POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH
PIK

Dispatchable capacity in IAM Germany's net-zero scenario using Bidirectional model coupling

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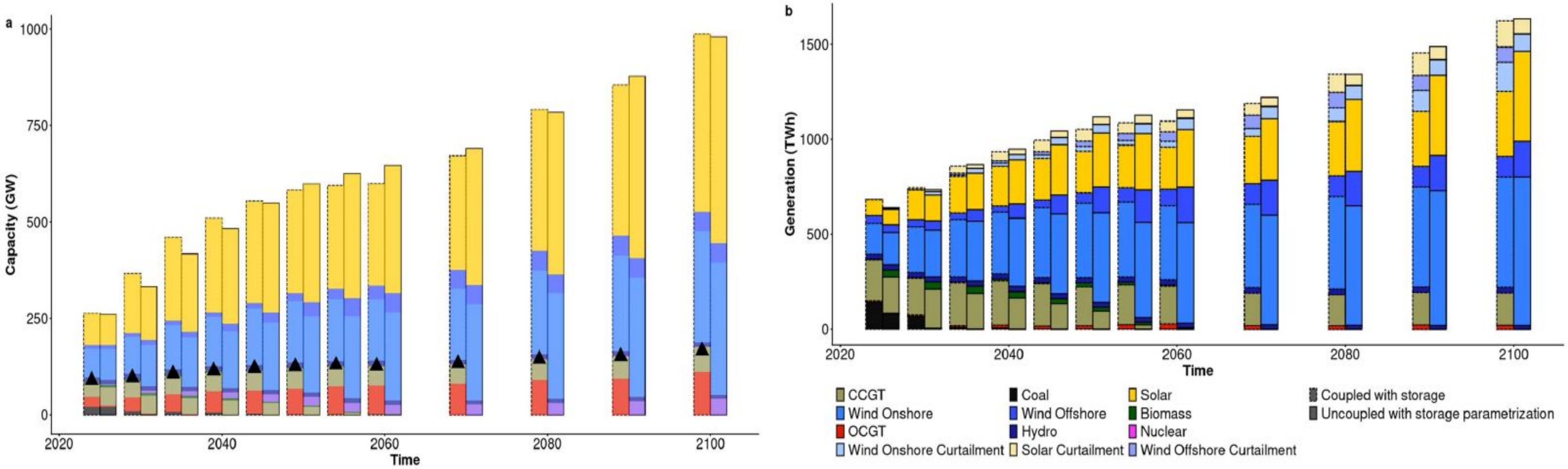
Leibniz Association

Motivation

- Decarbonization process: 2020~2100
- Wind and solar output: vary from hour to hour

=> major challenge for long-term climate mitigation model to incorporate hourly resolution!
For REMIND, we parametrize based on REMIX, but long-term model does not “see” hourly peak load and the capacity requirement

- With coupling to hourly model, the long term models “see” capacity constraints of peak residual load, also market values of various generation (average revenue per MWh of XX type of generation)
- e.g. 2 degree climate policy for Germany (see below): with coupling, a lot more gas capacities!
- Some dispatchable capacity growth but not as much as generation



