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FUNDAMENTALE MODELLIERUNGSANSÄTZE ZUR UNTERSTÜTZUNG BETRIEBSWIRTSCHAFTLICHER ENTSCHEIDUNGEN IM ENERGIESEKTOR: AUSGEWÄHLTE ERKENNTNISSE UND FALLSTRICKE

Chair of
Energy Systems &
Energy Economics

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Workshop „Daten, fundamentale und stochastische Analysen – Wissenschaft trifft Energiewirtschaft“
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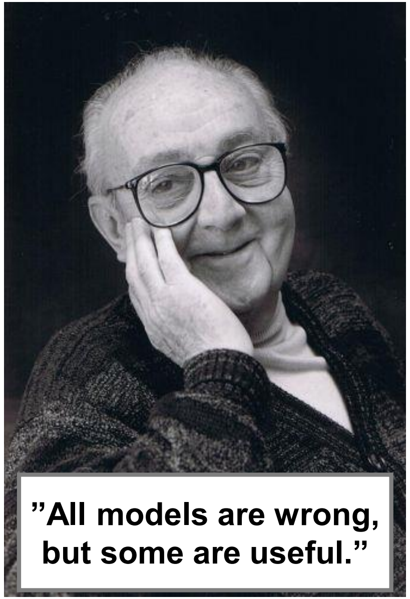
Fundamentale Modellierungsansätze zur Unterstützung betriebswirtschaftlicher Entscheidungen im Energiesektor *)

Agenda

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



George Edward Pelham Box (1919–2013)

**) The research presented draws on a variety of findings from different collaborations. In particular, I would like to thank Jonas Finke (RUB), and Valeria Di Cosmo (Uni Torino).*

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

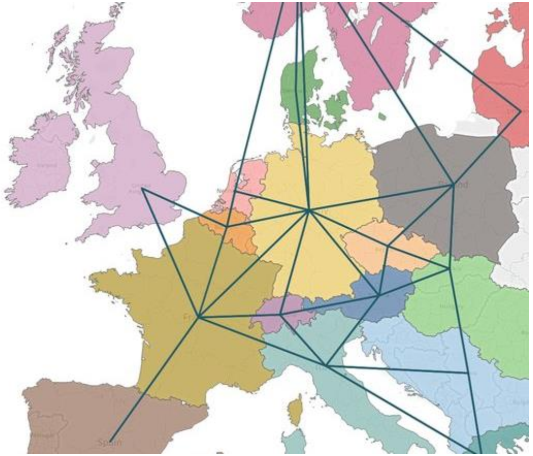
Motivation

- Energy systems 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?

A generic “central planning” use case

- Find cost minimal solution of technology mix to be installed to achieve given constraints (e.g., RES share or emissions constraint)
- Spatial system boundaries: e.g., Europe
- Typical approach (unless interested specifically in grid): One node per country



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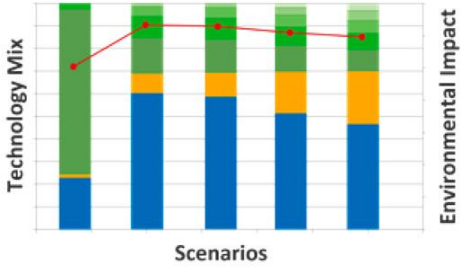
A generic “central planning” use case (cont’d)

- 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
- “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



“The devil’s in the details”: potential issues arising

- Marginals include investment-related peaks when capacity is added to the system
  - Methodologically consistent but from an investor’s perspective questionable if such peaks would occur in reality → risky to rely on such peaks for investment decision
  - Practical approach: replace peaks by lower prices in the corresponding hours → “risk reduction” but introduction of methodological inconsistency

“The devil’s in the details”: potential issues arising (cont’d)

