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# ENERGY SYSTEM MODELLING TO SUPPORT MANAGERIAL DECISION-MAKING IN THE ENERGY SECTOR: SELECTED INSIGHTS AND PITFALLS

Chair of
Energy Systems &
Energy Economics

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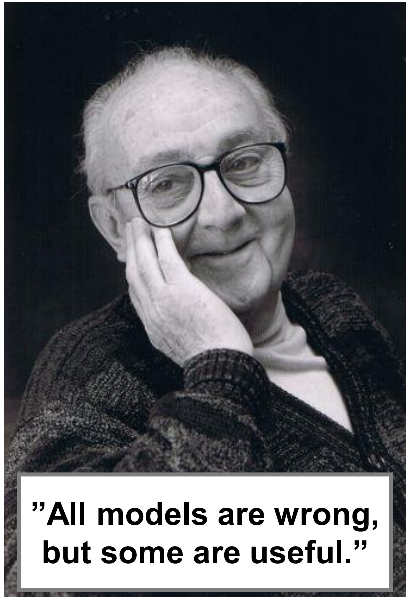
# Energy System Modelling to Support Managerial Decision-Making in the Energy Sector: Selected Insights and Pitfalls
## *Agenda*

- Motivation
- Test system
- Using energy system models (ESMs) to support managerial decisions
- Selected insights
- Conclusions and outlook




George Edward Pelham Box (1919–2013)



Source: Box, G. E. P., and Draper, N. R., (1987), Empirical Model Building and Response Surfaces, John Wiley & Sons, New York, NY.

# Motivation

- Energy system models have been developed and used for several decades to support decision makers in governments and companies in (sustainable) energy system planning
  - Typically central-planning approach
  - Simplifications and assumptions are made, e.g. for computational reasons
  - Inherent part of any modelling process, but: effects can remain unseen when only considering ESM results at the macroscopic level
- Using ESM output to support managerial decisions of energy companies (e.g. related to individual investment projects) reveals a number of such hidden effects

⇒ Question(s) arising: usefulness and robustness of the ESM output – also at the macroscopic level?

# Test system for illustration of selected insights

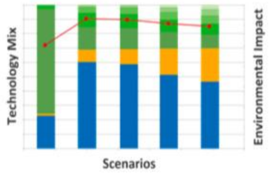
- Target year 2030
- Techno-economic data from Pietzcker et al. 2021, including $CO_2$ price of 129 €/t
- RES-E Shares based on National Energy and Climate Plans
  - FR: 43%
  - ES: 80%
  - PT: 87%
- Network topology, time series for demand and weather, conventional generation capacities, aggregation from PyPSA-Eur (https://arxiv.org/abs/1806.01613)
- 1 MW min. installed capacity for all RES-E



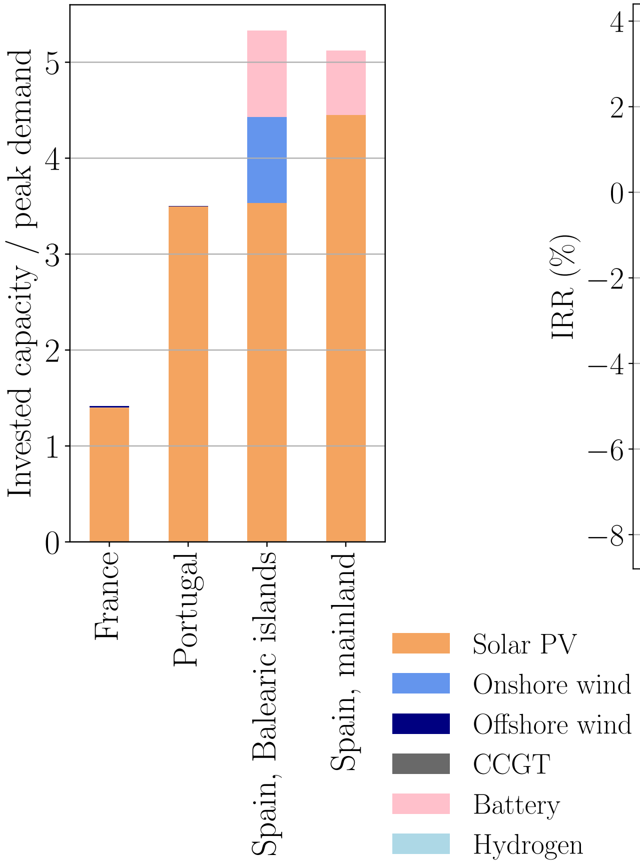
Source: Pietzcker, R., Osorio, S., Rodrigues, R. (2021) Tightening EU ETS targets in line with the European Green Deal: Impacts on the decarbonization of the EU power sector. Applied Energy 293, 116914. doi:10.1016/j.apenergy.2021.116914