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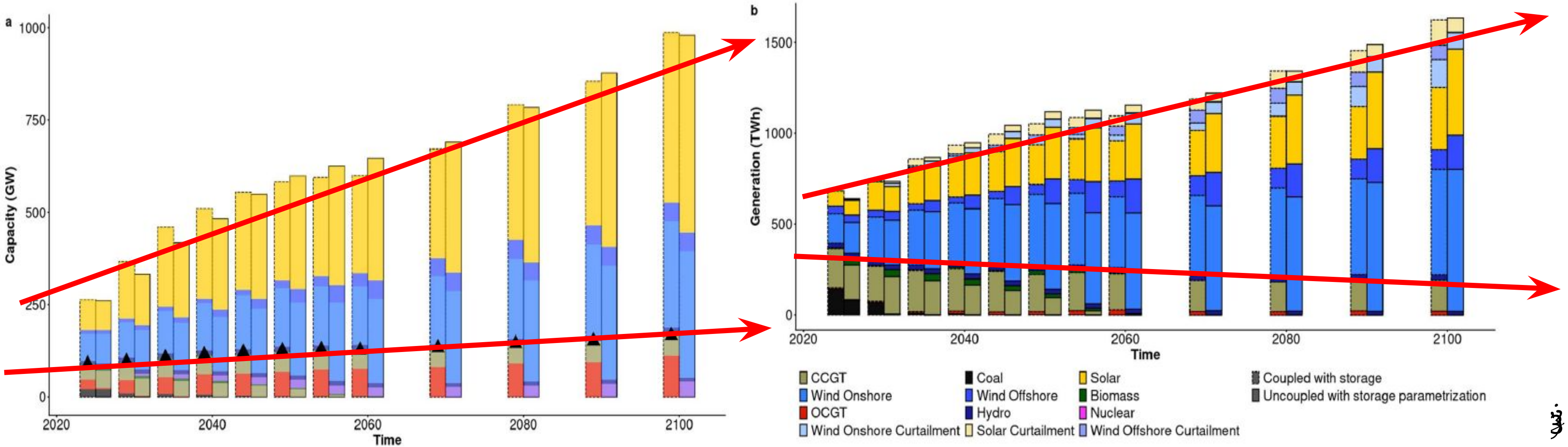
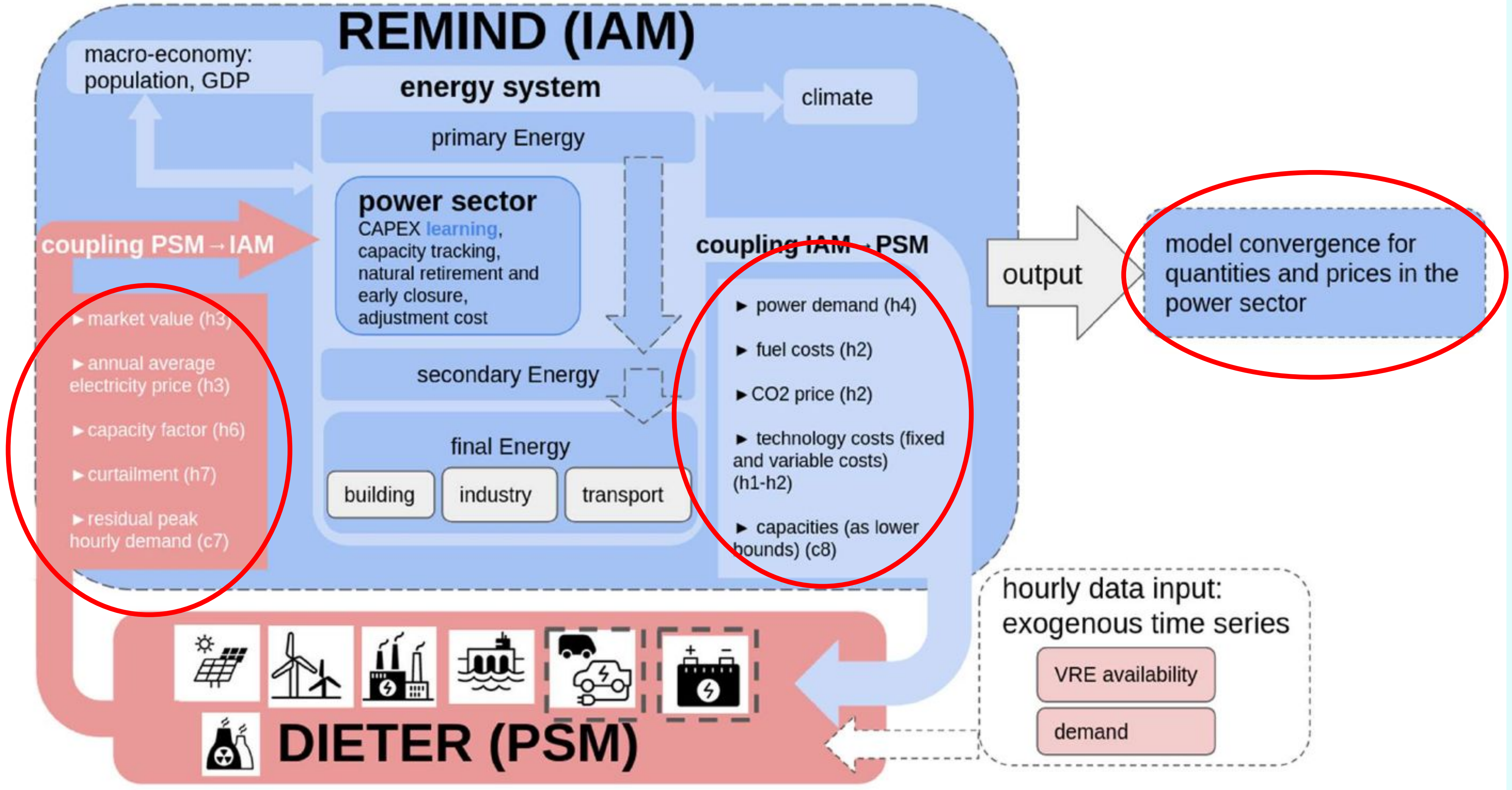
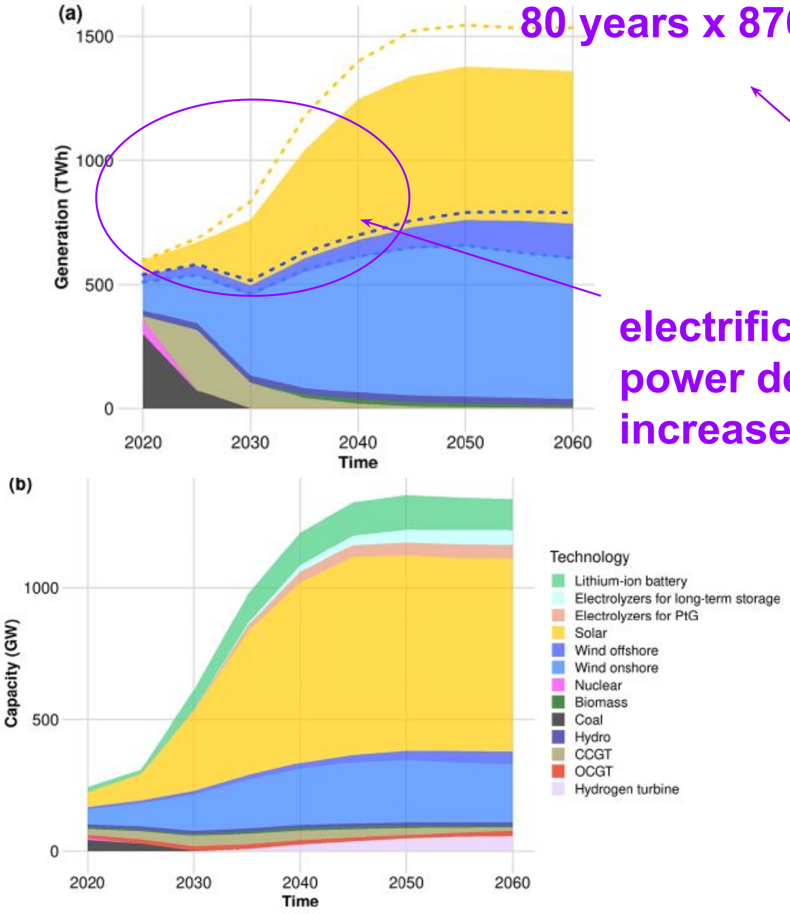


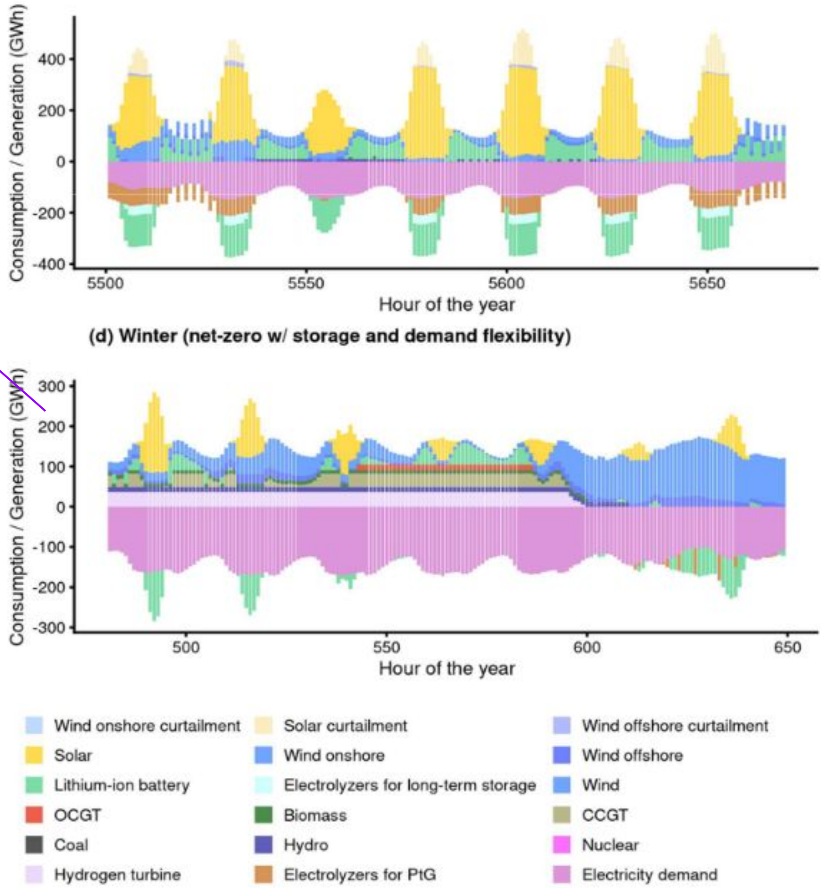

REMIND (IAM)
macro-economy:
population, GDP
energy system
climate
primary Energy
power sector
CAPEX learning,
capacity tracking,
natural retirement and
early closure,
adjustment cost
secondary Energy
final Energy
building
industry
transport
coupling PSM→IAM
► market value (h3)
► annual average electricity price (h3)
► capacity factor (h6)
► curtailment (h7)
► residual peak hourly demand (c7)
coupling IAM→PSM
► power demand (h4)
► fuel costs (h2)
► CO2 price (h2)
► technology costs (fixed and variable costs) (h1-h2)
► capacities (as lower bounds) (c8)
output
model convergence for quantities and prices in the power sector
hourly data input:
exogenous time series
VRE availability
demand
DIETER (PSM)