- Impact of formulation of constraints on marginals, e.g.
  - Capacity-based formulation of RES constraints may lead to different marginals than energy-based formulation, particularly at the lower end, i.e. zero or negative marginal
  - Marginals obviously depend on emission prices
    - Is a RES constraint or an emission constraint used?
    - Are emission prices input or output of the model?
    - How can consistency between emission constraints and prices be ensured?
- Impact of integer variables on marginals

“The devil’s in the details”: old world vs. new world

- “Old” world:
  - Marginals and profitability of thermal generation technologies mainly driven by fuel and CO_2 price uncertainty and assumptions

  $\Rightarrow$ Create set of scenarios covering uncertainty range

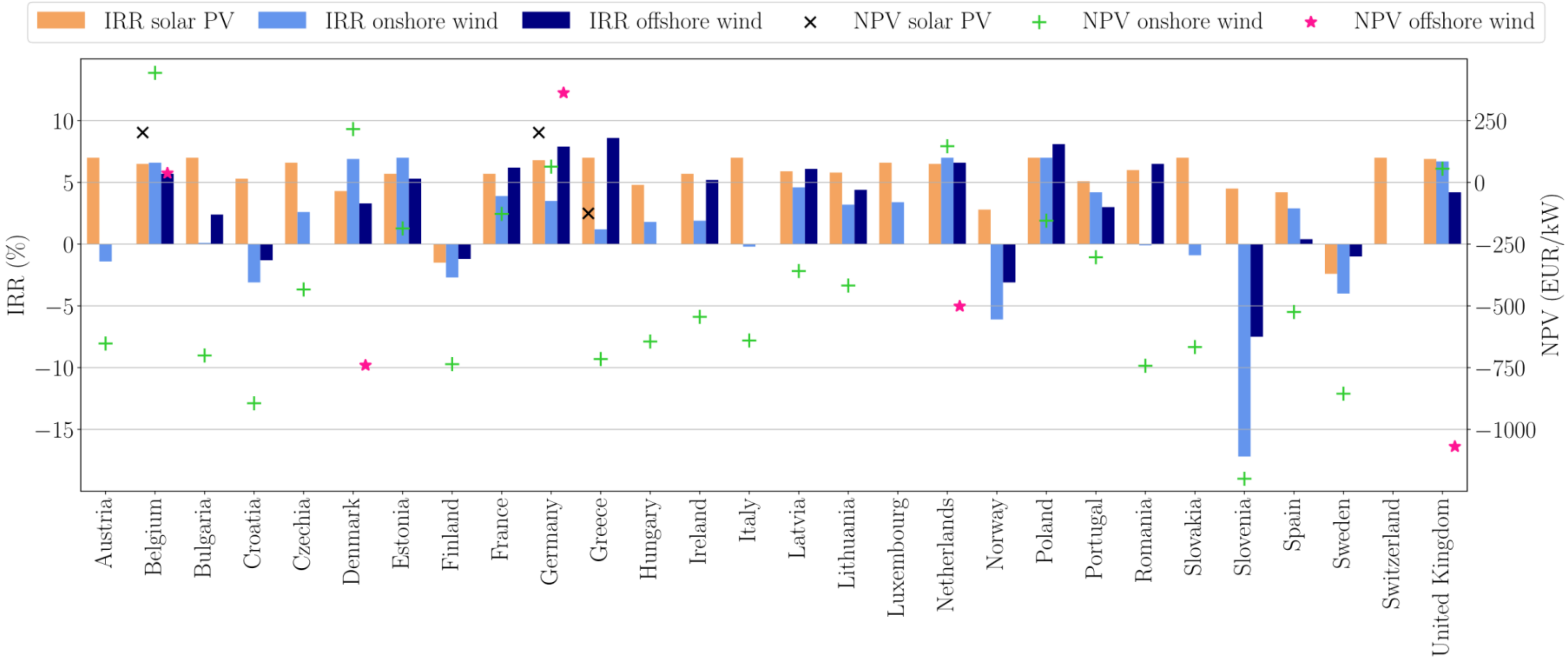
- “New” world:
  - Investment focus has shifted to RES and possibly storage
  - RES are largely driven by market values
    - Driven by marginals, too → fuel and CO_2 price uncertainty
    - Also highly sensitive to modelling decisions (e.g., resolution)

