THE EFFECT OF COARSE WEATHER DATA RESOLUTION ON ENERGY SYSTEM MODEL RESULTS

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MOTIVATION

Current situation: weather data resolution

Modeling the weather requires fine resolutions

<u>Wind (reanalysis data)</u>

- Steady increase of spatial resolution (e.g. ERA-Interim=79km, ERA-5=31km), regional reanalysis models up to 1km
- **Relevance of spatial resolution**
  - Near-surface wind speed depends on surface roughness which can vary within short distances
  - Large spatio-temporal variability in complex terrain

<u>PV (satellite data)</u>

- Since first solar irradiance retrievals in 1960s, continuous improvement of measurement capabilities and spatial resolutions (Huang et al, 2019)

- **Relevance of spatial resolution:**
  - Clouds can have small sizes (e.g. cumulus clouds with around 1km width)

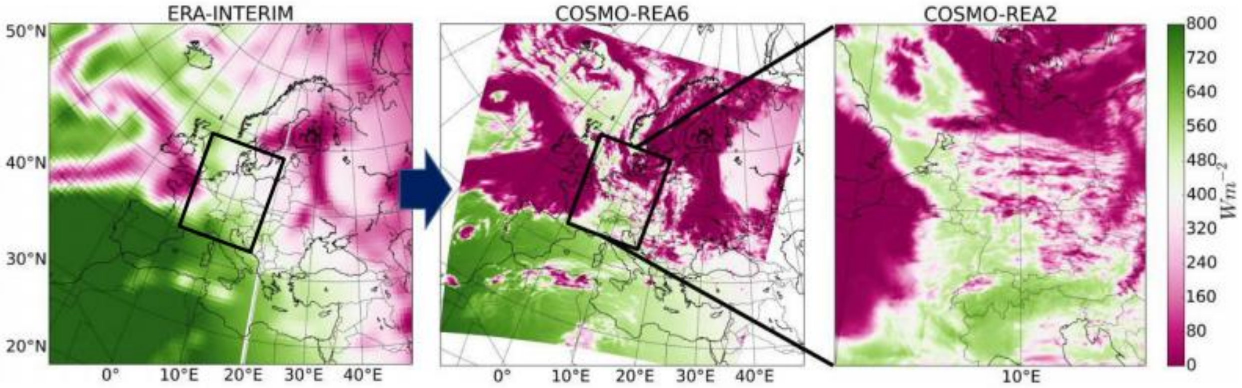
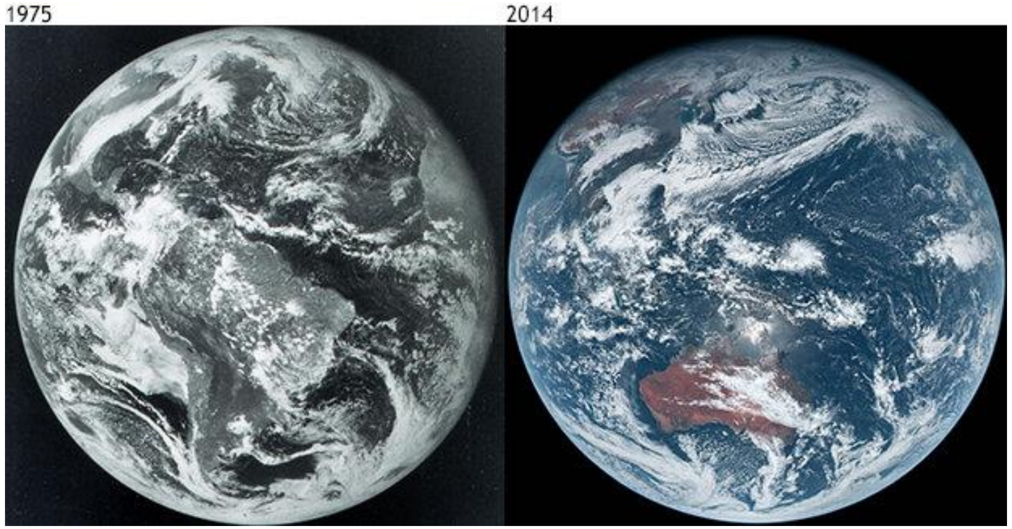


Illustration of the same meteorological situation (GHI) with different reanalysis datasets, Frank 2018
https://uol.de/f/5/inst/physik/ag/enmet/download/fachtagung_2016/2016_04_21/3_ENMET_fachtagung.pdf



Comparison of GOES-1 satellite and Himawari-8 satellite (NOAA satellites go HD with GOES-R | NOAA Climate.gov)

Huang et al., (2019) Estimating surface solar irradiance from satellites: Past, present, and future perspectives. *Remote Sensing of Environment, 233*

Current situation: Energy system modeling

Tendancy towards finer resolutions in **energy system modeling:**

- Shift from one bus per country to systems with many buses (e.g. *pypsa-eur*: 1024 for Europe, *Elmod*: 624 grid nodes for Germany (Gils, 2019))

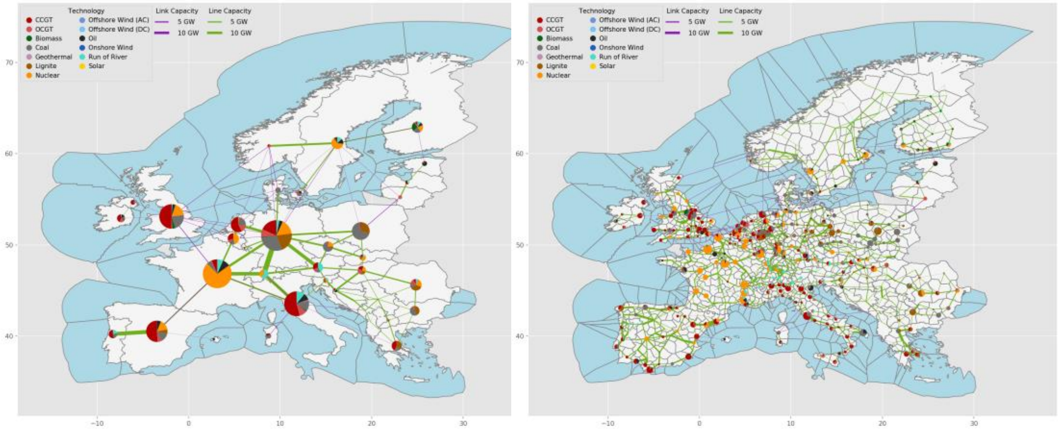


Illustration of ESM with different spatial resolutions (https://pypsa-eur-sec.readthedocs.io/en/latest/spatial_resolution.html)

Why higher spatial resolutions?

- Decentralized, renewable energy systems require regionalized information in contrast to conventional power plants
- Single points of failure in energy systems (e.g. line overloading)
- Surveys (Gregow et al. 2016) confirm the need from energy users who wish higher spatio-temporal resolution of atmospheric models
- Effect of clustered information unpredictable

Gregow et al., (2016) Worldwide survey of awareness and needs concerning reanalyses and respondents views on climate services. *Bulletin of the American Meteorological Society, 97(8)*
Gils et al. (2019), Comparison of spatially and temporally resolved energy system models with a focus on Germany's future power supply Applied Energy 255 (2019)

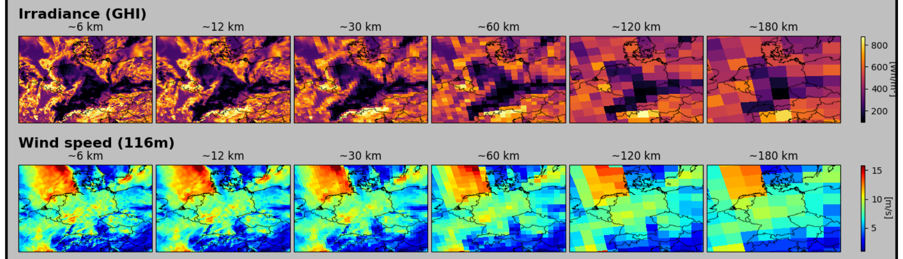
Motivation

Does spatial resolution of weather data matter for energy system modeling?