Germany net-zero 2045 scenario

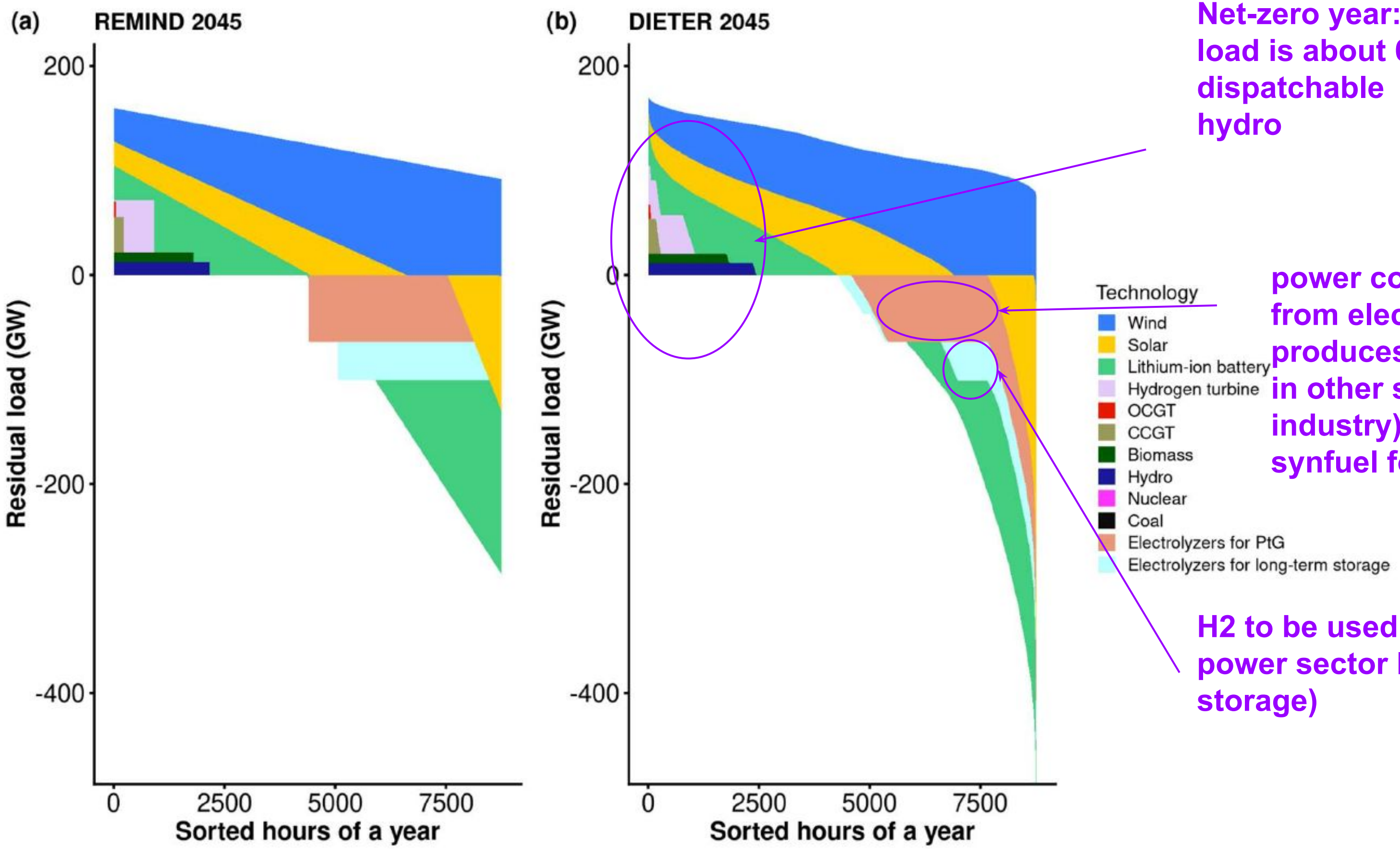


80 years x 8760h!

electrification: power demand increase



RLDC: sorted time series to visualize peak load hour, wind and solar shortfall and minimum required dispatchable capacities

