COMPUTING TRANSFORMATION PATHWAYS TOWARDS A CLIMATE NEUTRAL ENERGY SYSTEM

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DLR

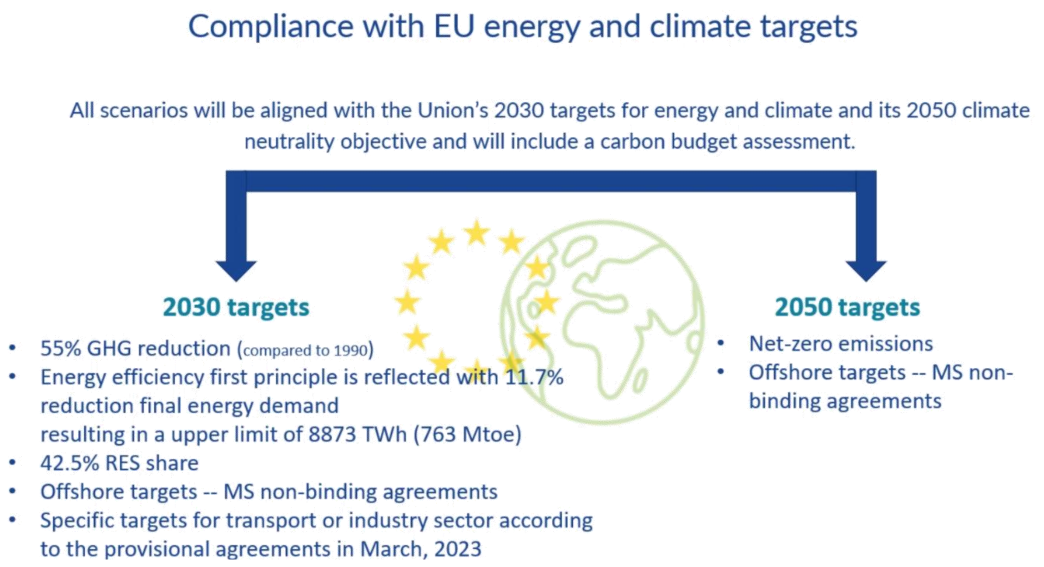
Challenges in European energy strategy

Climate risk and geopolitical crises drive the urgency for transformation:

- Decarbonizing the energy supply systems across sectors
- Providing security of energy supply

How can the system be transformed to reach these goals?

- What it the optimal timing for switching to hydrogen and green energy carriers?
- How can electrolyzers be ramped up efficiently for increasing demand of hydrogen?
- What are the implications for power grids and pipeline networks and their respective topology?



TYNDP2024 stakeholder consultation

Tab. 1 – Strategic choices in the European clean hydrogen value chain

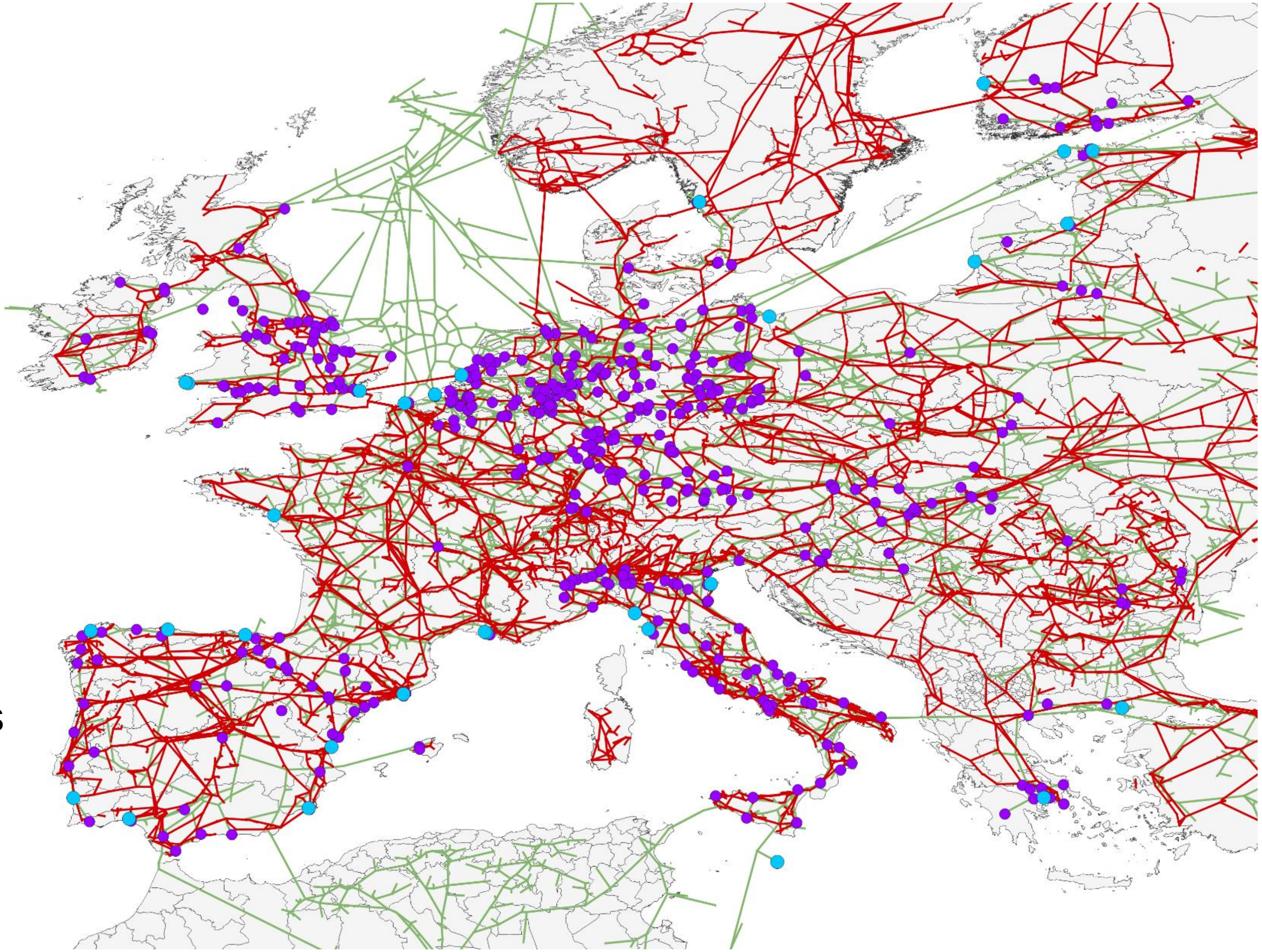
European Union	**40 GW** **10 MtH_2**	• Push for renewables • Promotes a "Hydrogen Valley" approach to facilitate local integration and growth • By 2024: **6 GW** electrolyzers, **1 MtH_2** • By 2030: **40 GW** electrolyzers, **10 MtH_2** • 2030-2050: large-scale deployment across all hard-to-abate sectors
Germany	**10 GW** **3 MtH_2**	• Push for renewables • Emphasis on imports of hydrogen (low-carbon hydrogen not excluded) • €8bn of public budget has already been allocated to 62 pre-selected projects • Up to €3.4bn to build refuelling stations