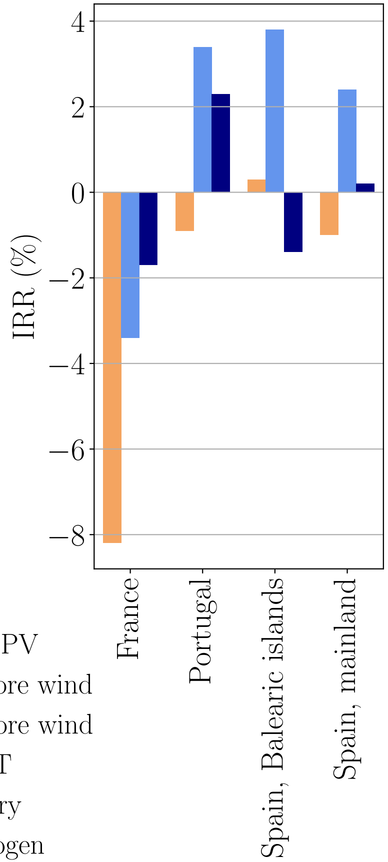
# “Standard” Modelling Approach

- Find cost minimal solution of technology mix to be installed to achieve given constraints (e.g., RES share or emissions constraint)
- Typical approach (unless specifically analysing grid): One node per country
- Results
  - Technology mix and distribution across regions
  - Fuel use and emissions
  - System costs
- Drawback: cost-min objective function → no information on technology profitability from investor’s perspective → **economic feasibility in liberalised market(s)?**
- “Solution”: use further ESM output for ex-post profitability assessment (outside the main ESM)
  - Time series of marginals
  - Generally accepted as good indicator / proxy for prices