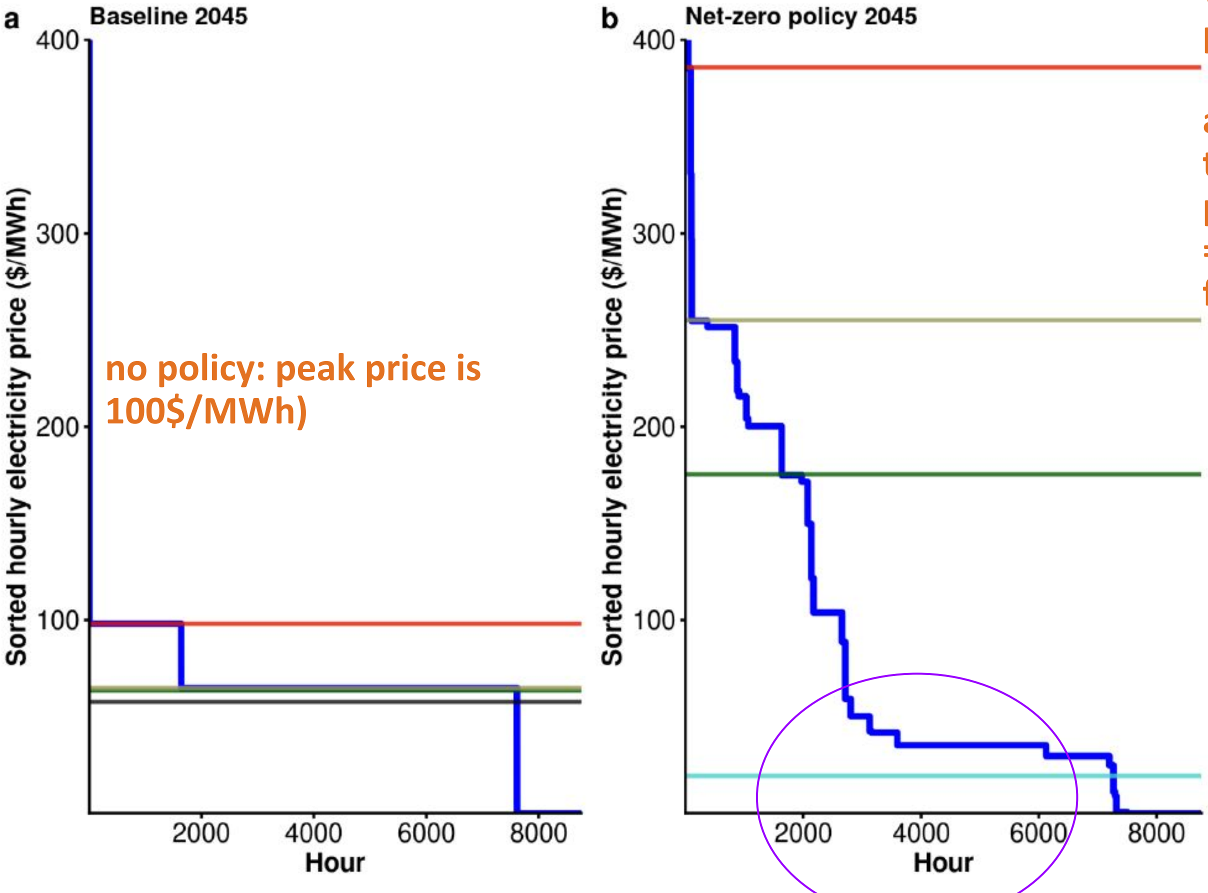


Net-zero year: peak residual load is about 60% covered by dispatchable and pumped hydro

power consumption from electrolysis, which produces H2 to be used in other sectors (mostly industry) in gas or synfuel form

H2 to be used in CHP (as a power sector long-term storage)

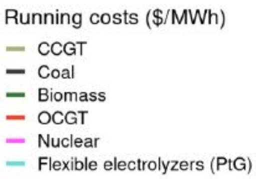
Net-zero year: 100 hours - price set by OCGT or higher (~400$/MWh)
900 hours - set by CCGT (250$/MWh)



no policy: peak price is 100$/MWh)

with carbon price:
peak price is higher

additional policies are needed to deal with high spot market prices of gas capacity
=> capacity market,
flexible demand incentive, etc..



H2 production (flexible); electricity scarcity price spikes will not impact H2 production/price if it is flexible

However, if imported H2 suddenly become scarce could push up fuel cost for a few hundred hours (peaking hours, which then impact average power cost)!

Summary, outlook and discussion

- **What we did:** proof-of-method study of model coupling on Germany net-zero power sector
  - novelty: **both long-term planning horizon and short-term high resolution**
- **What we found**:
  - Total annual power demand increase because power price is cheaper in the coupled model (more electrification)
  - minimum **capacity requirements** and **high scarcity prices**
    -> reserve market?
  - dispatchable capacity of Germany in 2045 is around **60% of peak hourly load** (rest is instantaneous wind and solar plus battery discharge)
- **Impact**: studies such as this can help settle debates on power plant capacity strategy "Kraftwerkstrategie"
  - **stress testing** system with different weather years, climate extremes
  - how much **storage** capacity should be invested?
  - how much **dispatchable** capacity should be invested (e.g. H2-ready gas power)
  - what does **price** structure look like with various market mechanism (also import exposure, prevent imported inflation from green fuel abroad)

- **Ongoing work**: apply it to large regions like China and India (more spatial nodes)
  - capacity building, experience transfer (is this network interested?)

Thank you!

Backup slides

Combine two methodologies of energy system modelling

- soft-coupling of IAM & power sector model, iterative, bi-directional, model convergence

- coupling is "price-based": give both models sufficient freedom to invest, "as endogenous as possible"

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    - **"price" of supply**: generation variability corresponds to different market value to the system, given fixed demand

    - **"price" of demand**: demand-side flexibility corresponds to different "capture price" of electricity in the system, given variable supply

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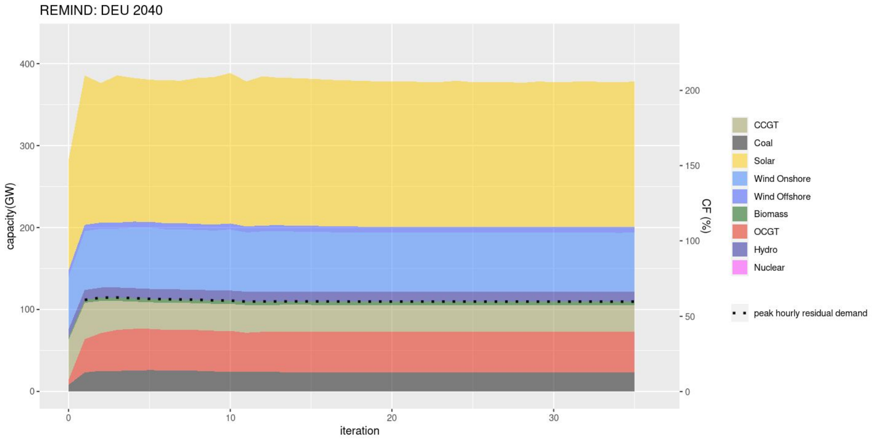
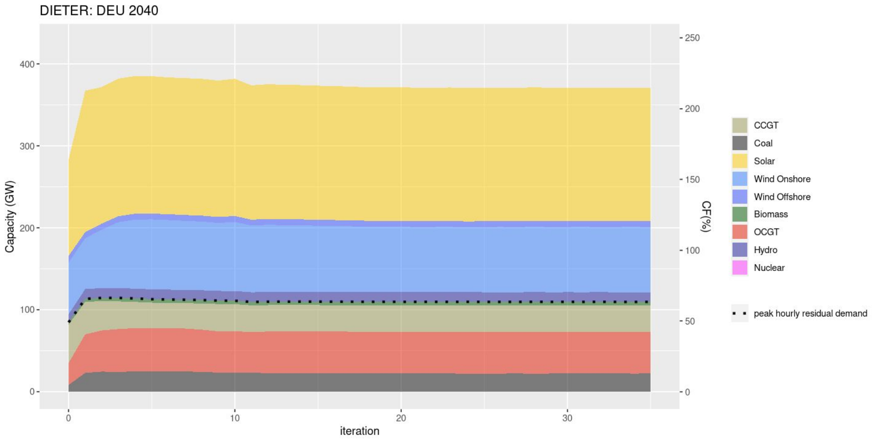
- full convergence -> **joint equilibrium** of both models, "best of both worlds"

Main result: we derived convergence conditions, criteria, and achieved almost full numerical convergence