Deloitte 2022 The European hydrogen economy

European power and gas infrastructure

- One model region per country
- Increased spatial resolution
- Integration of high res power grid
- Integration of high res gas network
- Integration of LNG terminals
- Power and gas network with LNG terminals and gas power plants

→ European infrastructure modelling requires high spatial and temporal resolution



Own depiction based on ENTSO-E GridKit and SciGrid_gas IGGIELGN

Modelling toolchain

SciGRID Gas

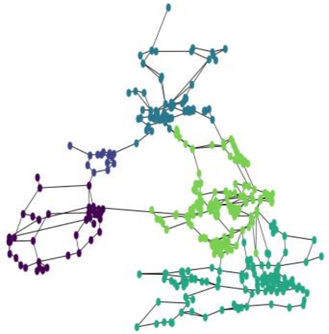
bdw/GridKit

GridKit is an power grid extraction toolkit

eGo^n

→

Topology reduction for networks



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Calculation of EEZs

- Area allocation based on coastlines or points

→

REMix
Renewable Energy Mix

Open source publication
- Source code release
- Python API and PyPI release

Model development
- Infrastructure repurposing
- Improved model formulation
- PIPS-IPM++ for pathways

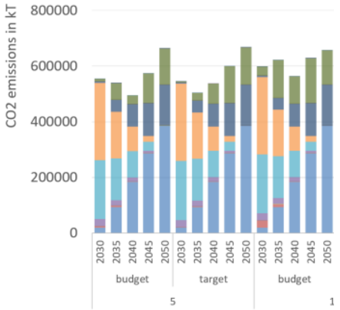
↑

Renewable energy potentials and feed-in

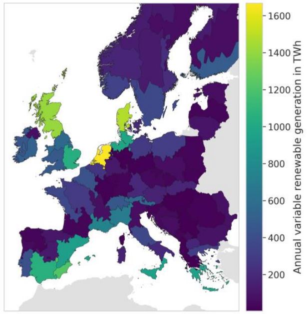
→

Results from the REMix model

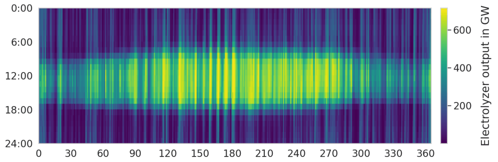
- Annual energy balances



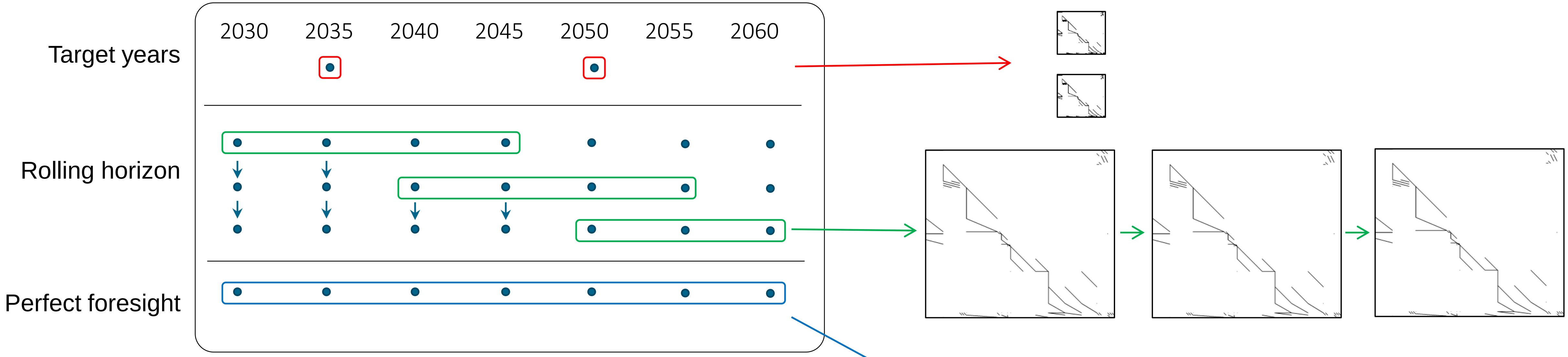
- Spatial allocation of technologies

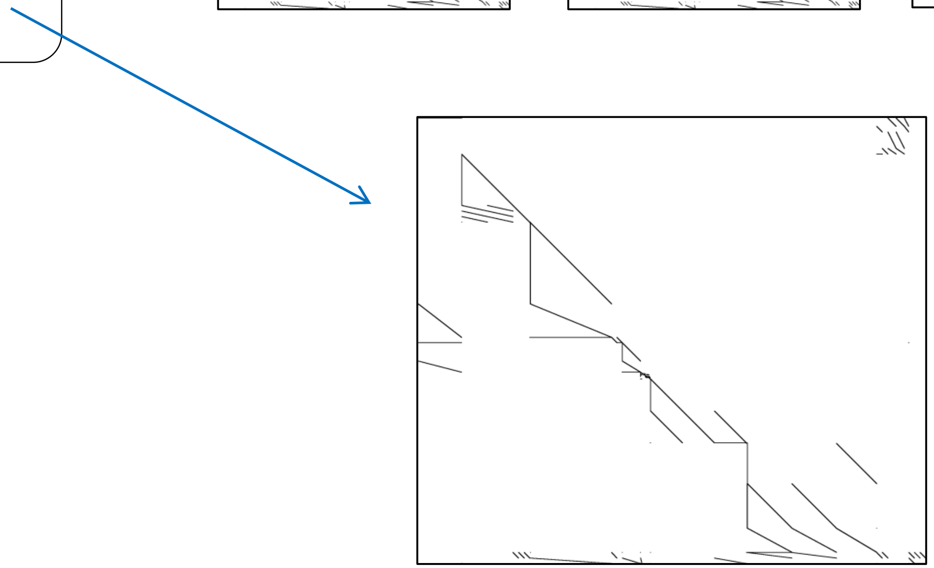


- Hourly interactions between technologies



Target years, myopic and perfect foresight





Limited foresight can lead to lock-in effects

- Short term investments into fossil power plants
- Exceeding the allowed carbon budget

Drivers of model complexity

Scaling from **18** to **488** model regions

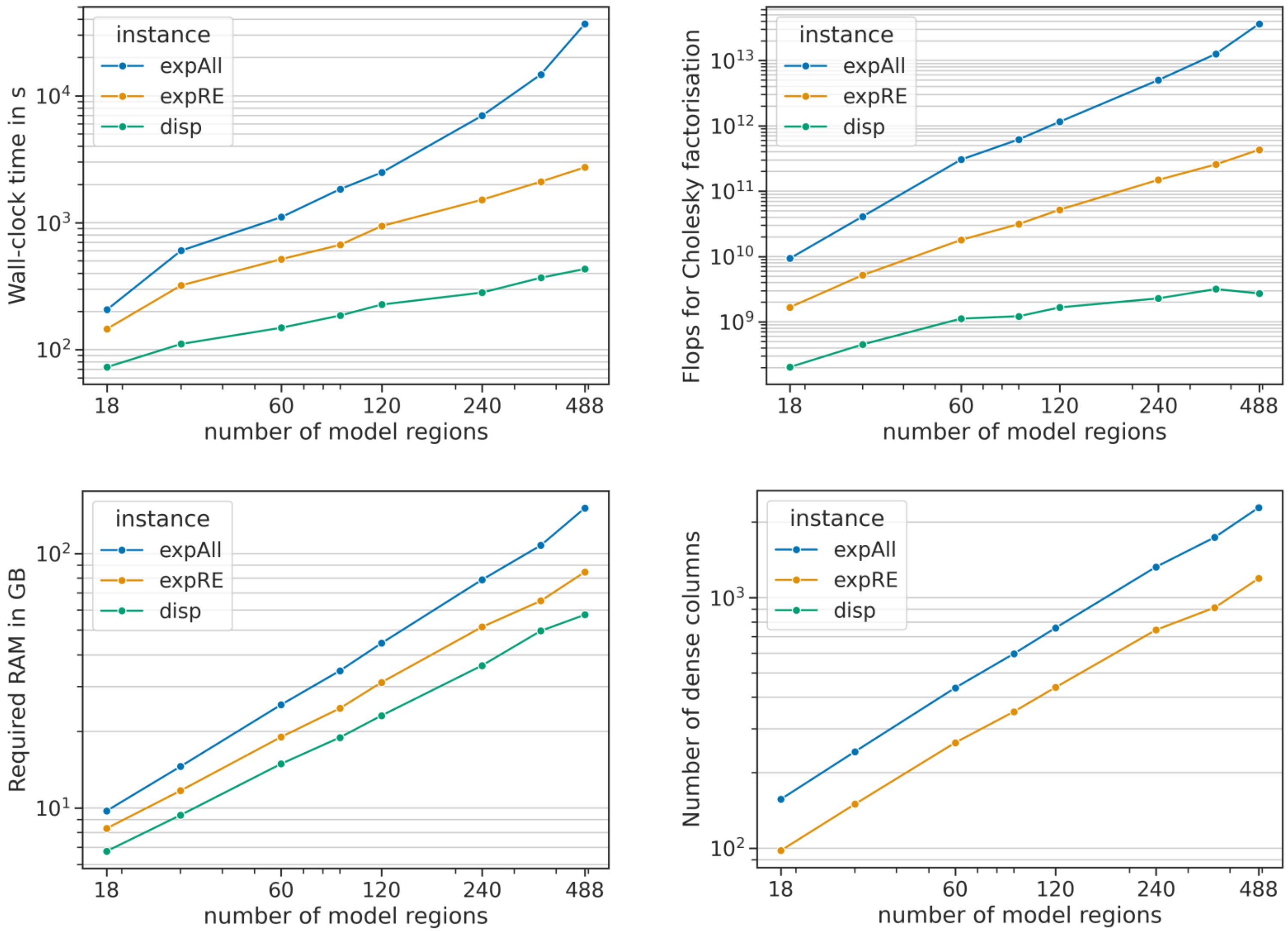
disp: Only economic dispatch

expRE: Only investment in VREs

expAll: Investment in VREs, generators, grid and storage

Key driver for model performance:

- Number of investment decisions
- Size of the optimization problem



Wetzel et al., Energy System Optimization Models on High Performance Computers: Application and Performance Evaluation of a Parallel Interior Point Solver, submitted

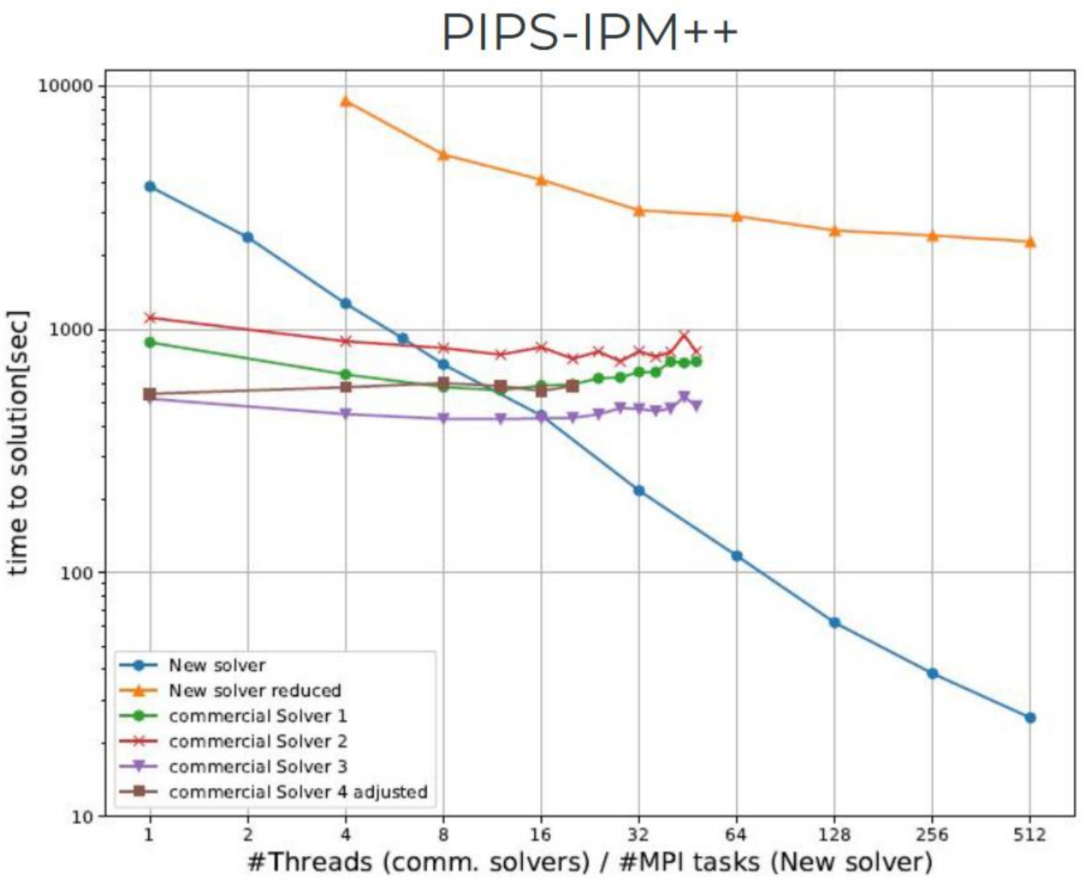
Solver performance for REMix model instances

Barrier methods for commercial solvers show scaling behaviour with optima at 8 - 16 threads