# Selected insights: installed capacities vs. IRR

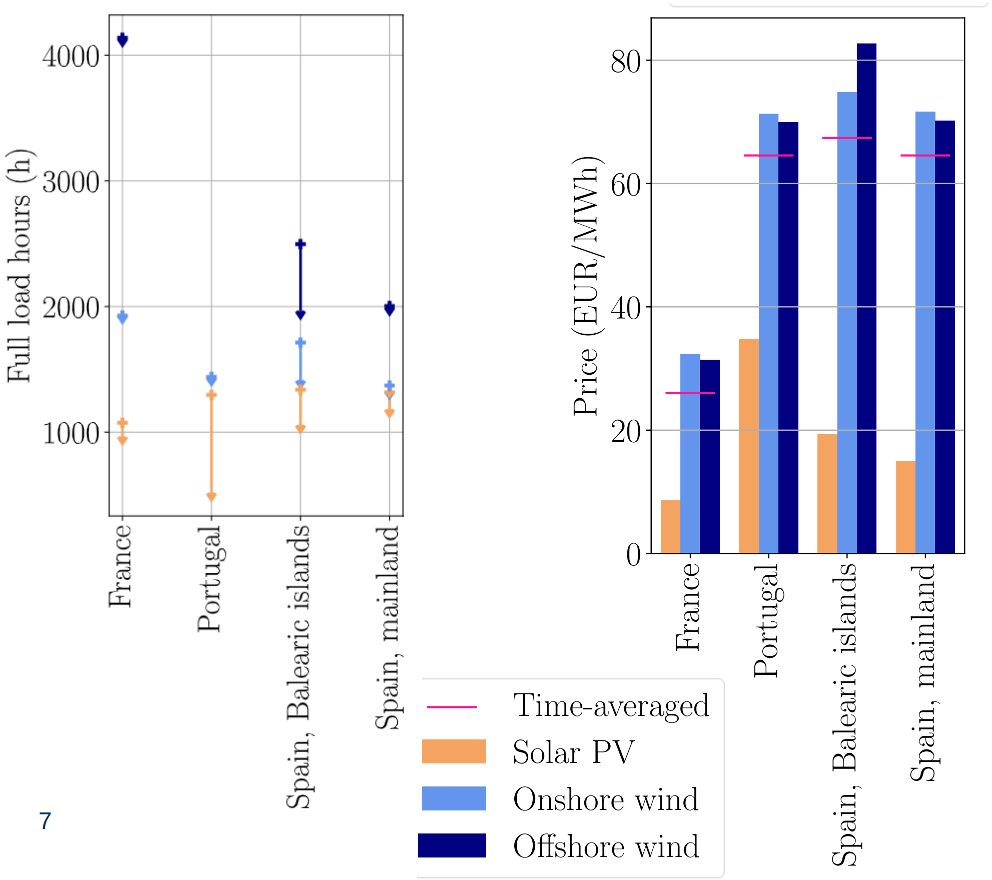



- Least cost solution seems to have a strong preference for solar PV over wind power
  - Driven by cost assumptions only?
  - Impact of modelling decisions?
- At the same time, IRR of solar PV much lower than that of wind power
  - What happens?

Source: Finke, J., Bertsch, V. (2022) Work in Progress.

# Selected insights (cont‘d): curtailment and market values




- Not surprisingly, theoretical full load hours of solar PV in Spain and Portugal higher than in France
- Highest PV curtailment in Portugal
- Solar PV ***market values (MVs)*** much lower than time-averaged power prices (marginal costs)
- RES cannibalisation effect known

⇒ Impact of modelling approach?

Source: Finke, J., Bertsch, V. (2022) Work in Progress.



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# Implications of “one-node-per-country” modelling

- Least-cost optimisation identifies technologies that cover demand under given (RES) constraints in cost-minimal way
- Implications of representing each country by one node
  - In particular in larger countries, high heterogeneity of RES potentials (quality) across regions
  - Using only one node means using average RES generation profiles → **loss of heterogeneity**
  - Quality of individual regions overestimated or underestimated
- Curtailment: mixed effects
  - Overestimation because entire RES expansion based on one generation profile only
  - Underestimation because no grid within countries is considered when using one node only
- Implications related to market values
  - Using one profile only leads to overestimation of simultaneity and merit order effect, hence underestimation of market values