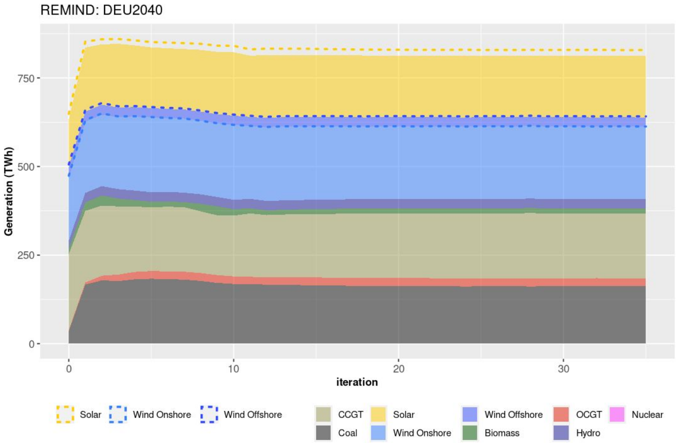
Quantities vs. iteration

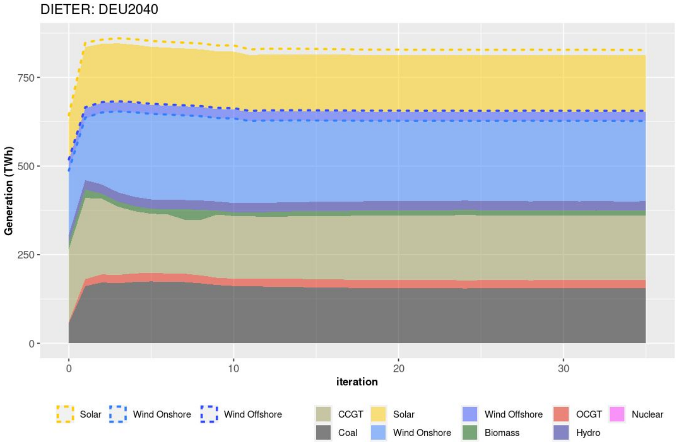
Capacity vs. iteration (2040)





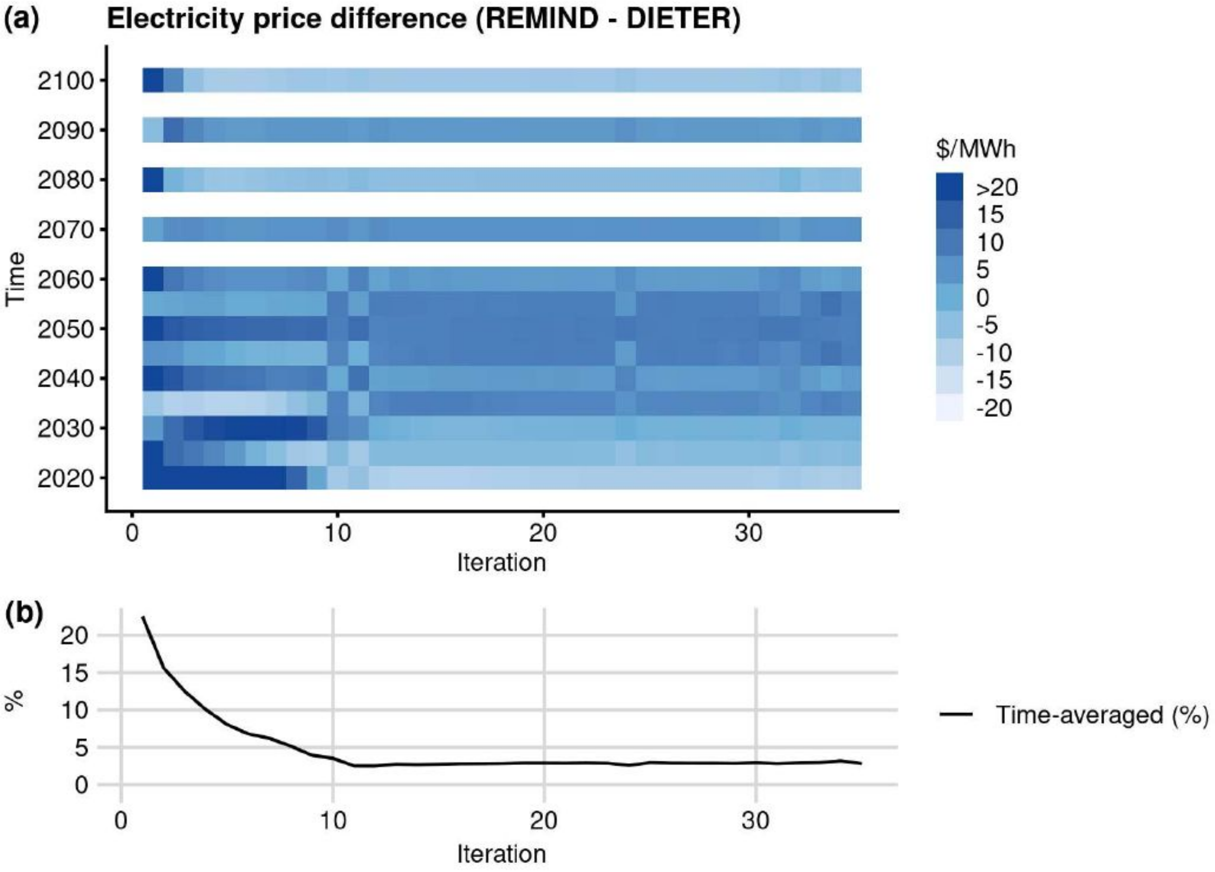
Annual generation vs. iteration (2040)