Alternative ways forward

1. Use different modelling approaches
   - E.g., game theoretic models, such as mixed complementarity problems, where generators each pursue profit maximisation, while consumers seek to minimise costs and market clearing constraint binds supply and demand and model finds equilibrium
   - Limited to linear problems (no integers can be considered)
   - Computationally not tractable for realistically-sized systems

2. Continue using ESMs but increase awareness for pitfalls and improve modelling on the basis of insights gained
   - Discussion of insights gained and derive (modelling) recommendations (WIP)

NPVs and IRRs of RES investments across Europe



Source: Finke, J., Bertsch, V., Di Cosmo, V. (2022) Are renewables profitable in 2030 across Europe? An analysis of market-based profitability and carbon emissions in a central-planning least-cost system (Work in Progress).

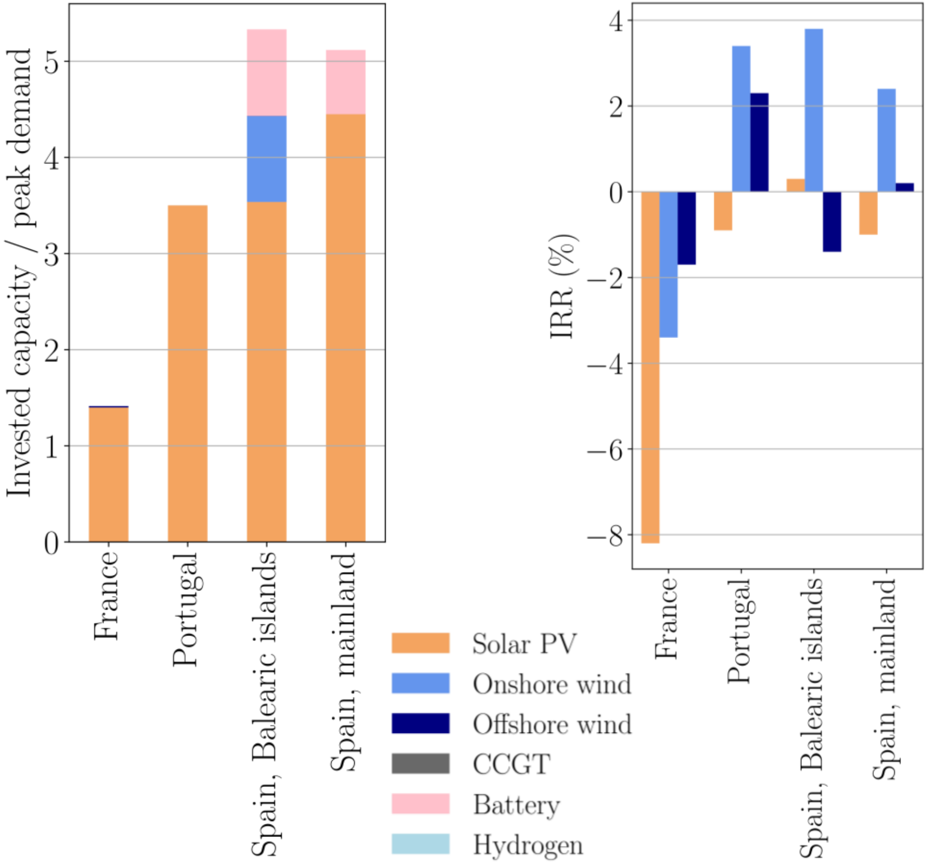
Test system for illustration of selected insights

- 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

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.