⇒ **Higher resolution approach required**


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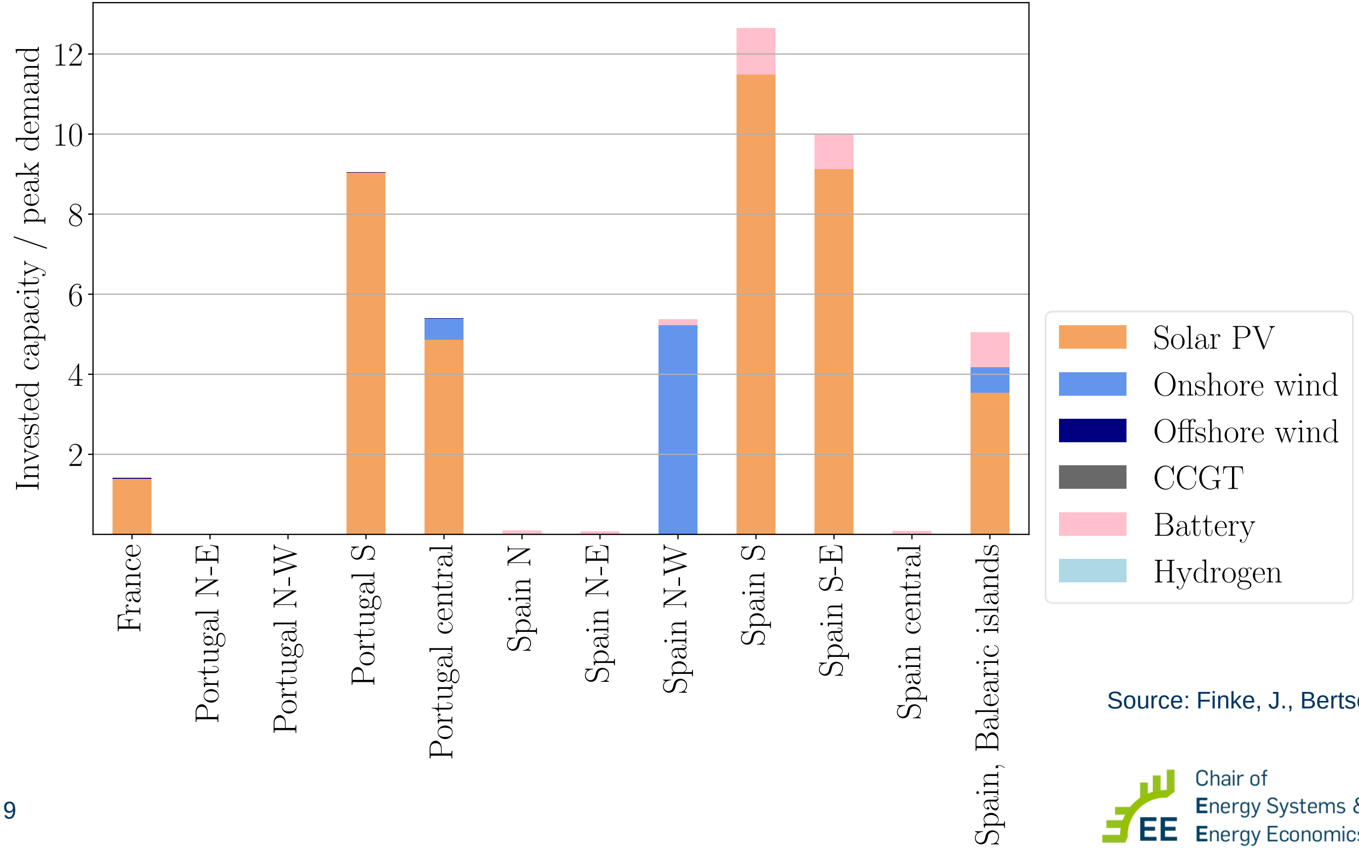
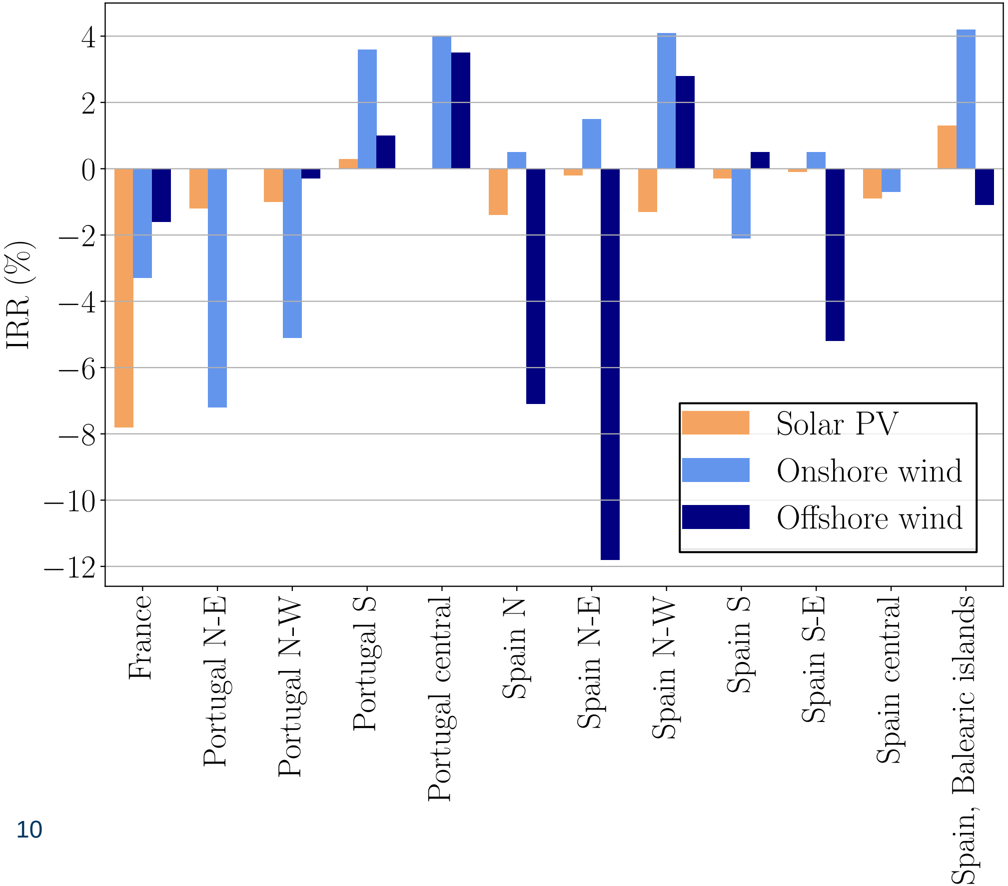
# Selected insights for increased spatial granularity