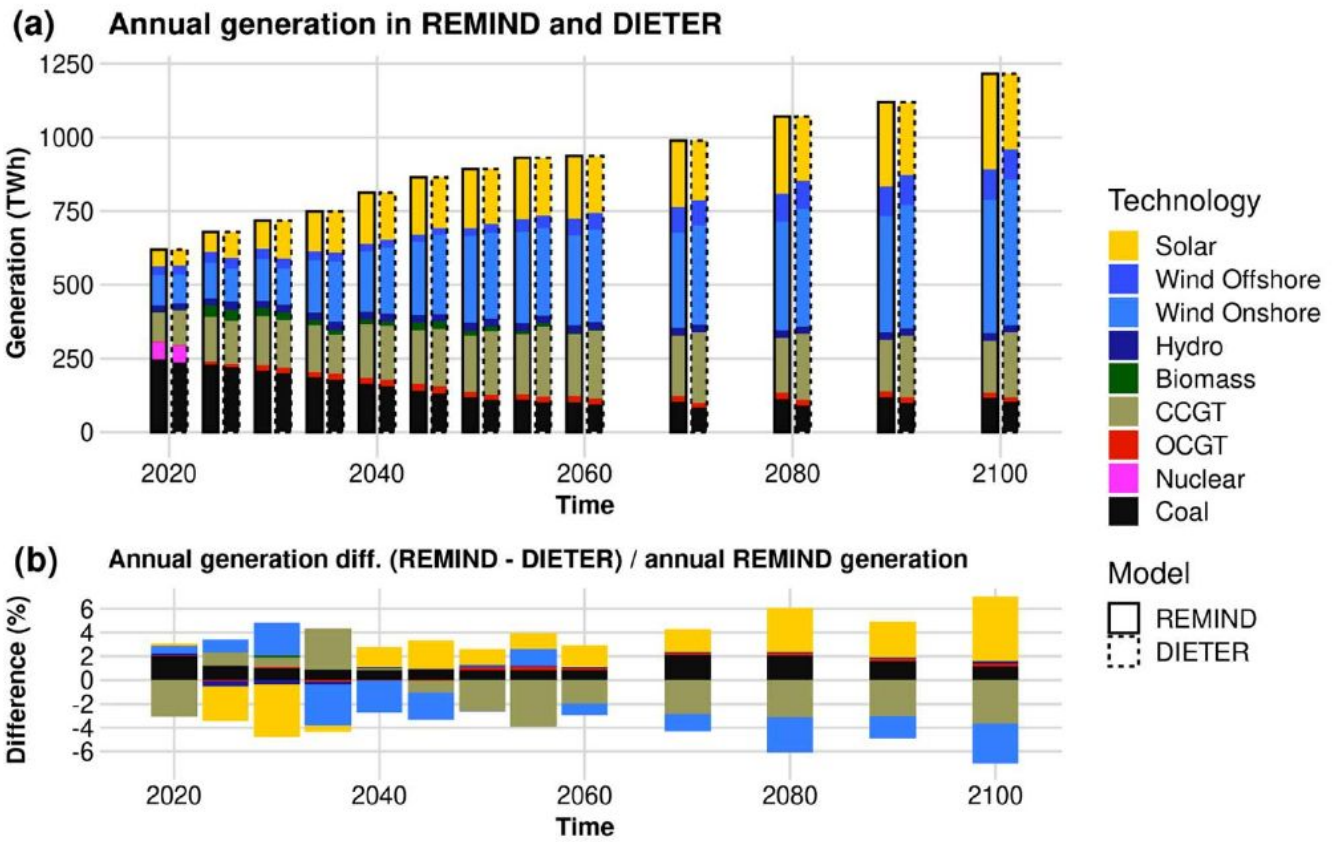
Price difference vs. iteration

Models’ price difference time series vs. iterations

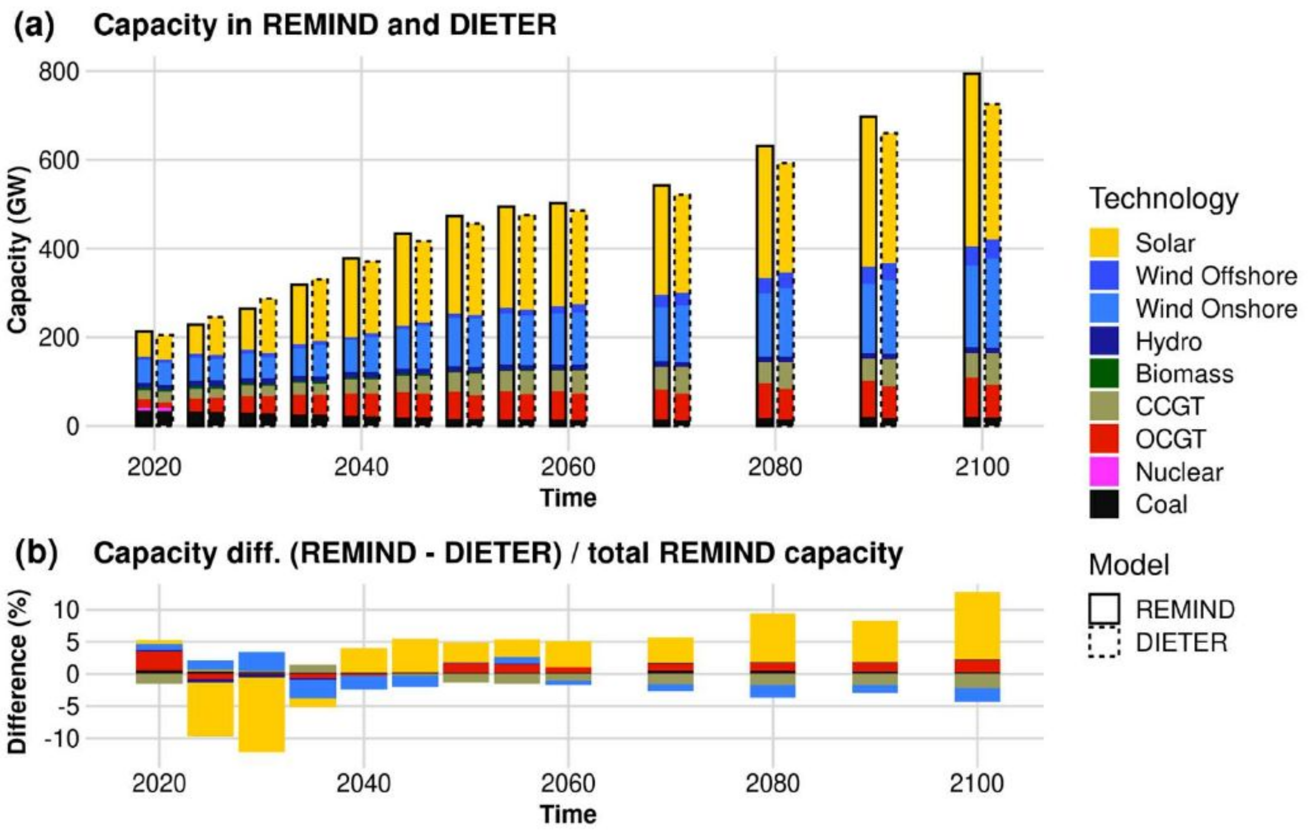


Quantity convergence

Generation vs. time (end of coupled convergence)