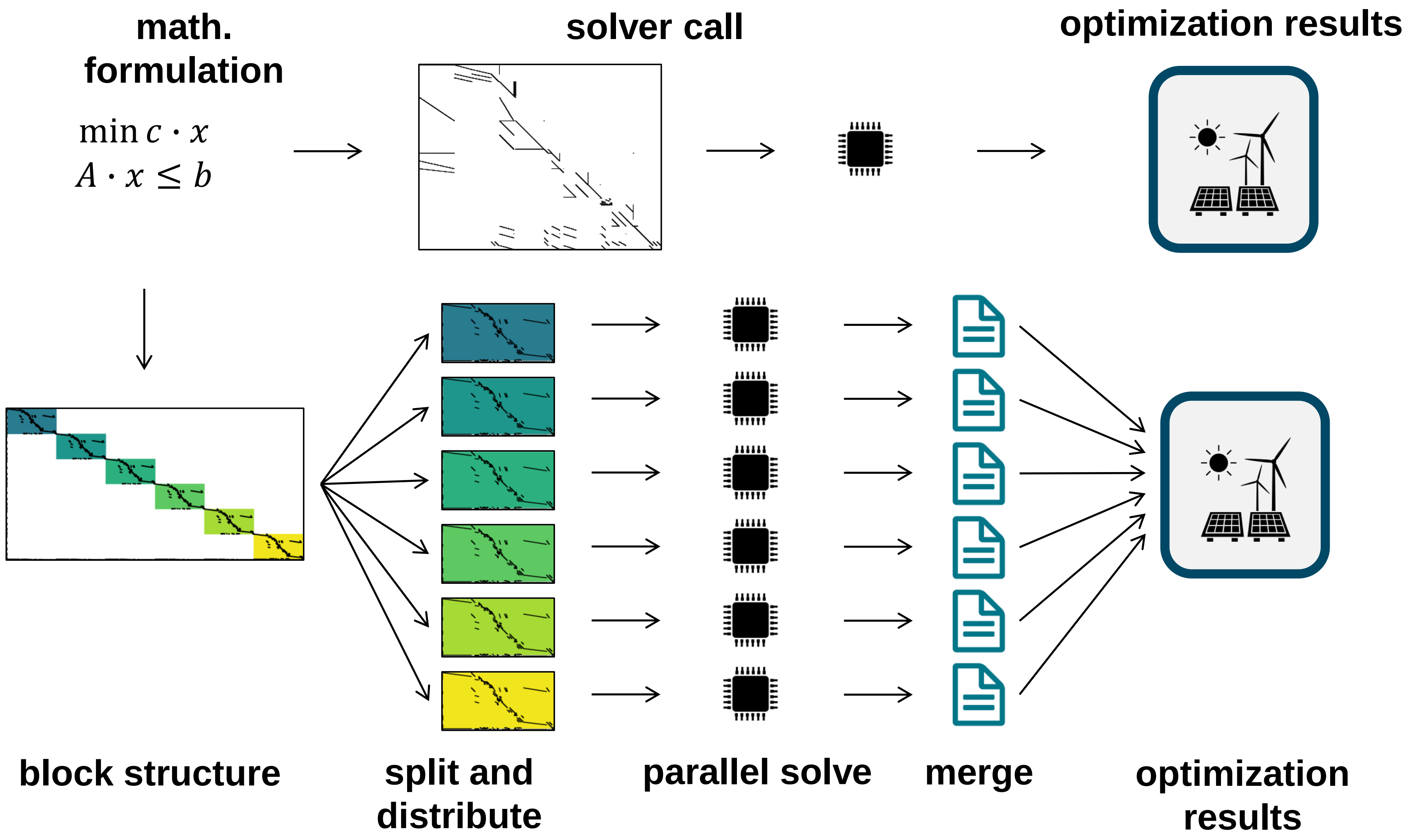
With increasing problem size either

- Available shared memory is insufficient
- Time to compute disproportionately long

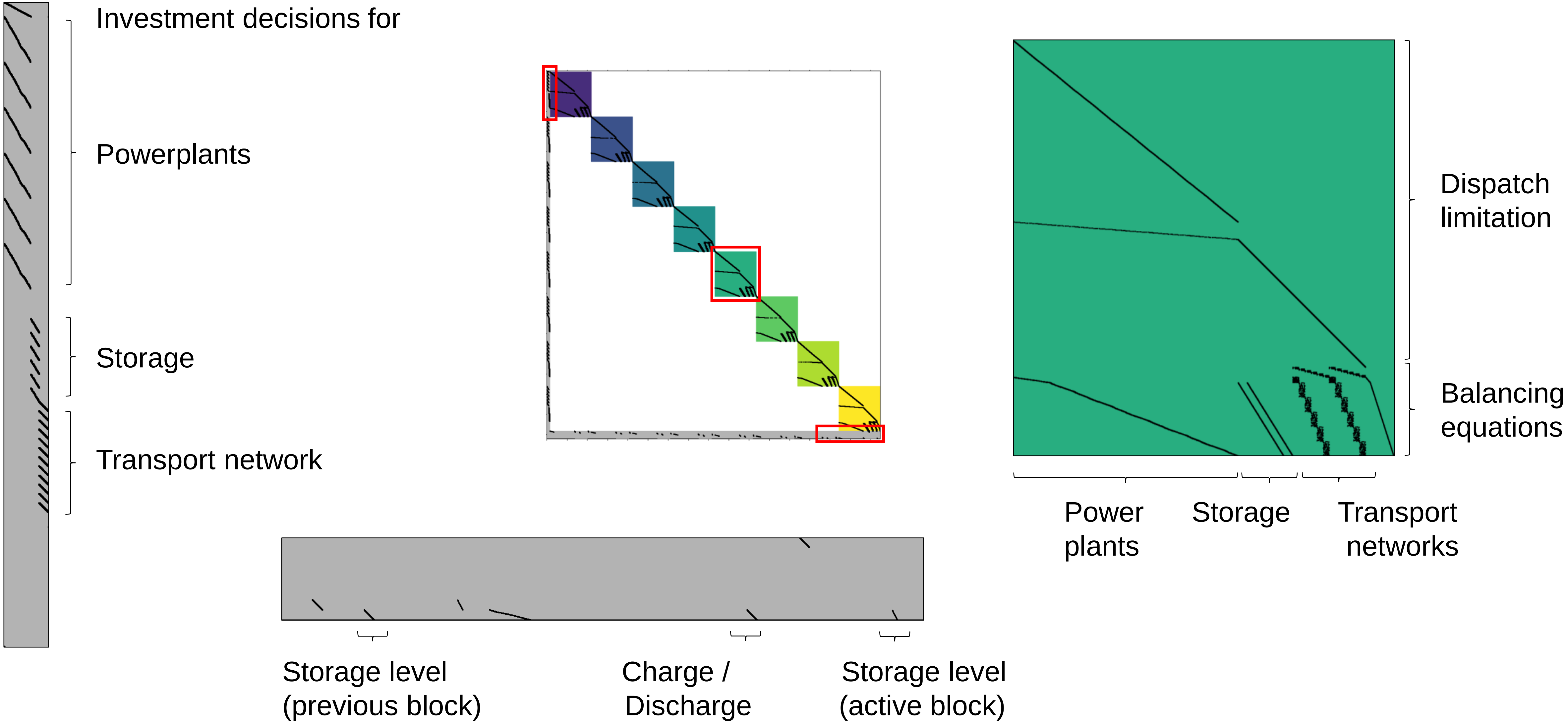
Decomposition and distributed memory necessary