- Increased onshore wind expansion in (north-west) Spain („windy“ region)
- Regional differences within countries reveal heterogeneity (e.g., exporting and importing regions)

Source: Finke, J., Bertsch, V. (2022) Work in Progress.

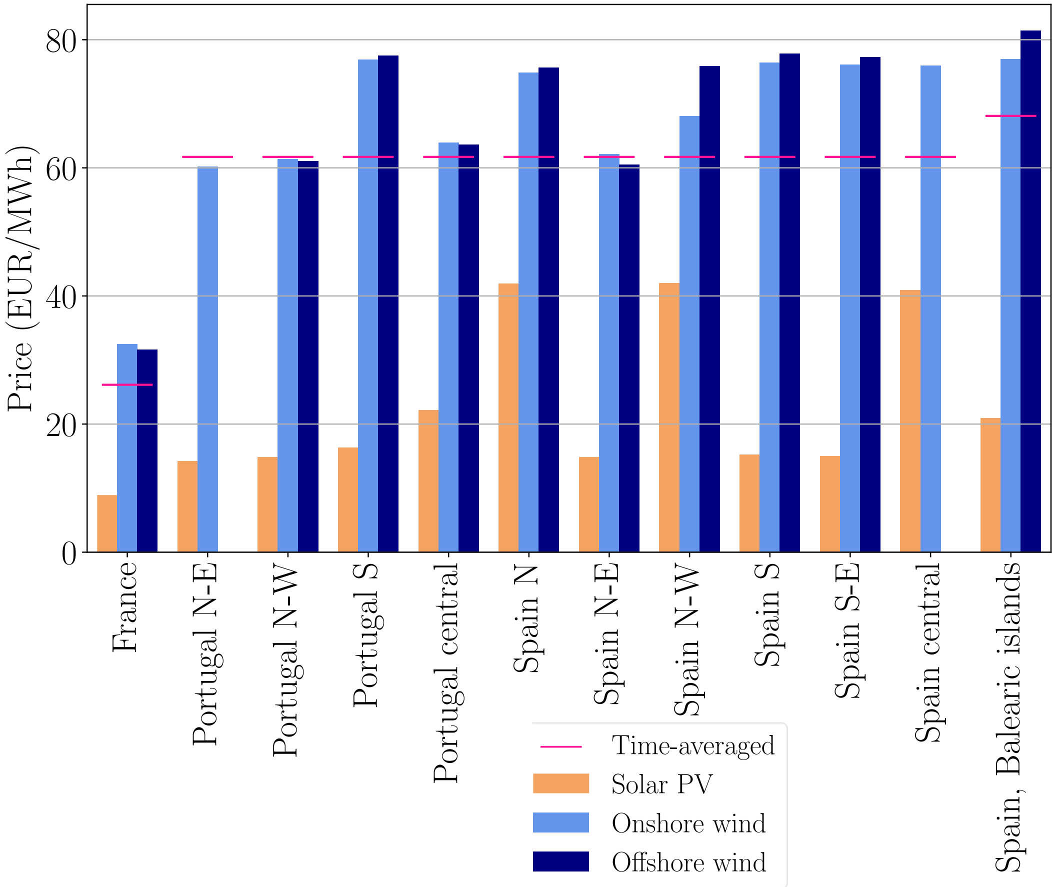
# Selected insights for increased spatial granularity (cont'd)