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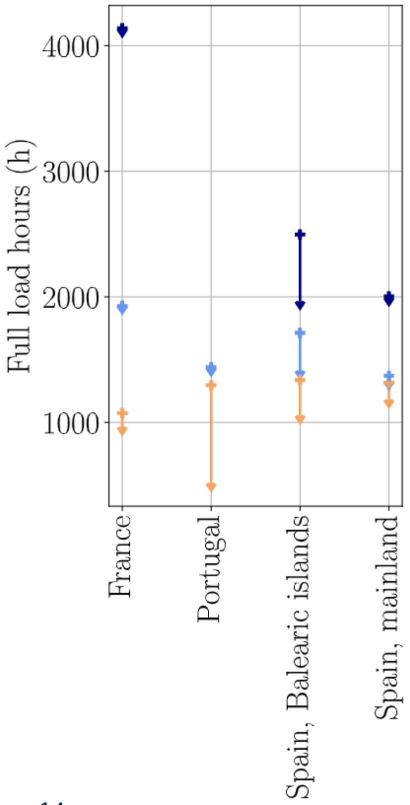
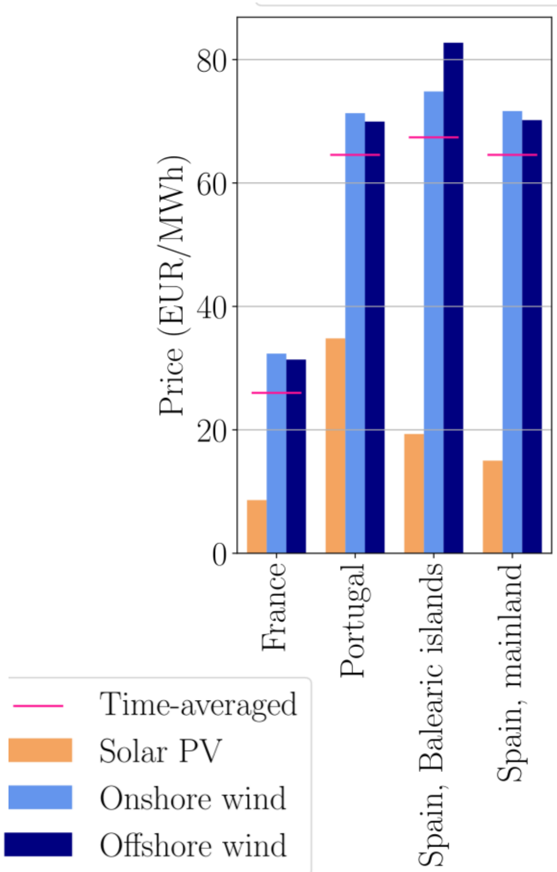
Selected insights (cont‘d): curtailment and market values





