-run requirements for CHP
- Ramping constraints
- NTC restrictions

Results

Hourly plant dispatch

Hourly power market prices

Commercial flows

Curtailment

Total generation costs

Welfare

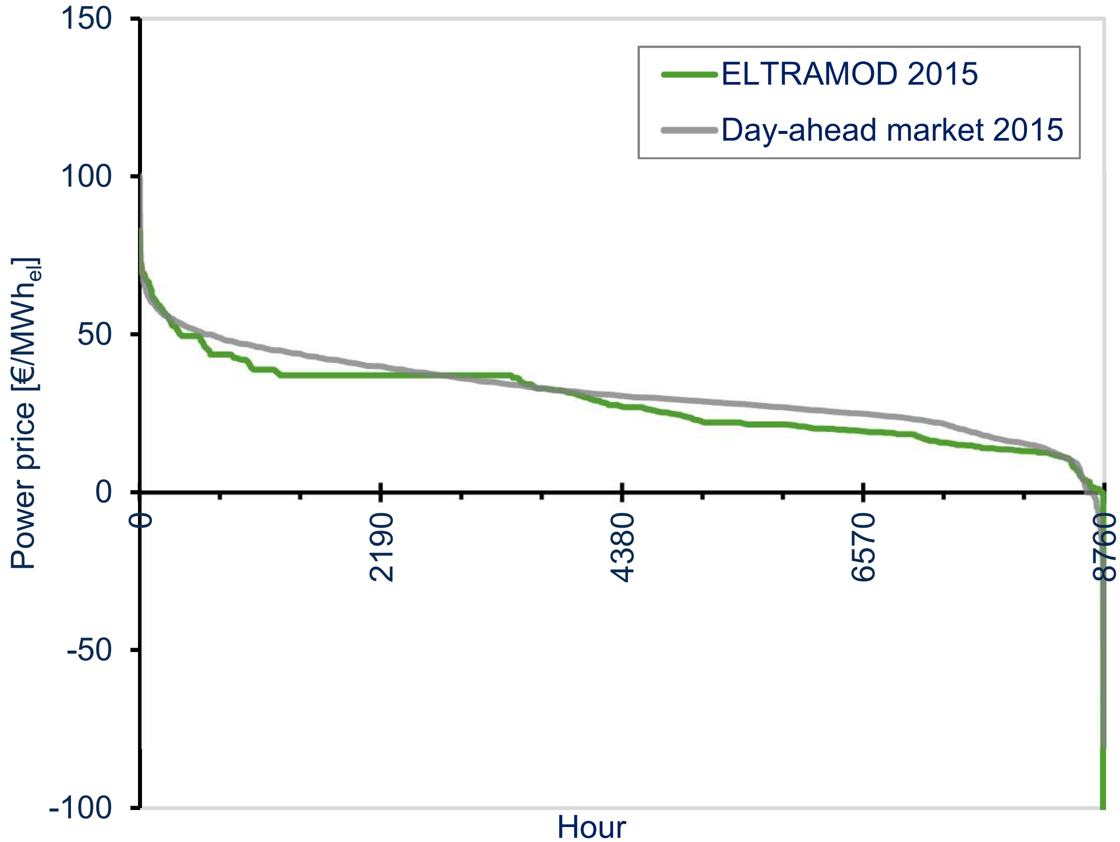
Market Value Assessment

1. Value factor development per technology
2. Regional value factor distribution

Can the fundamental model explain German power prices?

KPIs and price duration curve for 2015 as **benchmark**

Price duration curve



KPIs

	€/MWh
MAE sort.	4.02
RSME sort.	8.27
Ø ELTRAMOD price	28.24
Ø real price	31.63

Comments

- Modelled price match the price duration curve well
  - Slight underestimation of base load prices
  - Overall price level estimation fits
- ELTRAMOD prices include inaccuracies of modelled VRE feed-in