- Heterogeneity: e.g., Onshore Wind profitability in PT S, ES N-W compared to other regions in these countries
- Wind offshore: 1 MW min installed capacity per technology and region; low full load hours in corresponding regions lead to low profitability

Source: Finke, J., Bertsch, V. (2022) Work in Progress.

# Selected insights for increased spatial granularity (cont'd)




- Market values for wind power generally higher than for solar power (lower capacity expansion leading to lower merit order / cannibalisation effect)
- Strong heterogeneity across regions within countries

Source: Finke, J., Bertsch, V. (2022) Work in Progress.

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# Counteracting effects: full load hours vs. market values

- Obvious:
  - Profitability (IRR) increases with increasing full load hours and market values
- Least-cost ESMs are “agnostic” of market values
  - Qualitatively, higher full load hours will (all else equal) lead to lower market values
- Regions with lower full load hours potentially interesting for investors
  - Risk of “followers” → decreasing market value

| Market value (EUR/MWh) | Full load hours (h) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 700 | 750 | 800 | 850 | 900 | 950 | 1000 | 1050 | 1100 | 1150 | 1200 | 1250 | 1300 | 1350 | 1400 | 1450 | 1500 |
| 20 | -5% | -4% | -4% | -3% | -3% | -2% | -2% | -2% | -1% | -1% | 0% | 0% | 0% | 1% | 1% | 1% | 2% |
| 25 | -3% | -3% | -2% | -2% | -1% | 0% | 0% | 0% | 1% | 1% | 2% | 2% | 3% | 3% | 3% | 4% | 4% |
| 30 | -2% | -1% | 0% | 0% | 1% | 1% | 2% | 2% | 3% | 3% | 4% | 4% | 5% | 5% | 6% | 6% | 6% |
| 35 | 0% | 0% | 1% | 2% | 2% | 3% | 3% | 4% | 5% | 5% | 6% | 6% | 7% | 7% | 7% | 8% | 8% |
| 40 | 1% | 2% | 2% | 3% | 4% | 4% | 5% | 6% | 6% | 7% | 7% | 8% | 8% | 9% | 9% | 10% | 10% |
| 45 | 2% | 3% | 4% | 4% | 5% | 6% | 6% | 7% | 8% | 8% | 9% | 9% | 10% | 11% | 11% | 12% | 12% |
| 50 | 3% | 4% | 5% | 6% | 6% | 7% | 8% | 8% | 9% | 10% | 10% | 11% | 12% | 12% | 13% | 13% | 14% |
| 55 | 5% | 5% | 6% | 7% | 8% | 8% | 9% | 10% | 10% | 11% | 12% | 12% | 13% | 14% | 14% | 15% | 16% |
| 60 | 6% | 6% | 7% | 8% | 9% | 10% | 10% | 11% | 12% | 12% | 13% | 14% | 15% | 15% | 16% | 17% | 17% |
| 65 | 7% | 7% | 8% | 9% | 10% | 11% | 12% | 12% | 13% | 14% | 15% | 15% | 16% | 17% | 17% | 18% | 19% |
| 70 | 7% | 8% | 9% | 10% | 11% | 12% | 13% | 14% | 14% | 15% | 16% | 17% | 17% | 18% | 19% | 20% | 20% |
| 75 | 8% | 9% | 10% | 11% | 12% | 13% | 14% | 15% | 16% | 16% | 17% | 18% | 19% | 20% | 20% | 21% | 22% |
| 80 | 9% | 10% | 11% | 12% | 13% | 14% | 15% | 16% | 17% | 18% | 19% | 19% | 20% | 21% | 22% | 23% | 24% |