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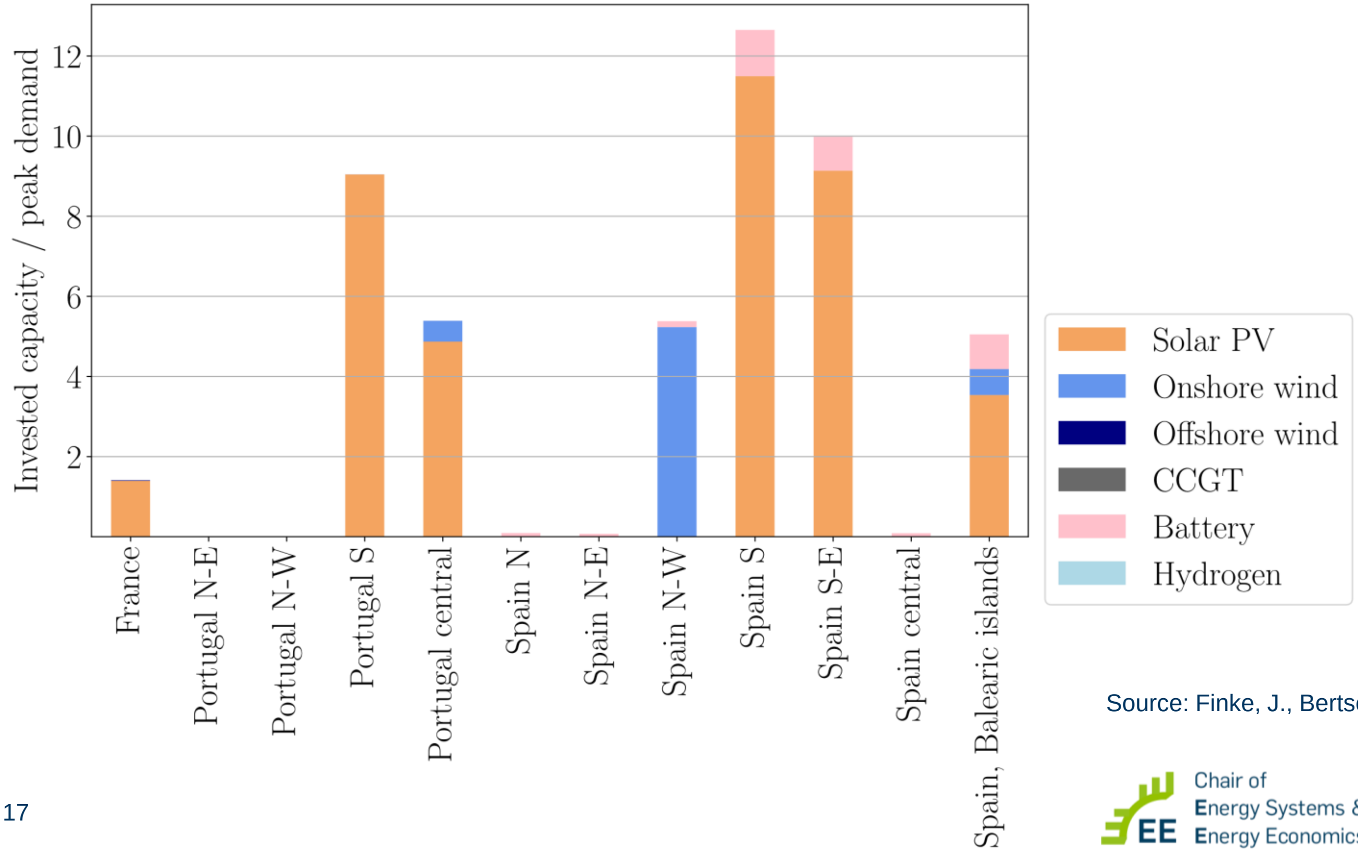
Implications of “one-node-per-country” modelling