PIPS-IPM++ workflow overview



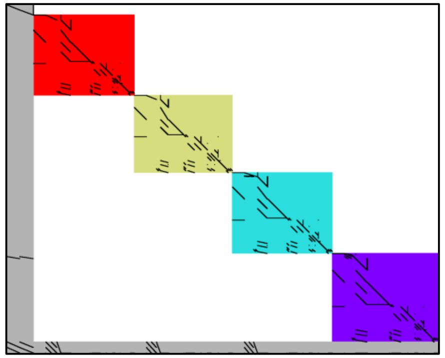
Understanding the block structure



Different types of decomposition

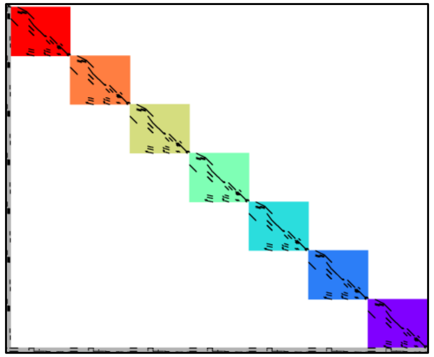
		spatial	temporal
Constraint	Global annual constraint, e.g. CO_2 limit	1	1
	Regional annual constraint, e.g. CO_2 limit		b
	Storage level		$b \cdot p_S \cdot n$
	Transmission limit	$l \cdot t \cdot p_T$	
Variable	Power plant capacity		$b \cdot p_P$
	Storage capacity		$b \cdot p_S$
	Transmission capacity	$l \cdot p_T$	$l \cdot p_T$
	Power flow	$l \cdot t \cdot p_T$	
	Total	$\sim l \cdot p_T \cdot (2t + 1)$	$\sim b \cdot ((1+n)p_S + p_P) + l \cdot p_T$

Regional decomp.



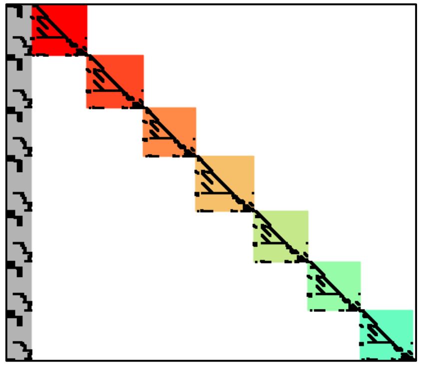
Large number of linking elements

Temporal decomp.



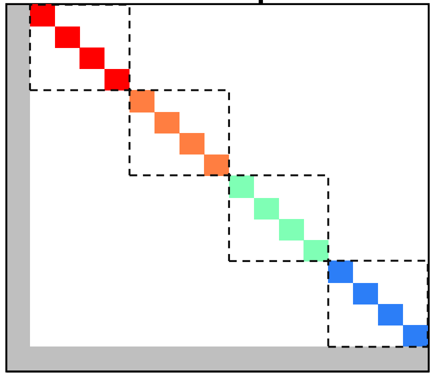
Most promising with up to 8760 blocks

Horizon decomp.



Limited number of blocks

Horizon + temporal decomp.