CASE STUDY

Study design

Downsampled meteorological input



Meteorological/energetic potential

PV

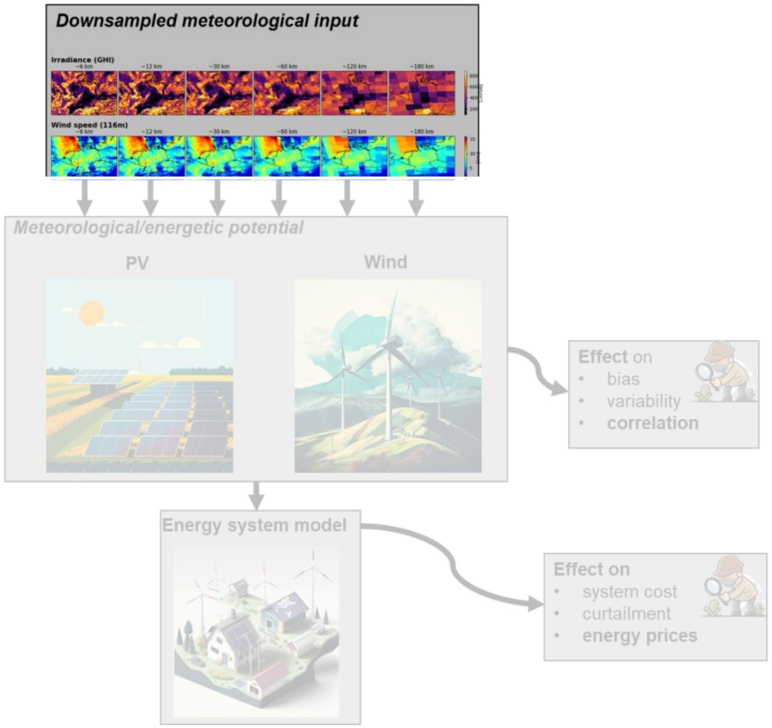
Wind

Effect on
- bias
- variability
- correlation

Energy system model

Effect on
- system cost
- curtailment
- **energy prices**

Model chain: Meteorological data



- Dataset: COSMO REA-6 (6 km), hourly
  - Wind speed: 6 vertical levels
  - Global Horizontal Irradiance (direct & diffuse)
- Artificially decrease spatial resolution by spatial averaging
  - 12, 30, 60, 120 and 180km

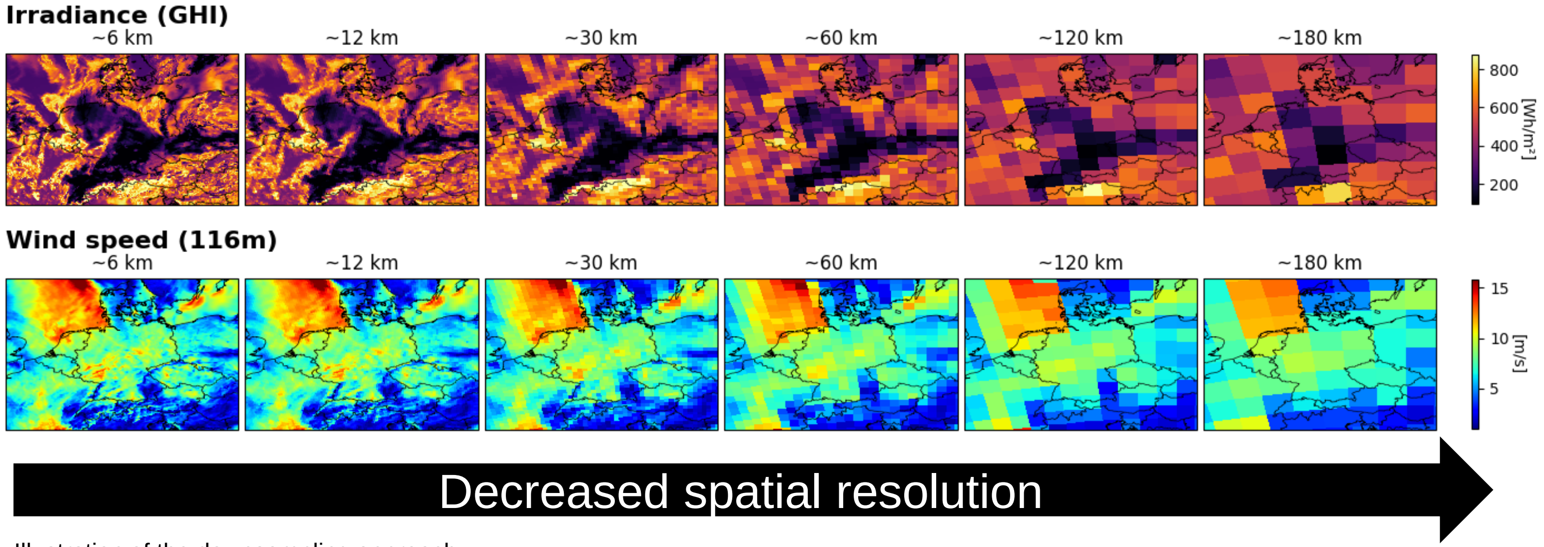
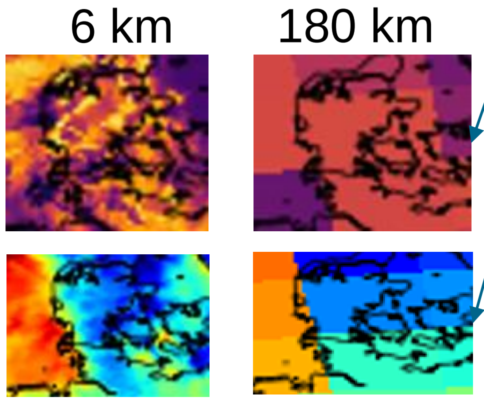
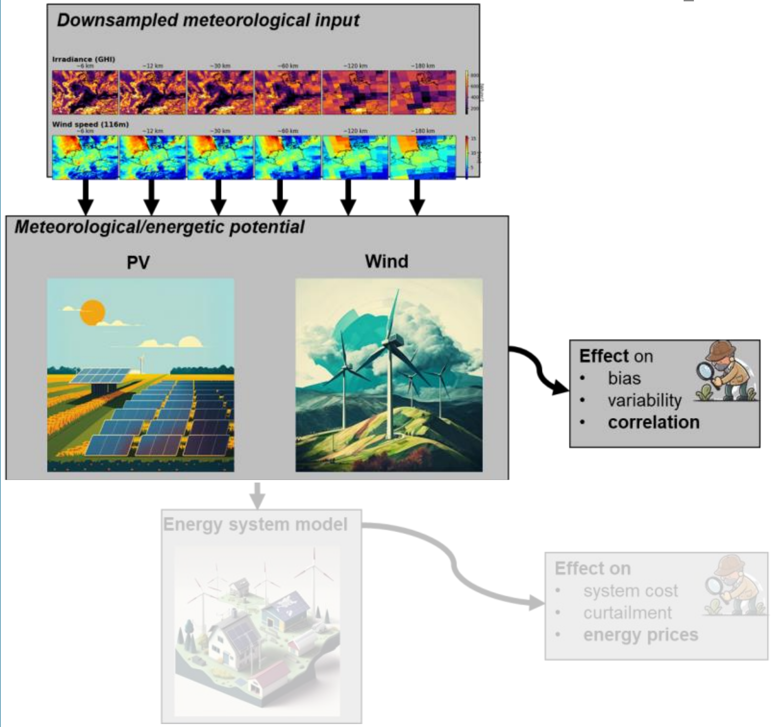