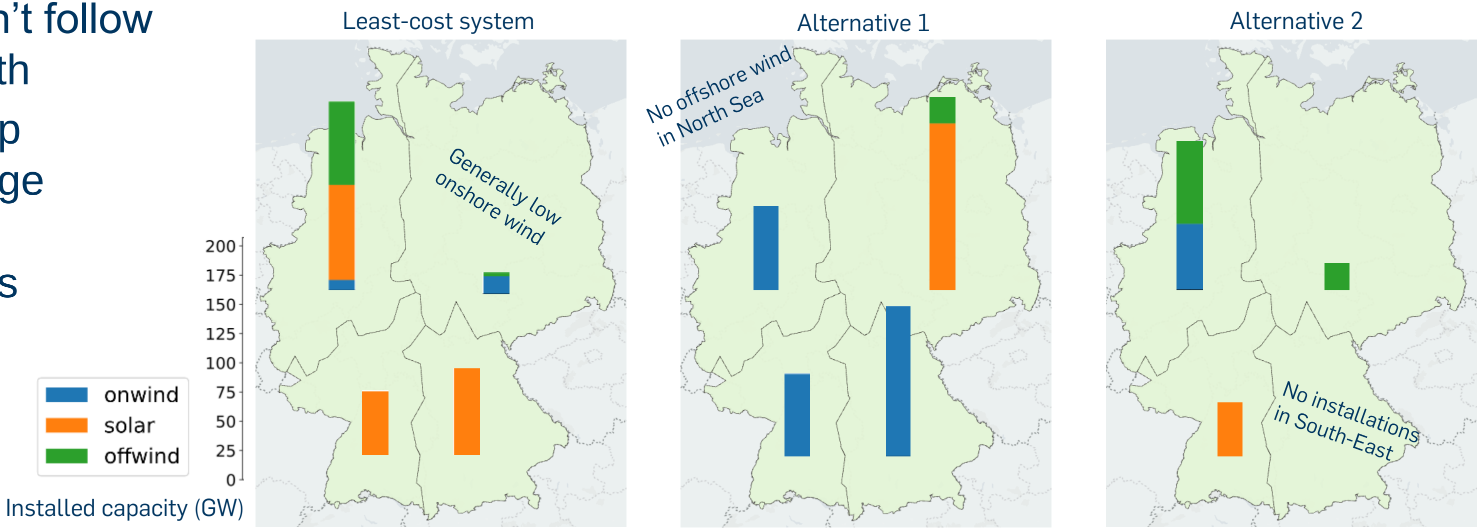
A specific investment of 500 €/kW was assumed for solar PV for this illustrative example.

Work in progress

# Outlook: Modelling to Generate Alternatives (MGA)

→ Example: Germany 2035

- MGA identifies different alternatives that are highly similar in solution space (e.g., < X% higher system costs compared to techno-economic optimum) but differ substantially in variable space (e.g., technologies expanded)
- Reality doesn't follow least-cost path
- MGA can help identify a range of possible developments and their impacts on RES-E profitability