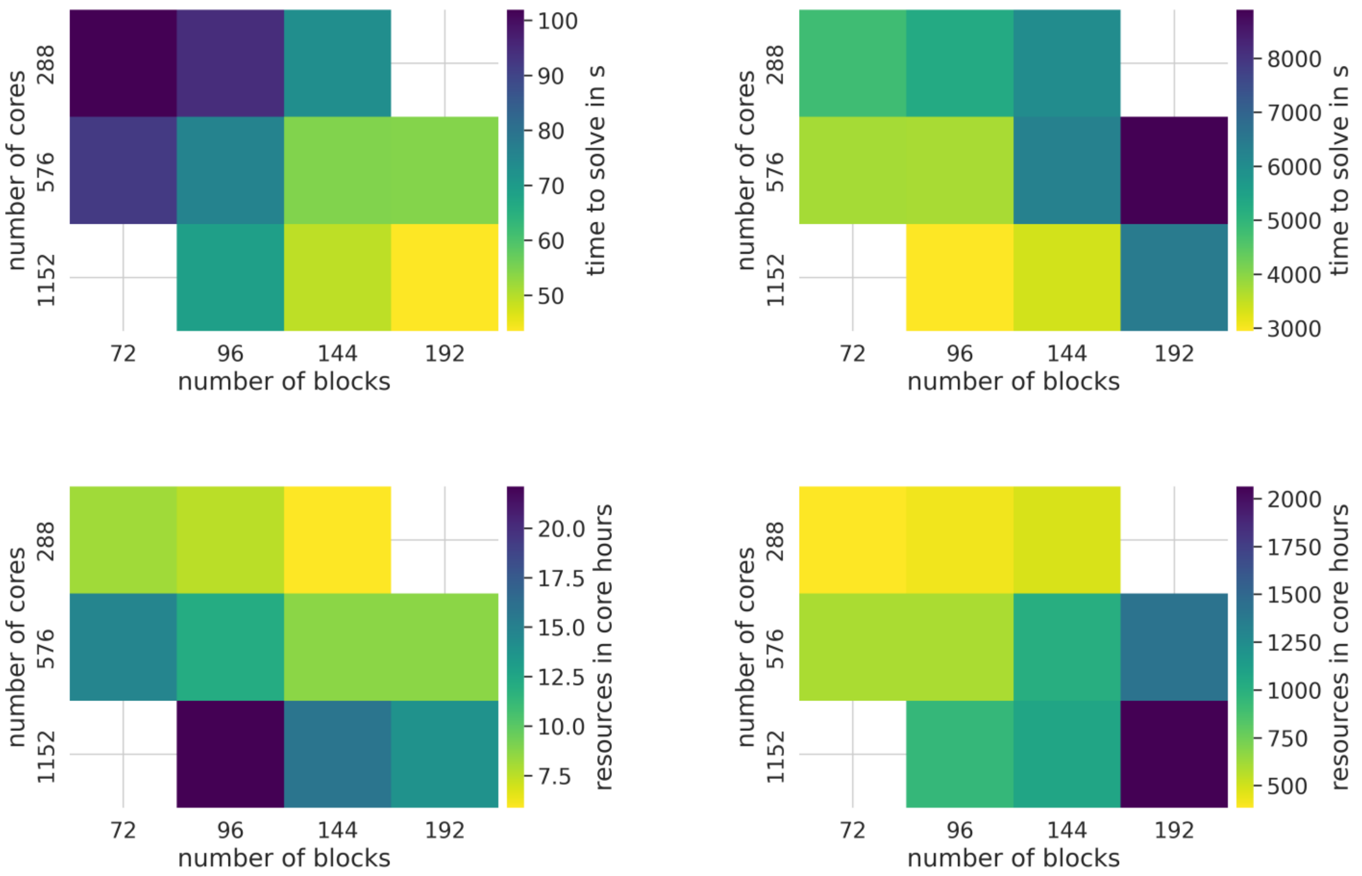
High synergy between decomposition

Solver configuration for PIPS

PIPS configuration depends on problem:

- Complex capacity expansion problems perform better with less blocks, dispatch problems benefit from more blocks
- More compute nodes reduce the required wall-clock time but increase the overall resource consumption
- Further assessments for different problem types planned later on

Economic dispatch | Capacity expansion



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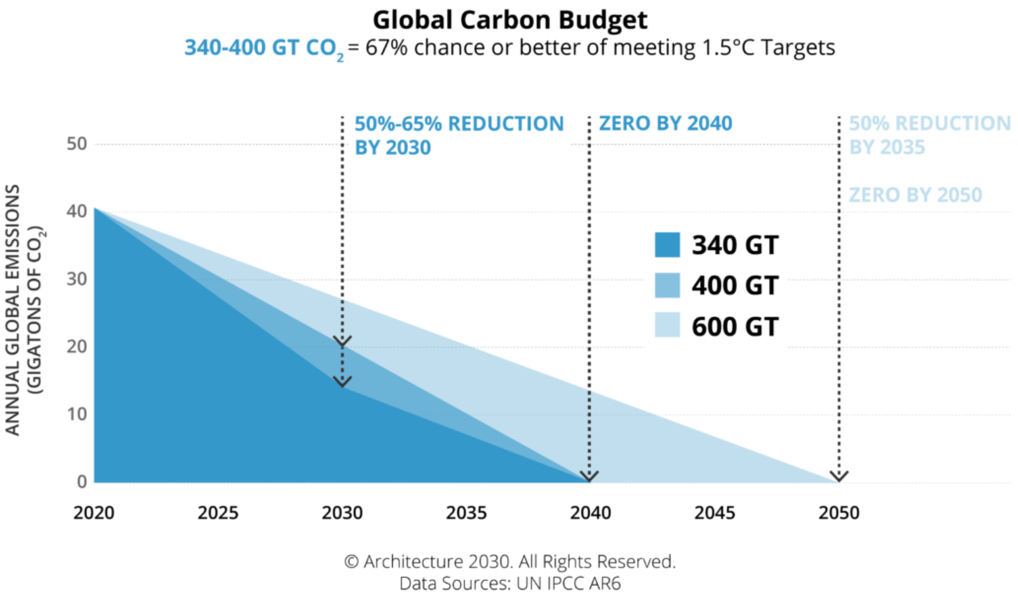
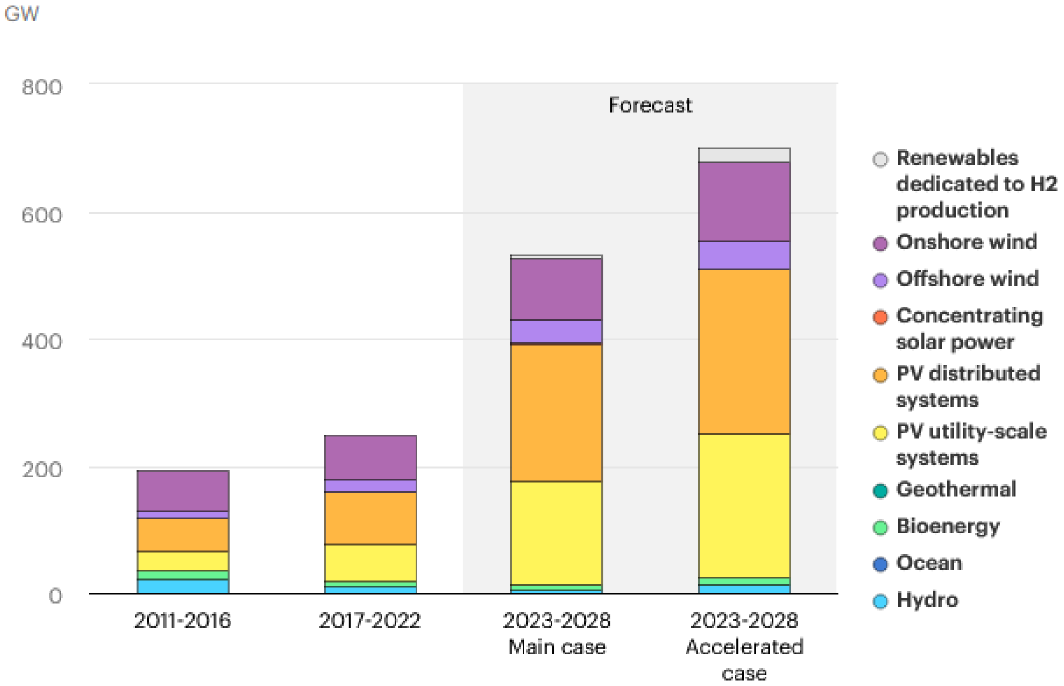
REMix results – scenario overview