Illustration of the downsampling approach



Spatial smoothing efefct zoomed in Denmark

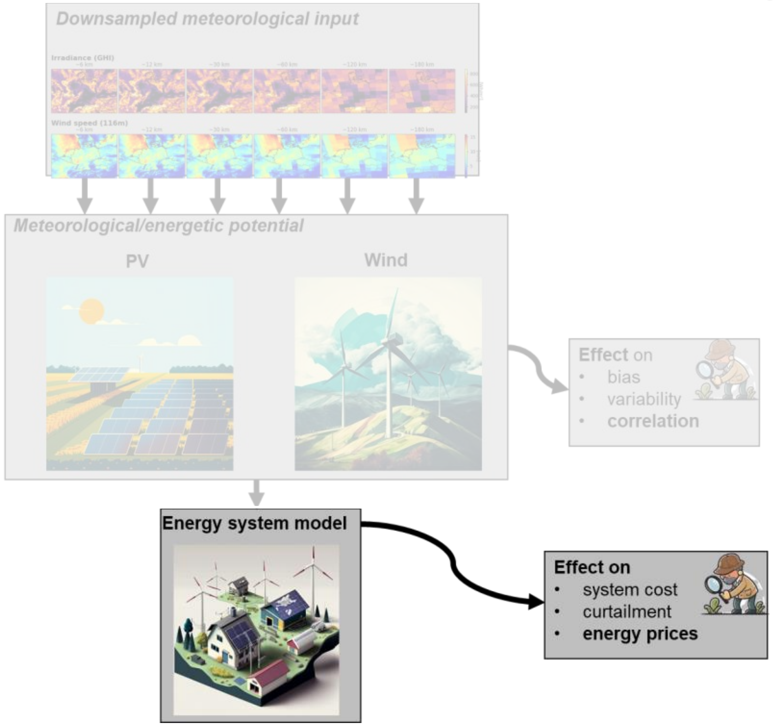
Model chain: Capacity factors



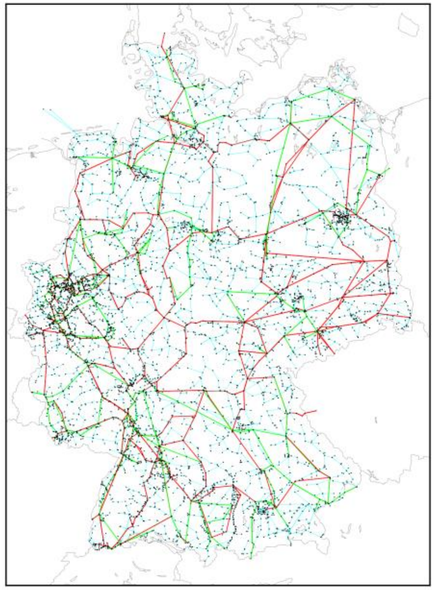
- Convert meteorological parameters into renewable energy capacity factors using feedinlib
  - Reference turbines selected based on wind potential
  - Characteristic PV cell
  - Bilinear interpolation for each wind/PV site

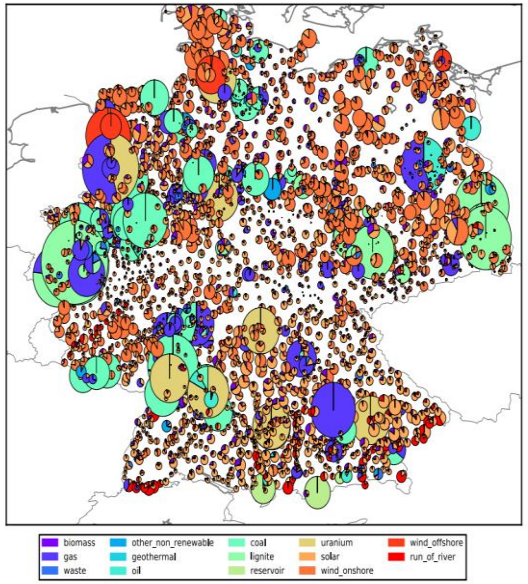
- Metrics:
  - Bias
  - Variability
  - Correlation length

Model chain: Energy system model



- Etrago (PyPSA based) model
  - 11320 buses, 17111 generators, 3800 storage units, year: 2011





- Solve optimal power flow model (LP) using a rolling horizon approach (7 days, 2 days look-ahead), cyclical storage constraint

- Systematically study the effect of renewable capacities and technology phase-outs
  - Existing renewable capacities multiplied by 2, 5 and 10
  - With or without nuclear power plants

  → 4*6*2=48 simulations

Revisiting merit-order/dual representation

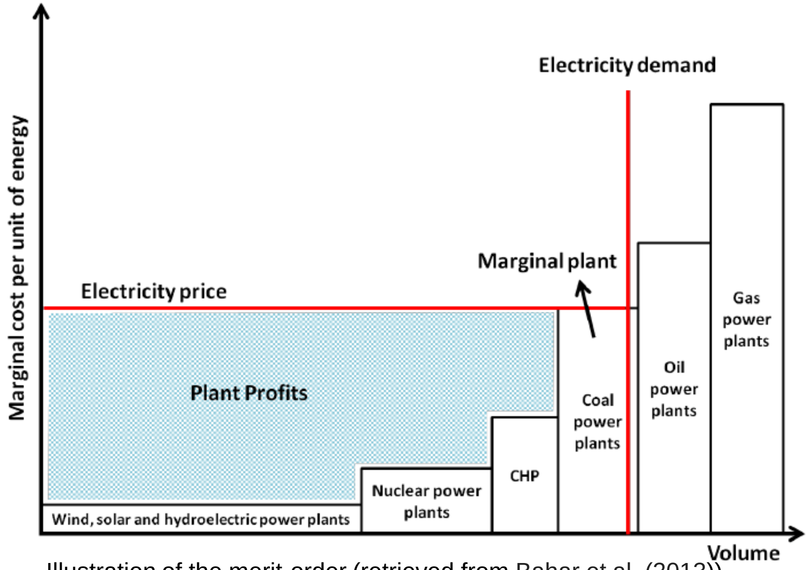


Illustration of the merit-order (retrieved from Bahar et al. (2013))

Merit-order

- The most expensive (marginal cost) power plant is price-setting
- Descriptive, not prescriptive → valid for all market settings

Energy system model formulation (Optimal power flow, adapted from Brown et al. (2017))

$$\min_{h_{n,s,t},\, g_{n,r,t},\, h_{n,s,t}} \quad \textit{Total System Cost}$$

$$\text{s.t.} \quad \ldots \textit{(Techno-economical constraints)}$$

$$\sum_r g_{n,r,t} + \sum_s h_{n,s,t} + \sum_l f_{l,t} = D_{n,t} \qquad \text{(energy balance)} \qquad : \lambda_{n,t}$$

Variables
$g_{n,r,t}$… generation
$h_{n,s,t}$… storage
$f_{l,t}$… flows
$\lambda_{n,t}$… prices (duals)