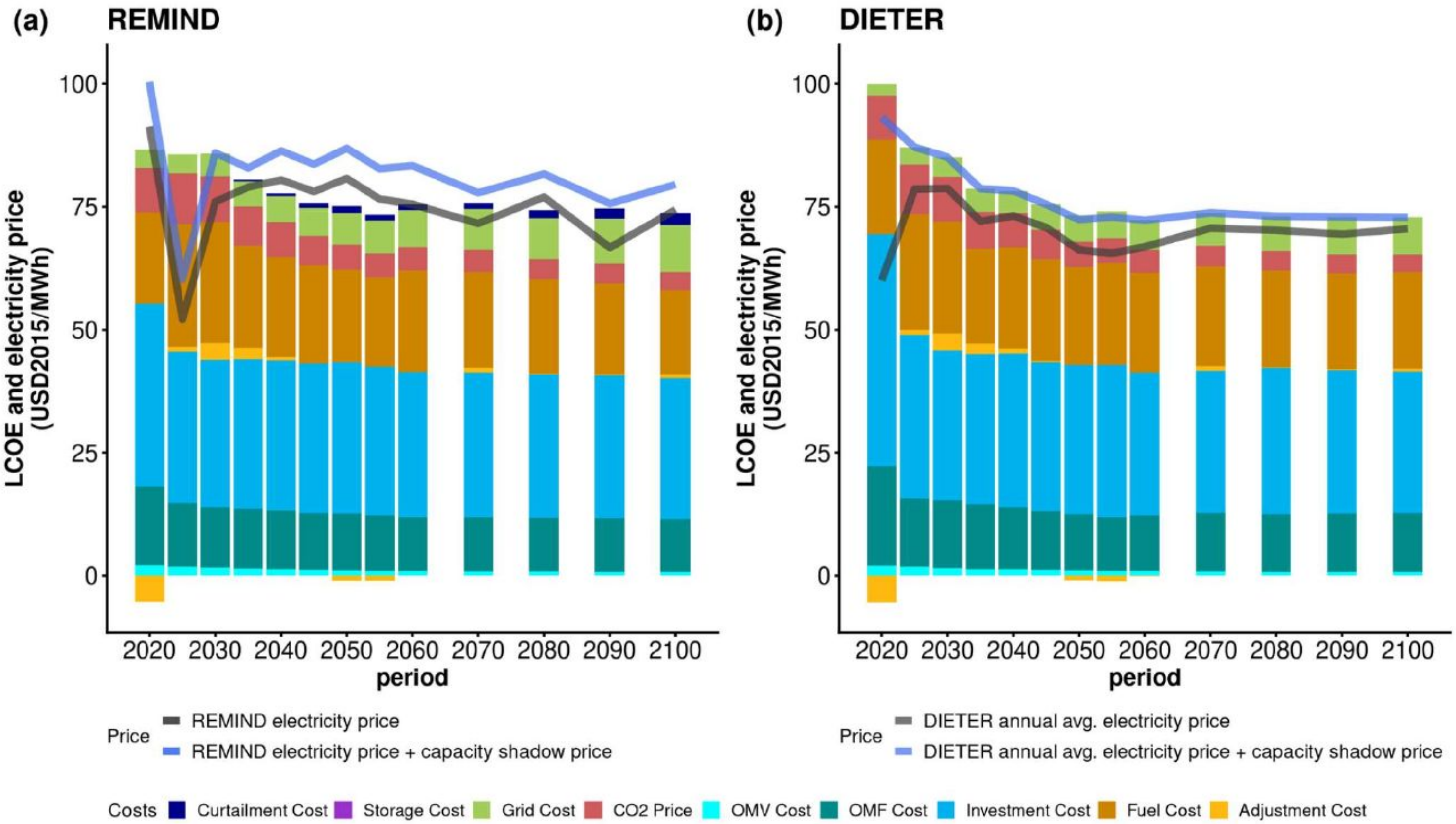


Capacity vs. time (end of coupled convergence)

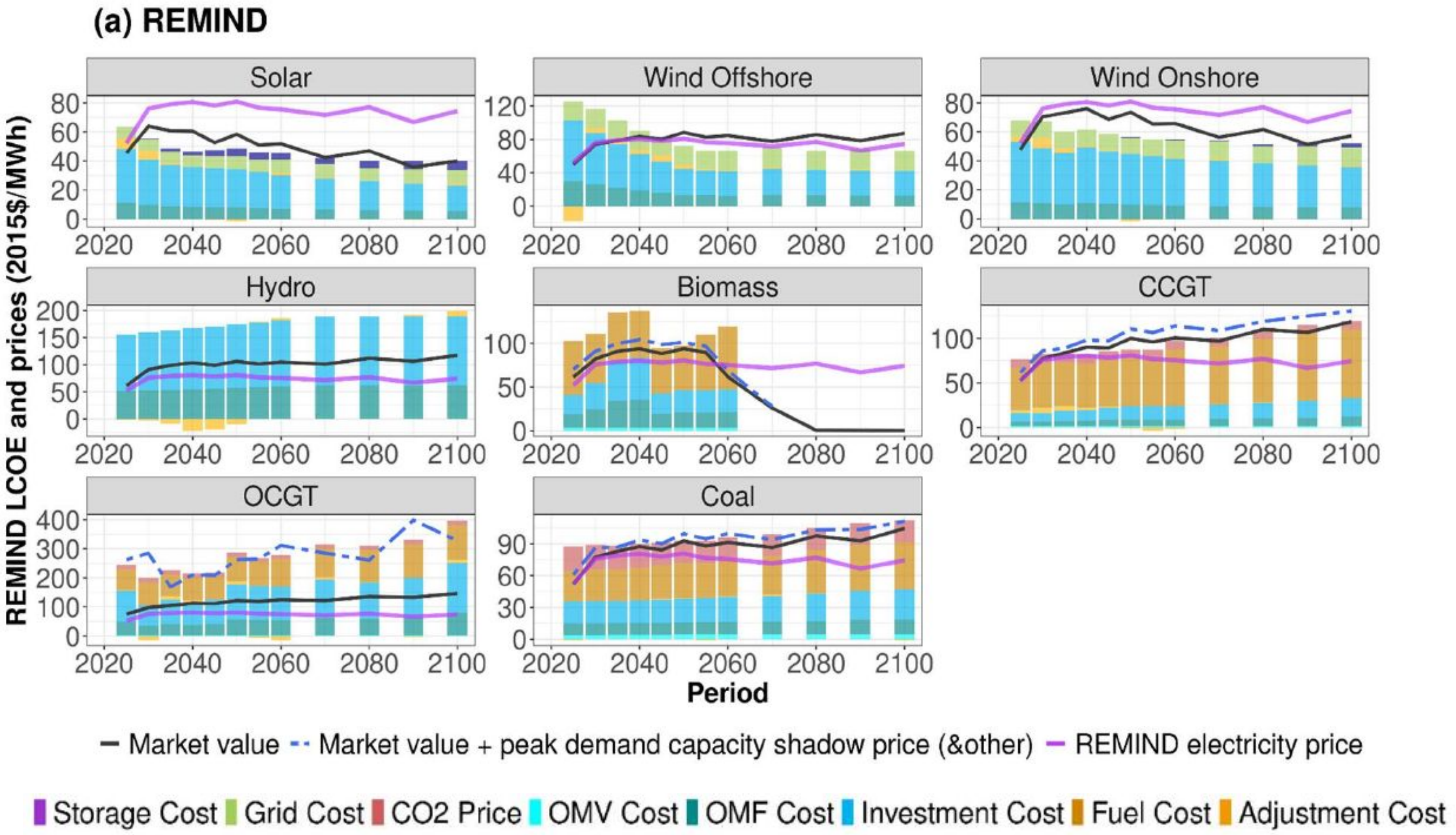


Price convergence

System price-cost structure vs. time (end of coupled convergence)



Technology market-LCOE structure vs. time (end of coupled convergence)