- 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

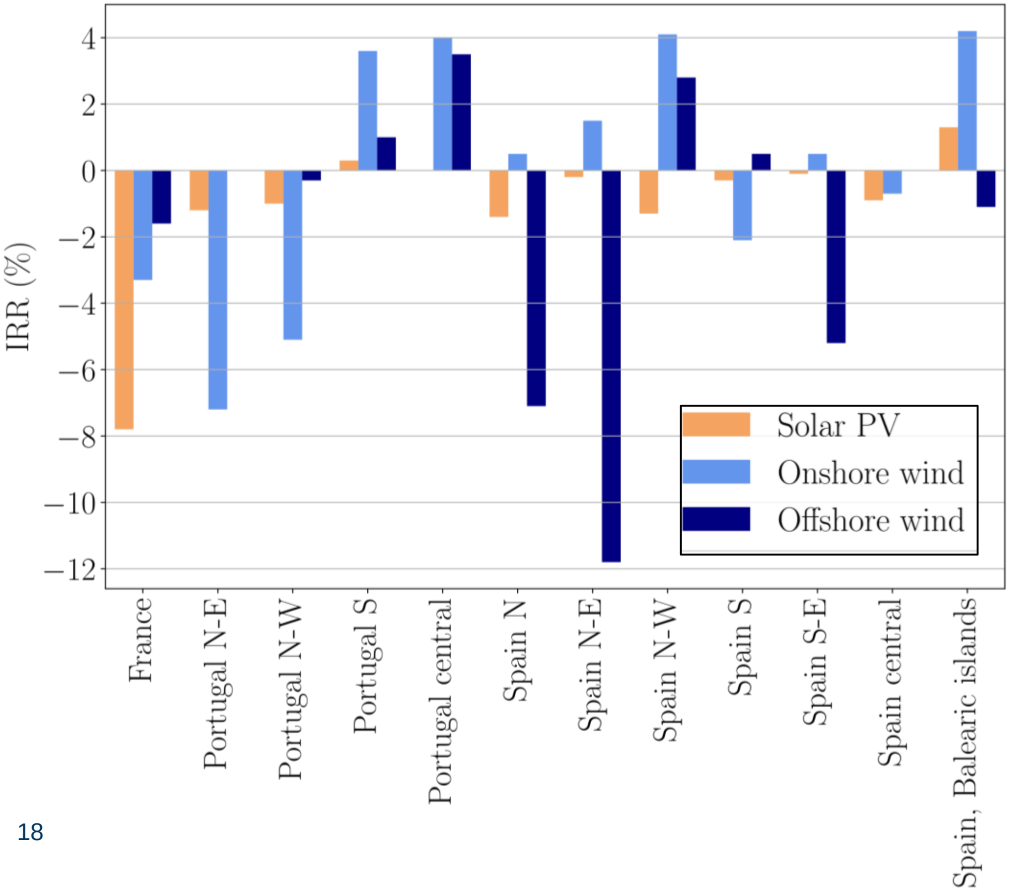
Selected insights for increased spatial granularity



- 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.

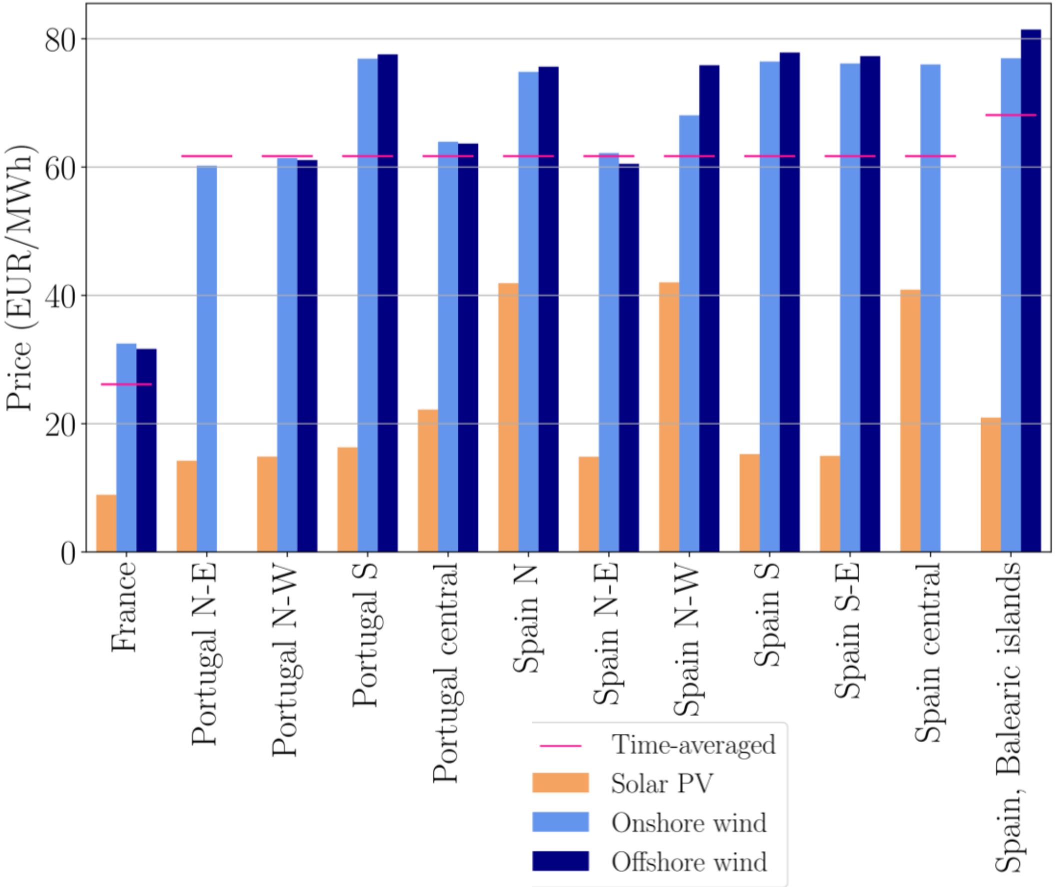
Selected insights for increased spatial granularity (cont’d)