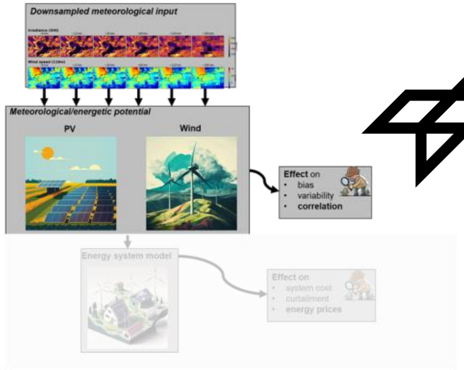
Dual of energy balance:

The dual variables are the marginal cost of a unit increase in energy in time interval t for node n (Sherali et al.,1982)

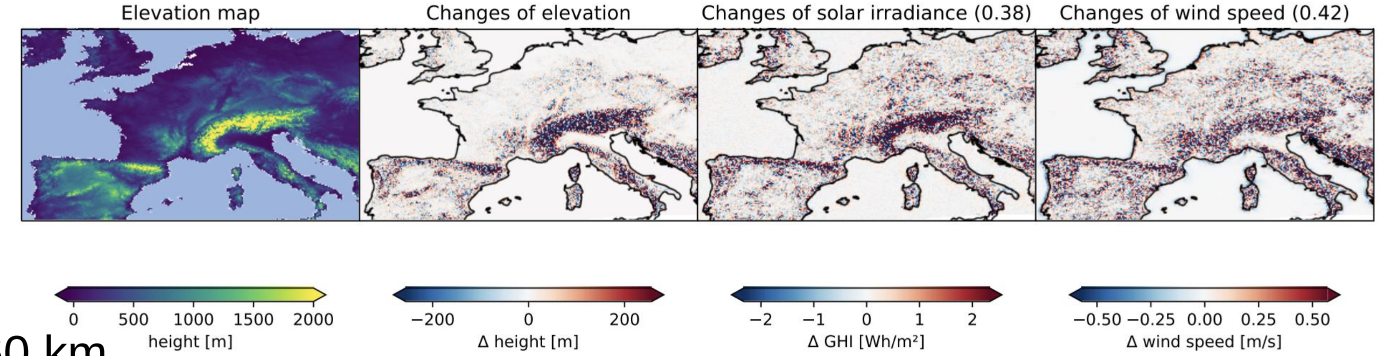
Brown, T., Hörsch, J., & Schlachtberger, D. (2017). PyPSA: Python for power system analysis
Sherali, H. D., Soyster, A. L., Murphy, F. H., & Sen, S. (1982). Linear programming based analysis of marginal cost pricing in electric utility capacity expansion. *European Journal of Operational Research*, *11*(4),
Bahar, H., & Sauvage, J. (2013). Cross-Border Trade in Electricity and the Development of Renewables-Based Electric Power

RESULTS

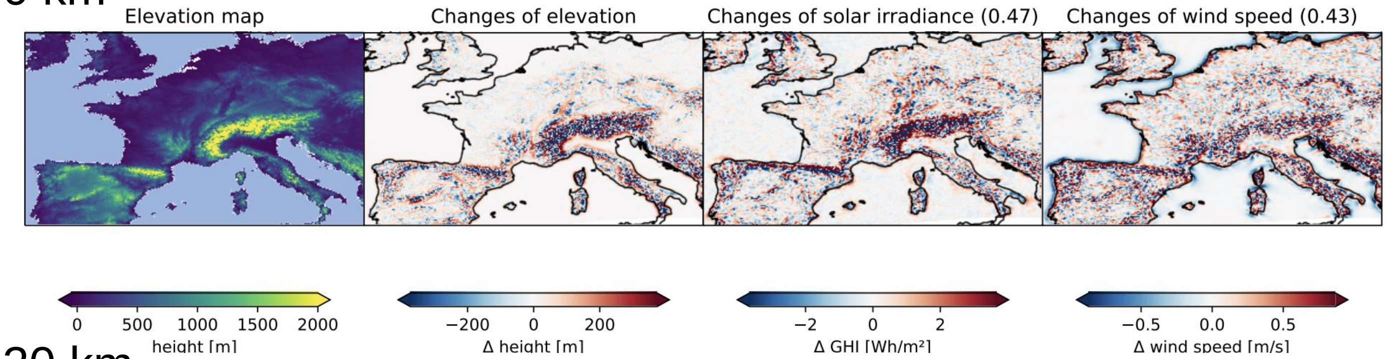
Changes in renewable energy: bias



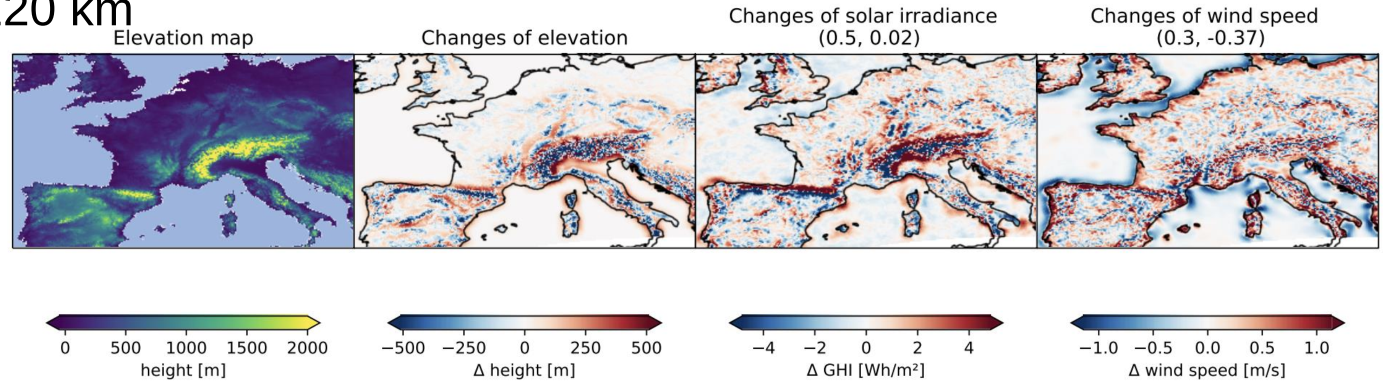
30 km



60 km



120 km



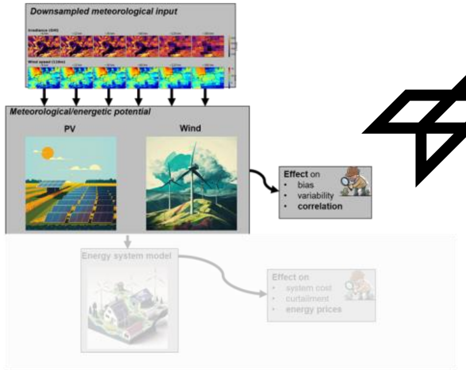
Solar irradiance

- **Positive correlation:** Overestimations in valleys, underestimations at summits → indication of valley-specific effects such as clouds/fog
- Minor sea-land interaction compared to orographic impact
- Smaller bias than wind speed particularly when considering capacity factors

Wind

- Strong impact of sea-land interaction → land surface show overestimations **(negative correlation)**
- Similar effect in complex orography like solar irradiance **(positive correlation)**
- With larger distances the impact of sea-land interactions become more important than orographic impact