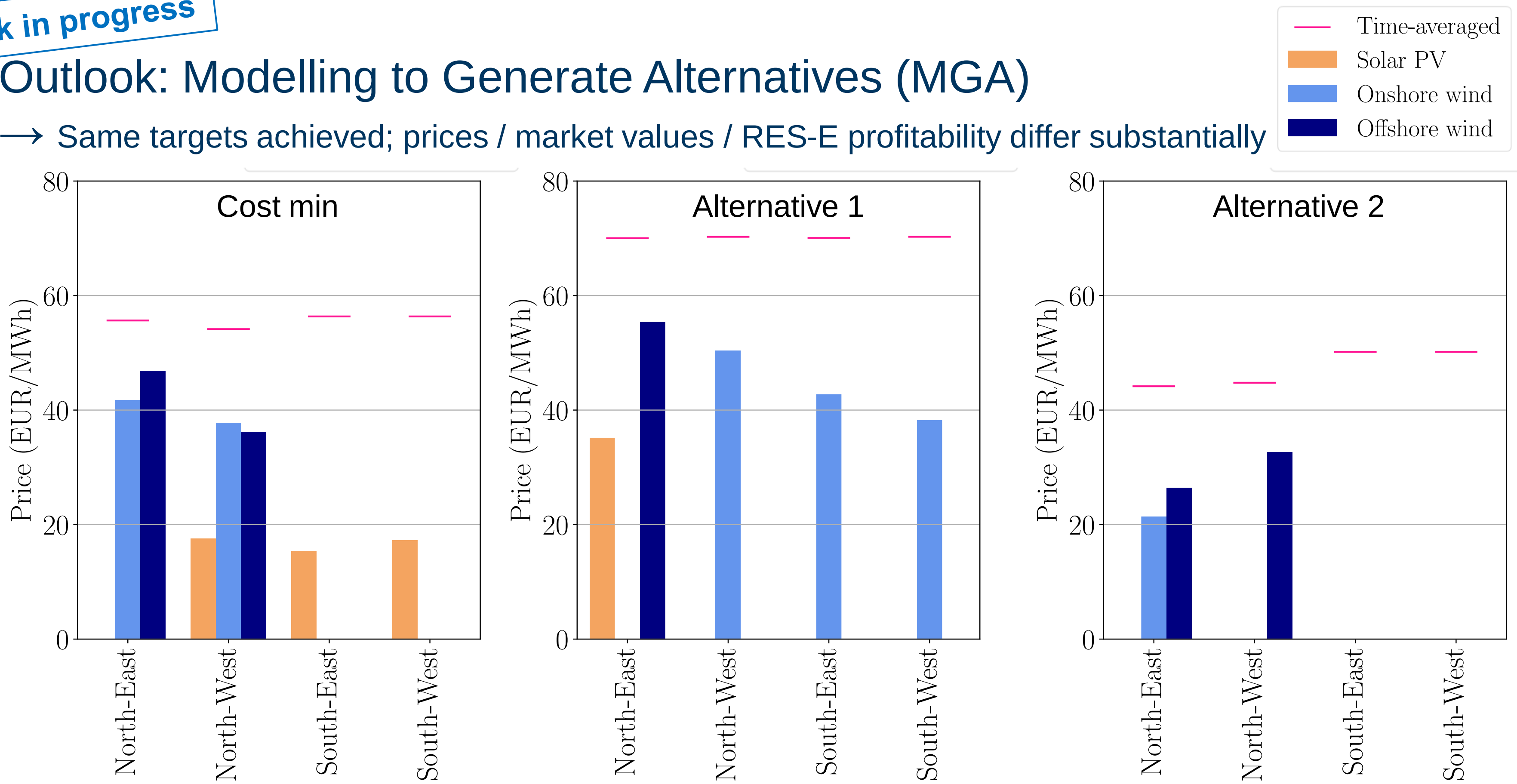



Hörsch et al., *PyPSA-Eur: An Open Optimisation Model of the European Transmission System*, Energy Strategy Reviews 2018. (See also https://github.com/PyPSA/pypsa-eur)
[1] Largely based on Pietzcker et al., *Tightening EU ETS targets in line with the European Green Deal: Impacts on the decarbonisation of the EU power sector*, Applied Energy 2021.

Work in progress

# Outlook: Modelling to Generate Alternatives (MGA)

⟶ Same targets achieved; prices / market values / RES-E profitability differ substantially






Source: Finke, J., Bertsch, V. (2022) Work in Progress.

# Conclusions

- Least-cost central planning ESMs are agnostic of managerial investment considerations
- They can nevertheless provide useful insights to support managerial decisions
  - Besides input data assumptions, modelling decisions may have a big impact
  - Important to be aware of potential pitfalls when interpreting results
  - Otherwise, usefulness of results questionable not just for potential investors, but also on the macroscopic level
    - Macroscopic level results often intended to inform policy makers or regulators
      - Their task is to create market conditions where investors have an interest to invest
      - Otherwise, renewable targets cannot be achieved
- Investment decisions are managerial decisions
- “Modelling for insights, not numbers” → modelling cannot replace thinking
- Further research needed for improved understanding of effects (e.g., consider profitability as part of MGA or multi-objective optimisation, …)

# Thank you very much for your attention!

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