- 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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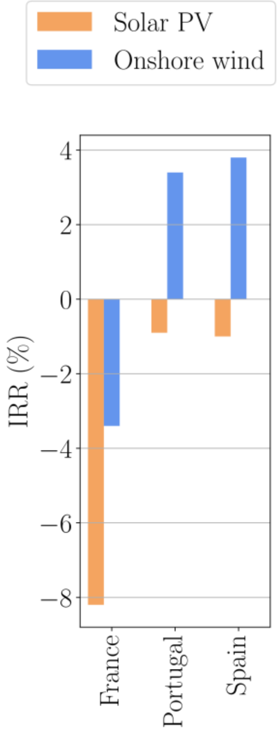
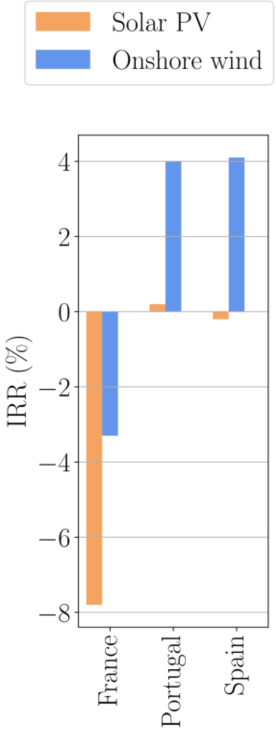
Aggregated level IRRs: "Standard" (left) vs. higher resolution (right)



- France largely unchanged (same resolution)
- PV in PT: reduced curtailment leads to higher IRR
- PV in ES: increased resolution captures heterogeneity better → high installation in "good FLH" region
- Onwind in ES: increased resolution captures heterogeneity better → high installation in "good FLH" region



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

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%
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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%
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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.

Conclusions

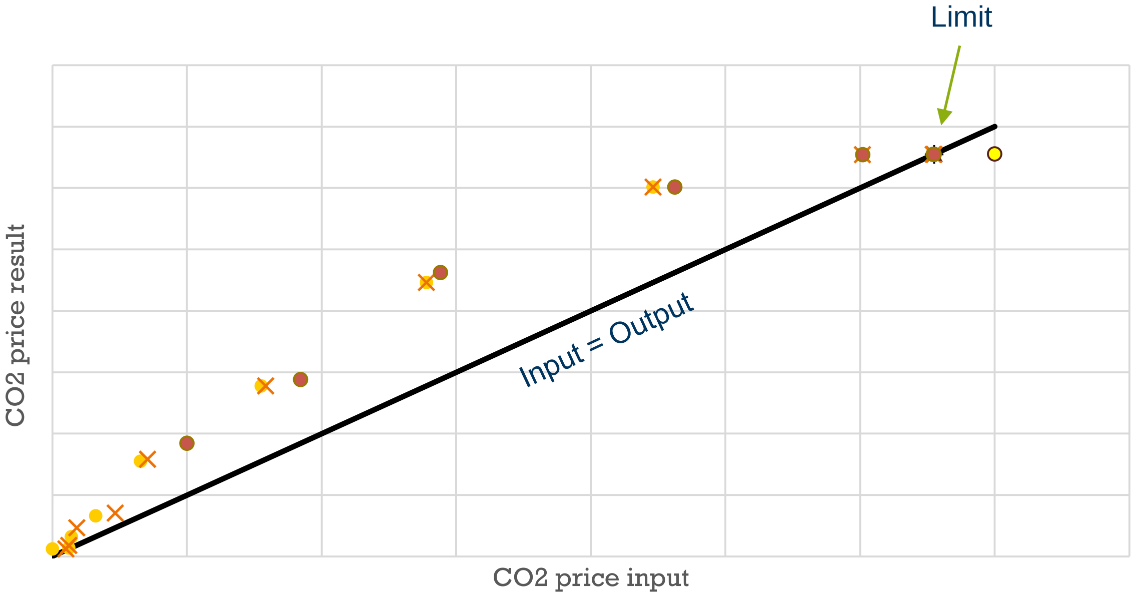
- Least-cost central planning ESMs are agnostic of managerial investment considerations
- They can nevertheless provide useful insights to support managerial decisions
  - Besides input data assumptions, modelling decisions may have a big impact
  - Important to be aware of potential pitfalls when interpreting 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