Changes in renewable energy: variability



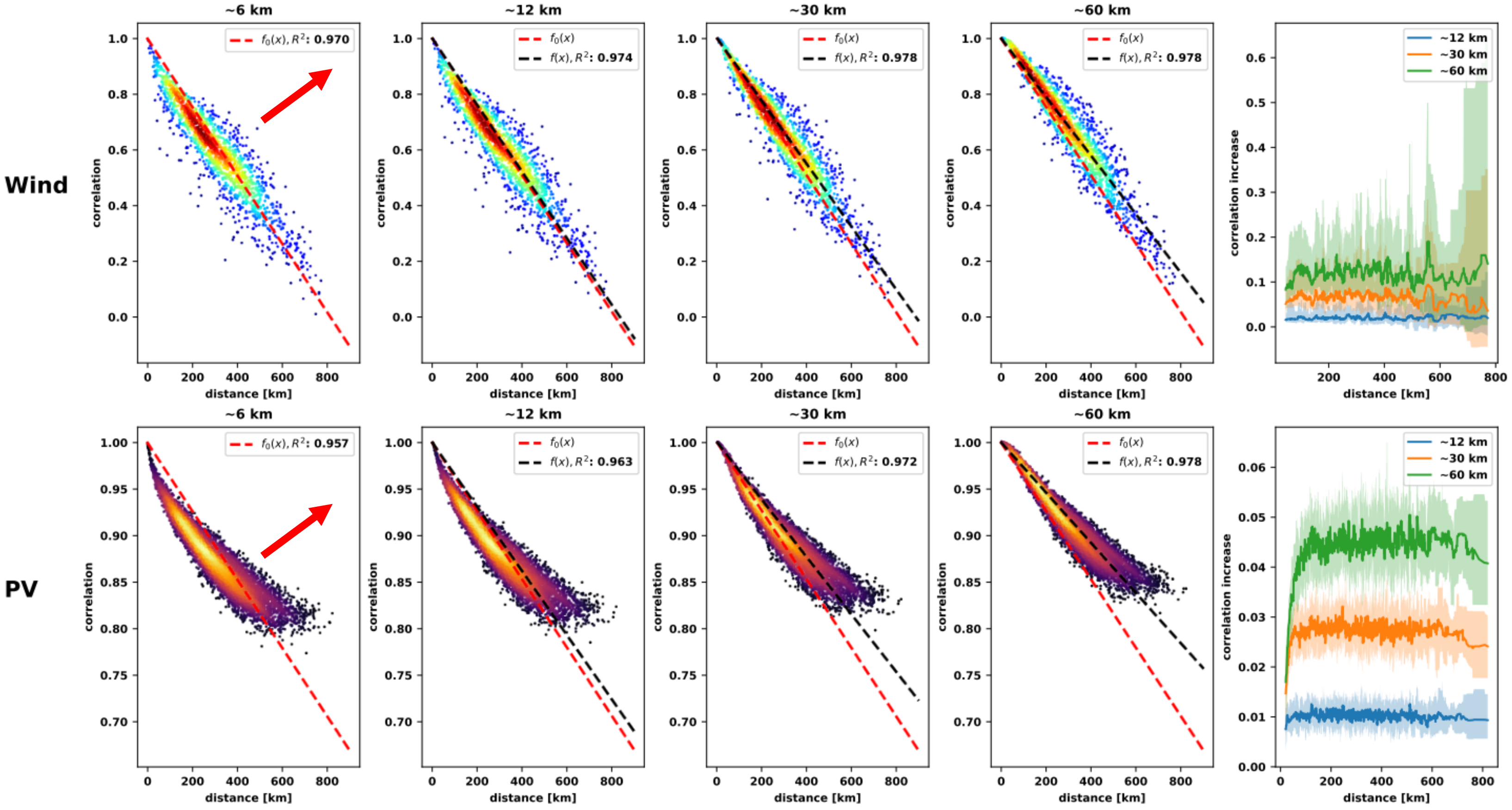
- Spatial smoothing increases the correlation length between sites: *sites become more equal*

Wind

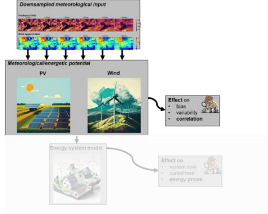
- Much stronger effect on wind than on PV (approx. 5x as large)
- Strong linearization of exponential decay function, spread decreases

PV

- More changes to curvature
- Less changes in absolute values



Changes in renewable energy: variability



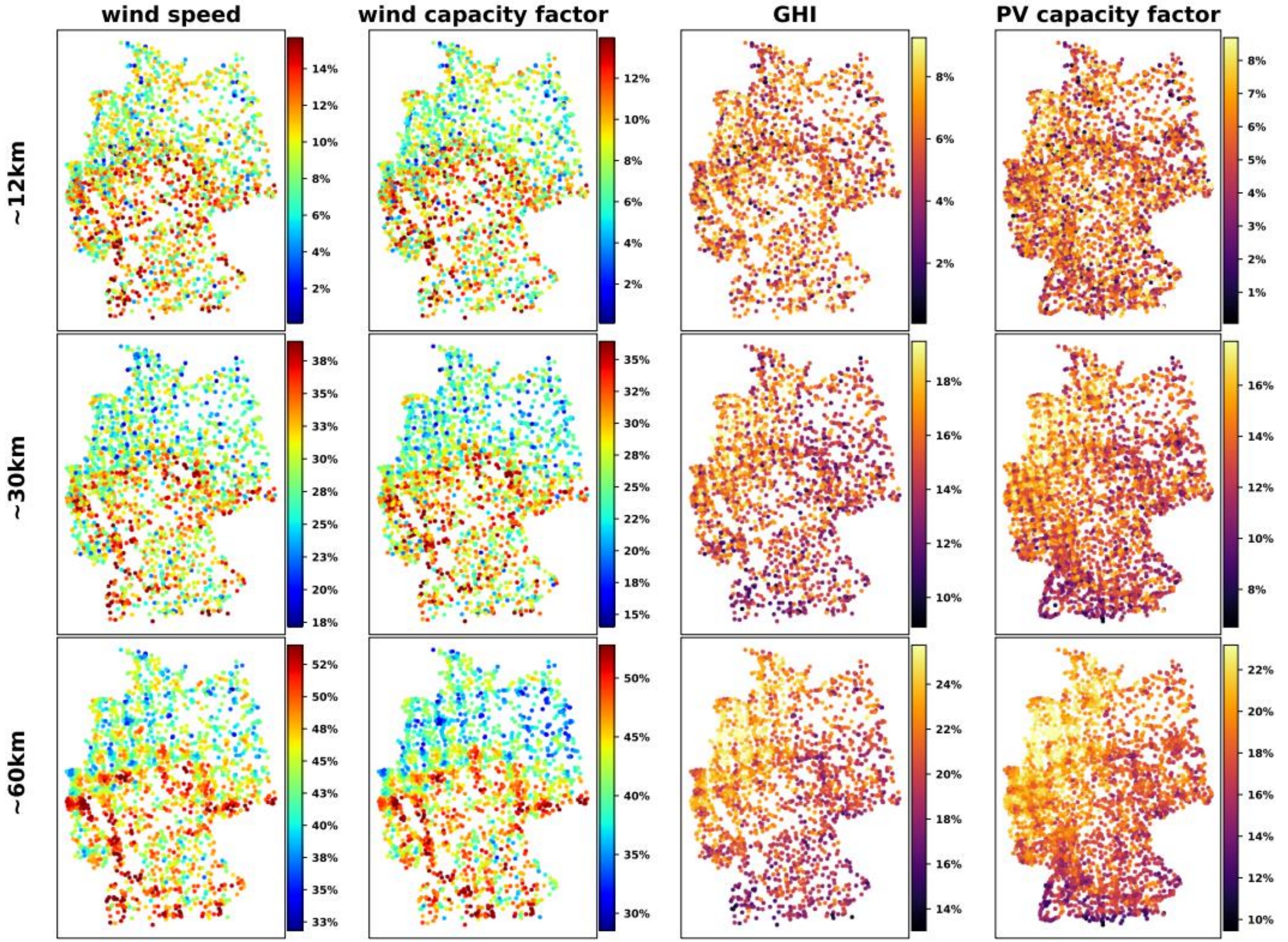
Spatial smoothing leads to large variability losses for short distances