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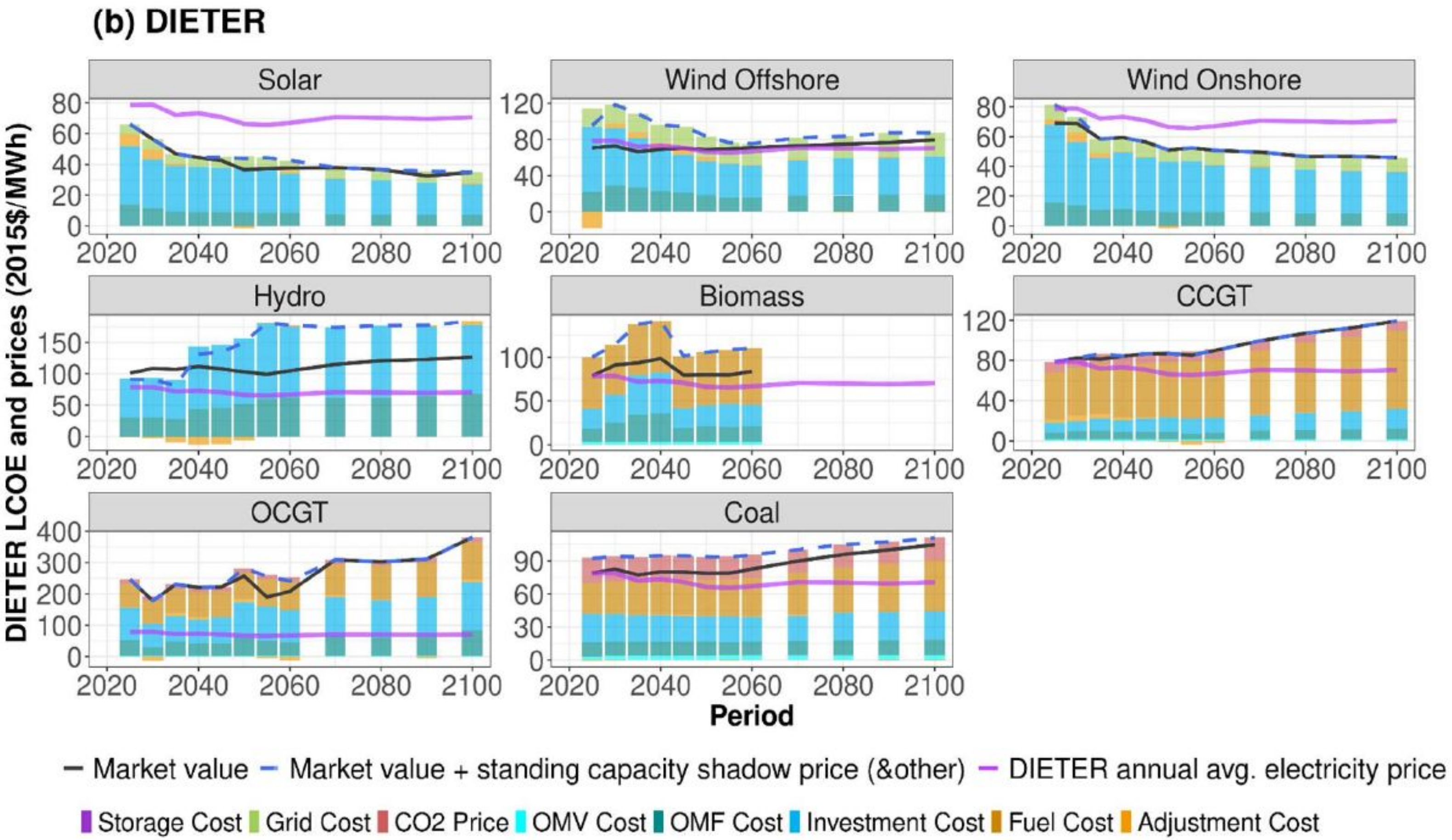
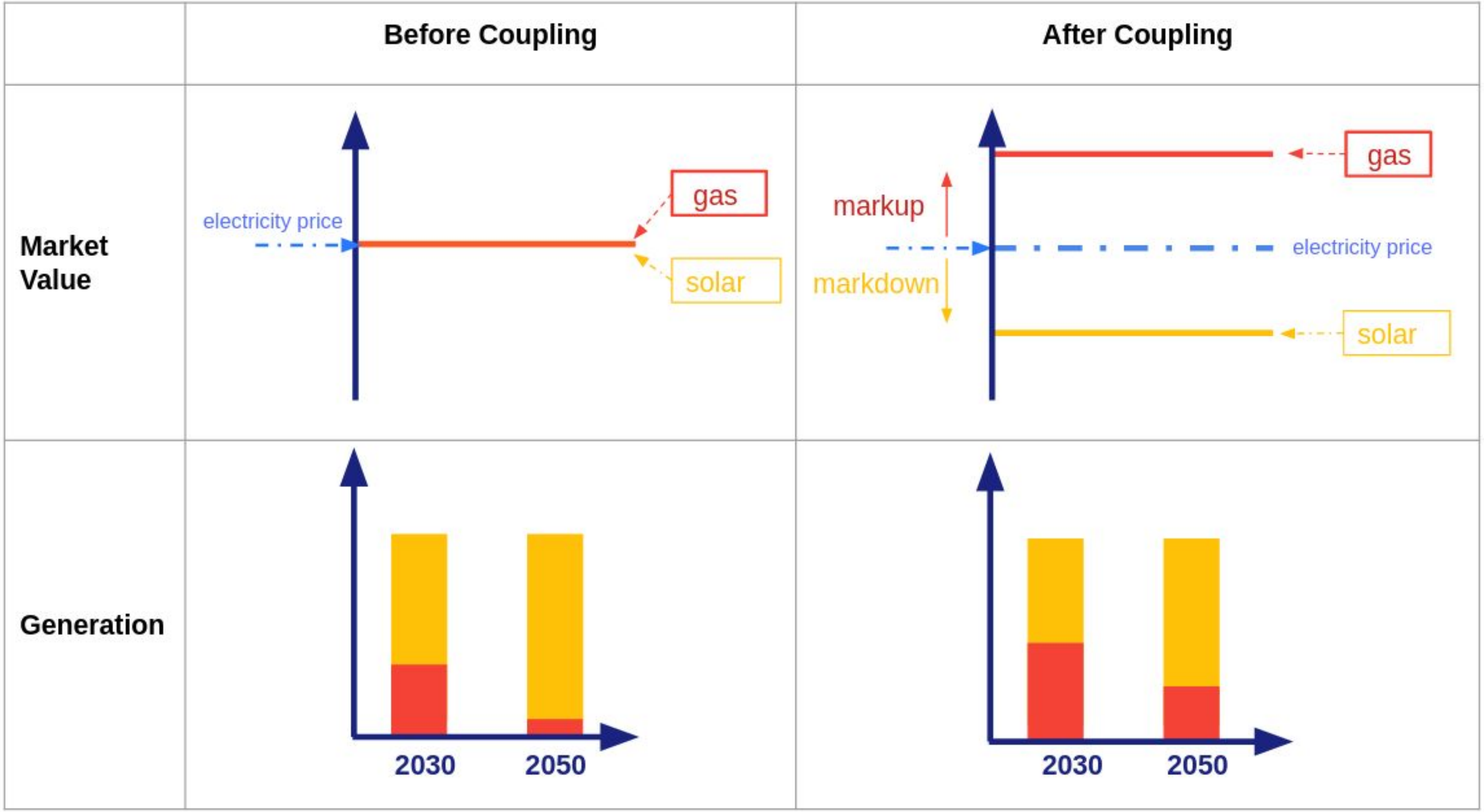


Conceptual intuition for “price-based coupling”: price differentiation tells quantities to move



Assume: solar > 50% share, so solar market value is below annual average price

Remaining differences:

Mostly two-folds:

- unable to fully harmonize “brown-field” and “green-field” models
  REMIND gets full historical capacity “for free”, DIETER bounds are more relaxed

- unable to fully harmonize “real-world optimal” and “model optimal”