Outlook: Ensuring consistency between emission constraints and prices

Iterative approach:

1. Input: RES-E % and CO_2 price
   Result: Realised CO_2 emissions
2. Input: CO_2 cap from 1.
   Result: Marginal CO_2 abatement cost → new CO_2 price for next iteration

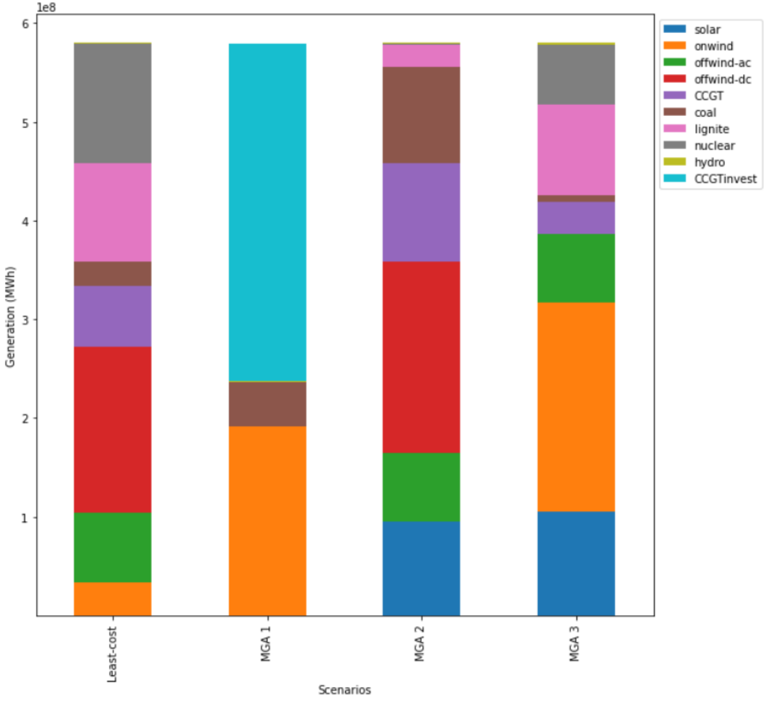
- Starting „from the left“: three series with different starting values converge towards the same CO_2 price “from below”
- Starting „from the right“: three series with different starting values also converge towards the same CO_2 price “from above”



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

Outlook: Modelling to Generate Alternatives (MGA)

- 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 attribute space (e.g., technologies expanded)
- Same targets are achieved, but prices and market values, hence RES-E profitability, may differ substantially
- Reality doesn’t follow least-cost path
- MGA can help identify a range of possible developments and their impacts on RES-E profitability



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

Thank you very much for your attention!

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