Wind

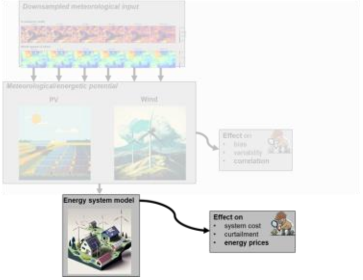
- North-south separation
- Southern Germany: 10-14%(12 km), 30-40% (30 km), 40-50% (60 km)
- Northern Germany: 2-10% (12 km), 20-30% (30 km), 30 to 40% (60 km)
- → Strong influence of the topography

PV

- North East-west separation
- Variability loss approximately half as large compared to wind



Changes in electricity prices

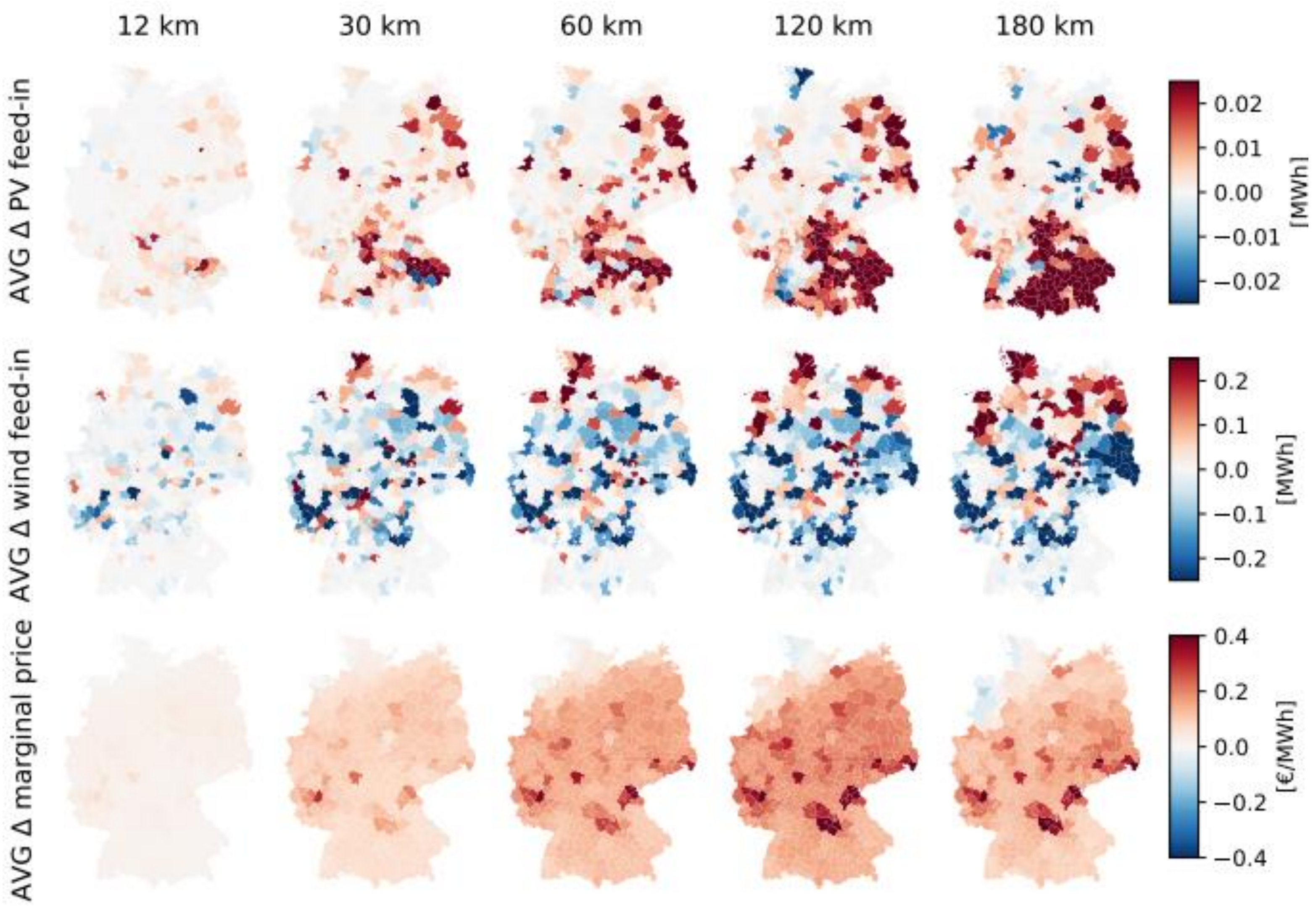


Effect on PV much smaller than on wind (approx. 10x)

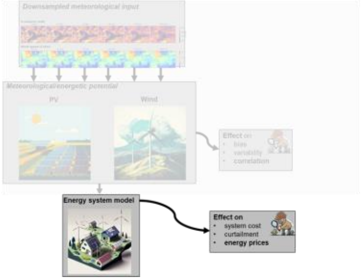
Wind:
- Sea regions show an overestimation induced by the close sea surface
- In the other regions, large underestimations are observable

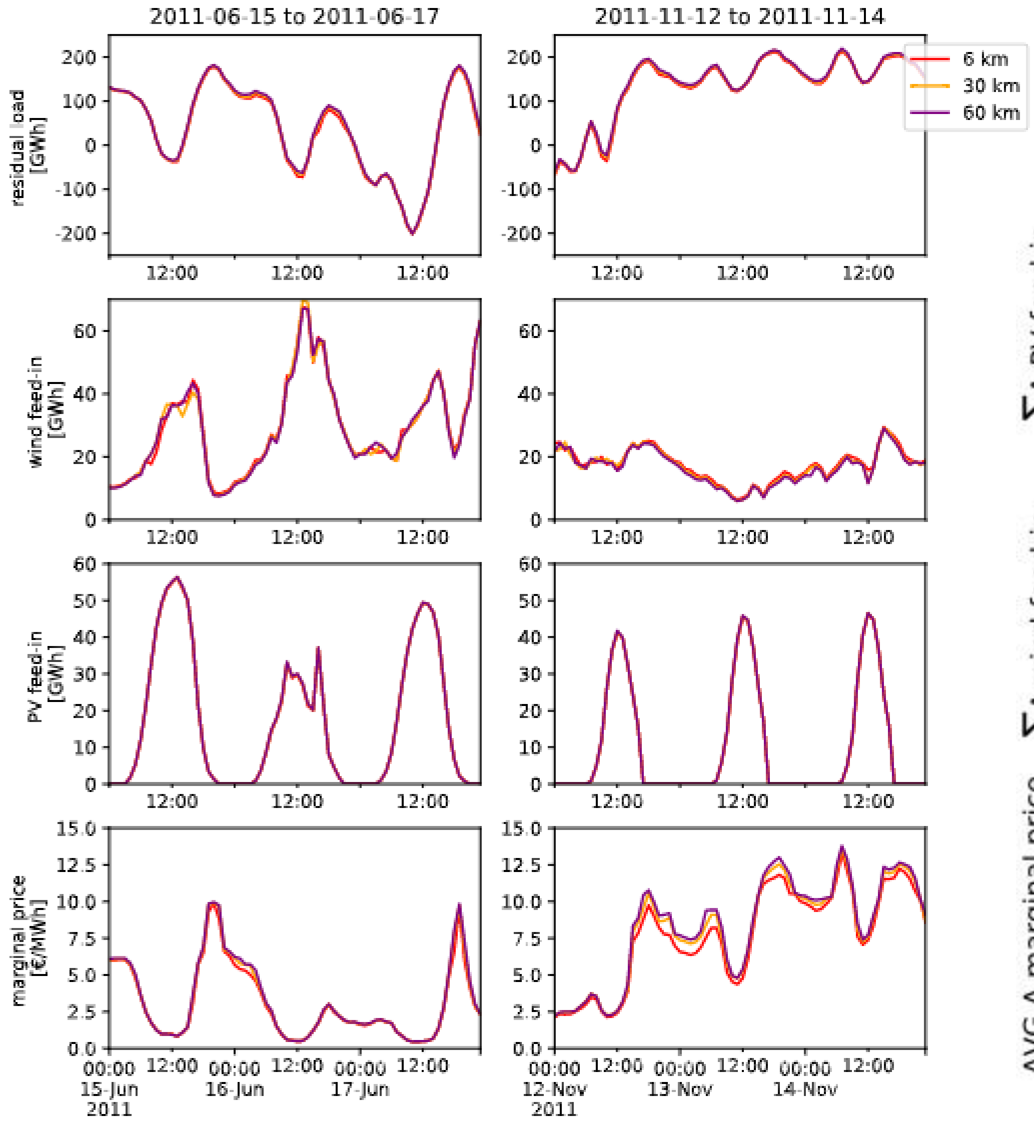
PV
- In most cases overestimation, yet small

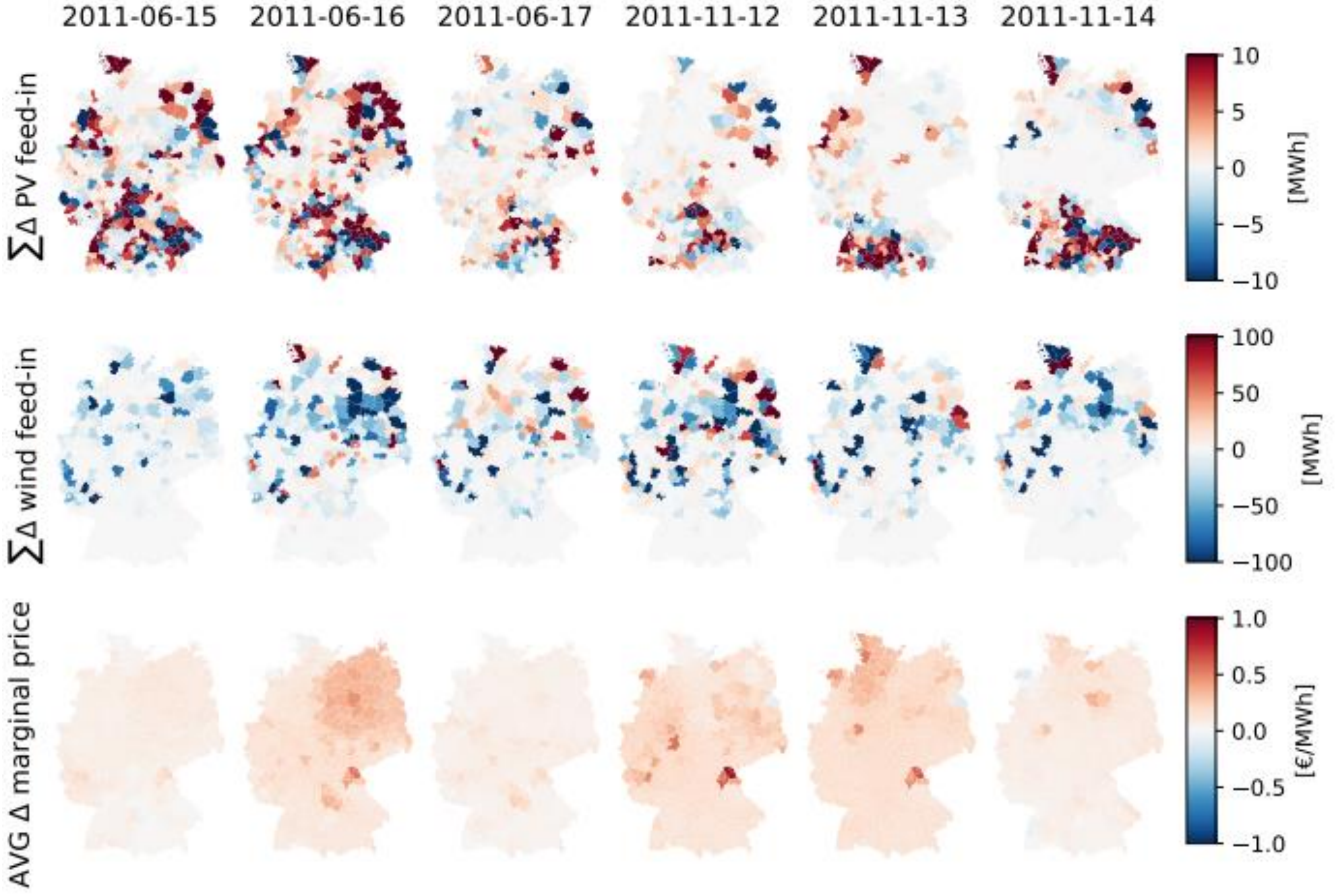
Prices
- In most cases overestimation of electricity prices, except close to the sea
- Prices show inverse pattern of wind → Wind as driving force for price changes



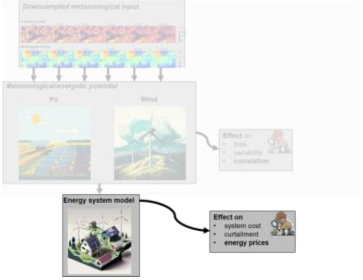
Changes in electricity prices



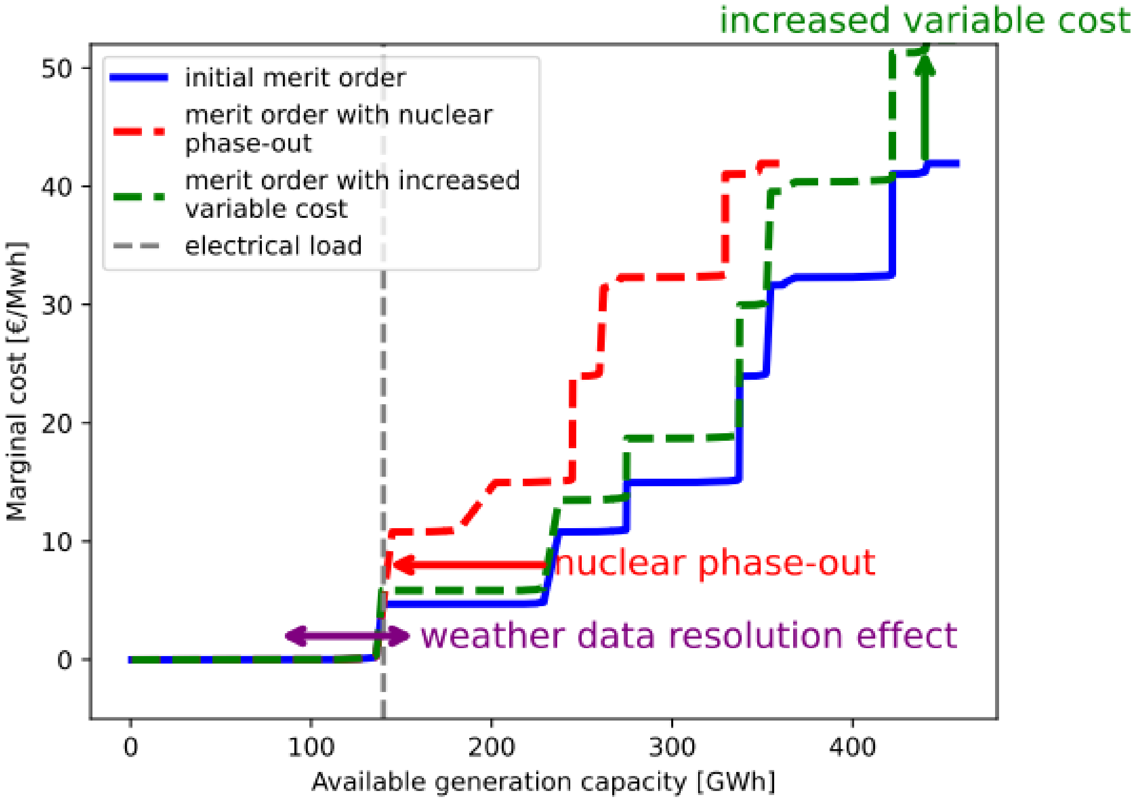


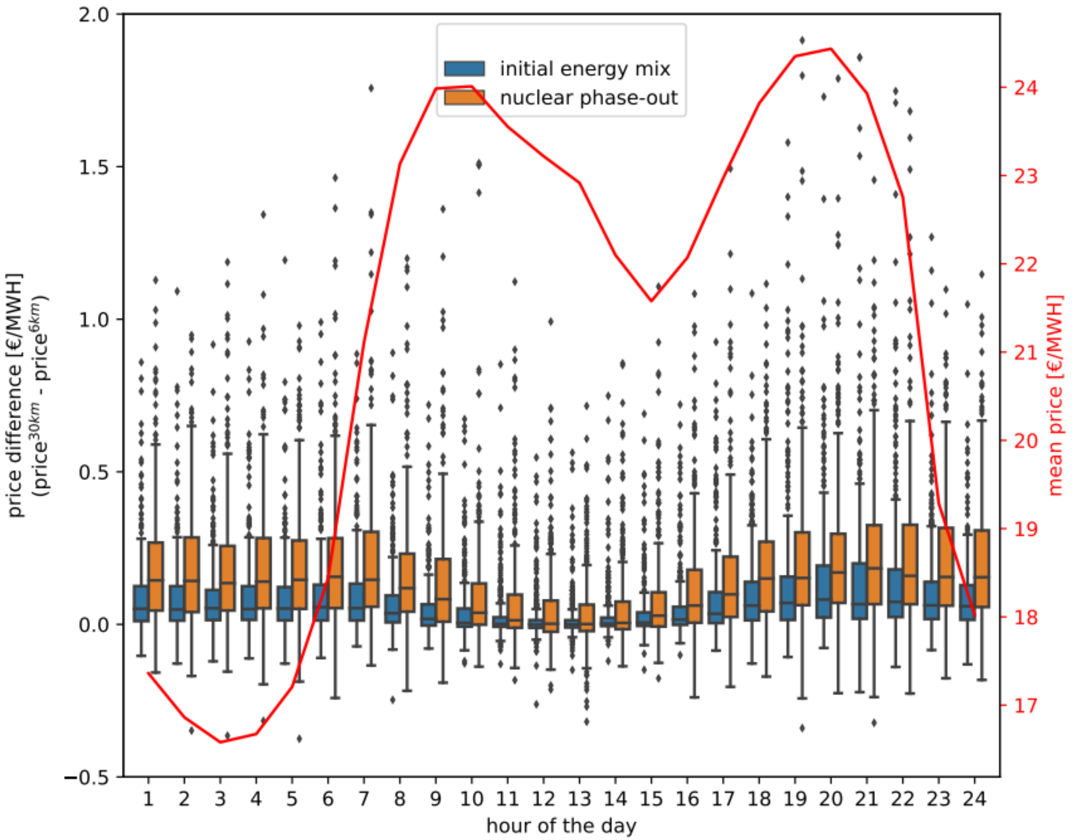


Nuclear phase-out



- Energy system models are highly sensitive technology/capacity assumptions
- The impact of the weather data resolution effect can be explained by the merit order
- Nuclear phase-out increases the spread of electricity prices by a factor of 2x already for spatial averaging of 30 km

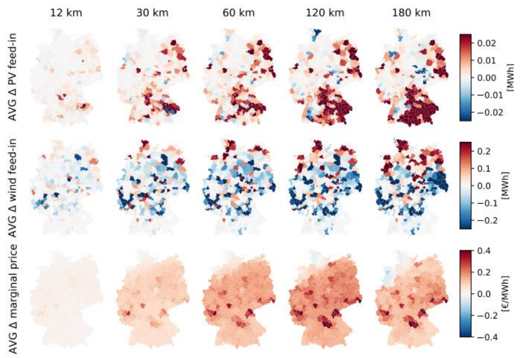




CONCLUSIONS

Conclusions

- Lower weather data resolutions can have a **large impact** on the **spatio-temporal characteristics of renewable energy potential** and **electricity prices**

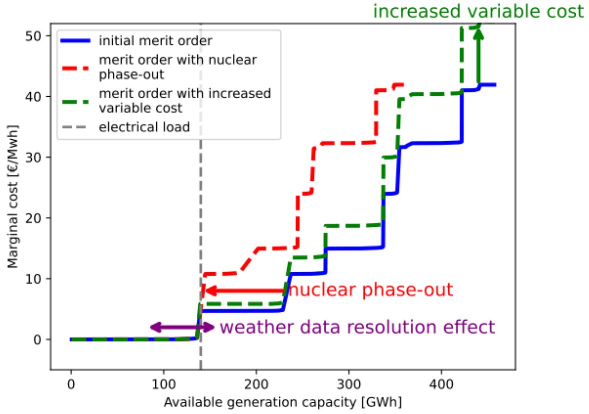


- **Wind speed/energy shows a stronger dependency** on spatial resolution than solar irradiance/energy

  → Yet, wind derived from reanalysis often has a much coarser resolution than solar energy from satellites

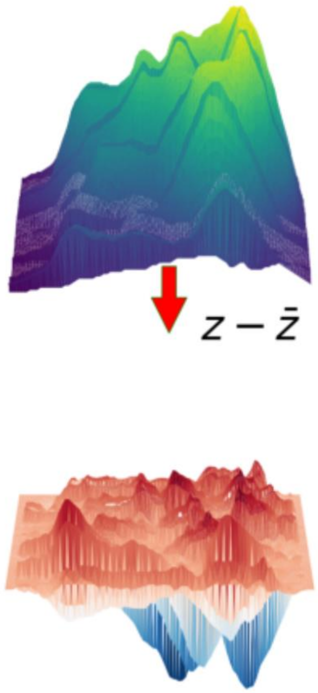
  → A **need for well-calibrated, high-resolution wind datasets**

- **Future scenarios lead to an aggravation of the investigated effect**
  - Technology phase-outs (nuclear, coal, lignite) lead to left shifts of the merit-order
  - Increase of fossil prices (e.g. CO_2 price/LNG) lead to upward shifts of the merit-order



Backup

Installed capacity range (MW)	Model	Hub height (m)
< 0.8	E-53/800	73
0.8–2	V90/2000	73
2–2.3	E-82/2300	108
2.3–2.4	N117/2400	120
2.4–3.3	V126/3300	137
> 3.3	E-141/4200	159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