IEA Renewables 2023

CO2 budget allocation

- **target:** linear reduction from 2025 to 2050 (myopic foresight)
- **budget:** model can allocate the available budget (perfect foresight)

CO2 budget amount

- Variation between **5 Gt, 10 Gt, 15 Gt**

Limitation of VRE capacity expansion rates for Europe + national

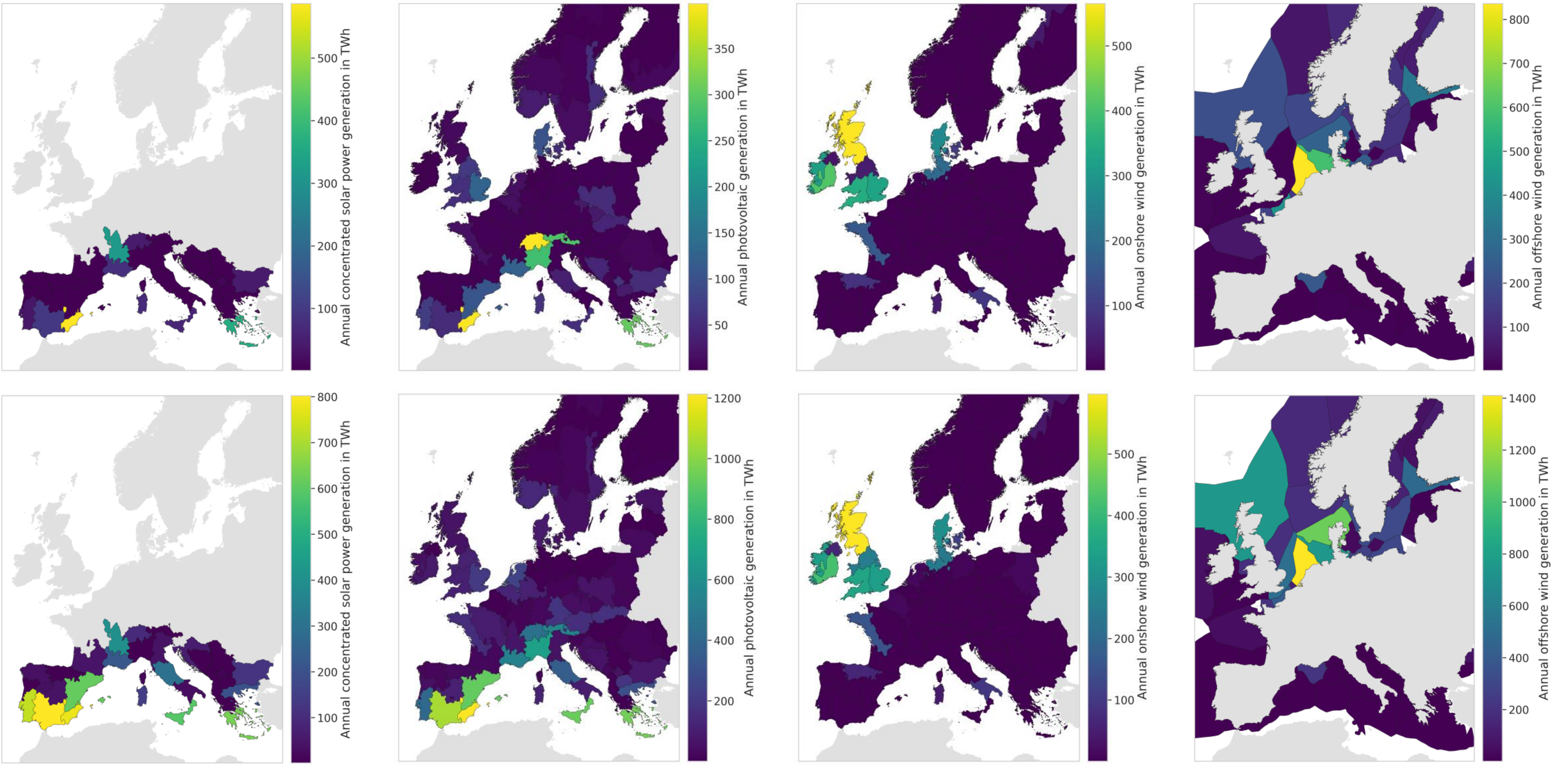
- **no-limit: No limitation of expansion rates**
- **RE0:** Baseline increasing to 2x per 5 years
- **RE+:** Baseline increasing to 3x per 5 years
- **RE++:** Baseline increasing to 5x per 5 years

Preliminary results – Electricity production sites

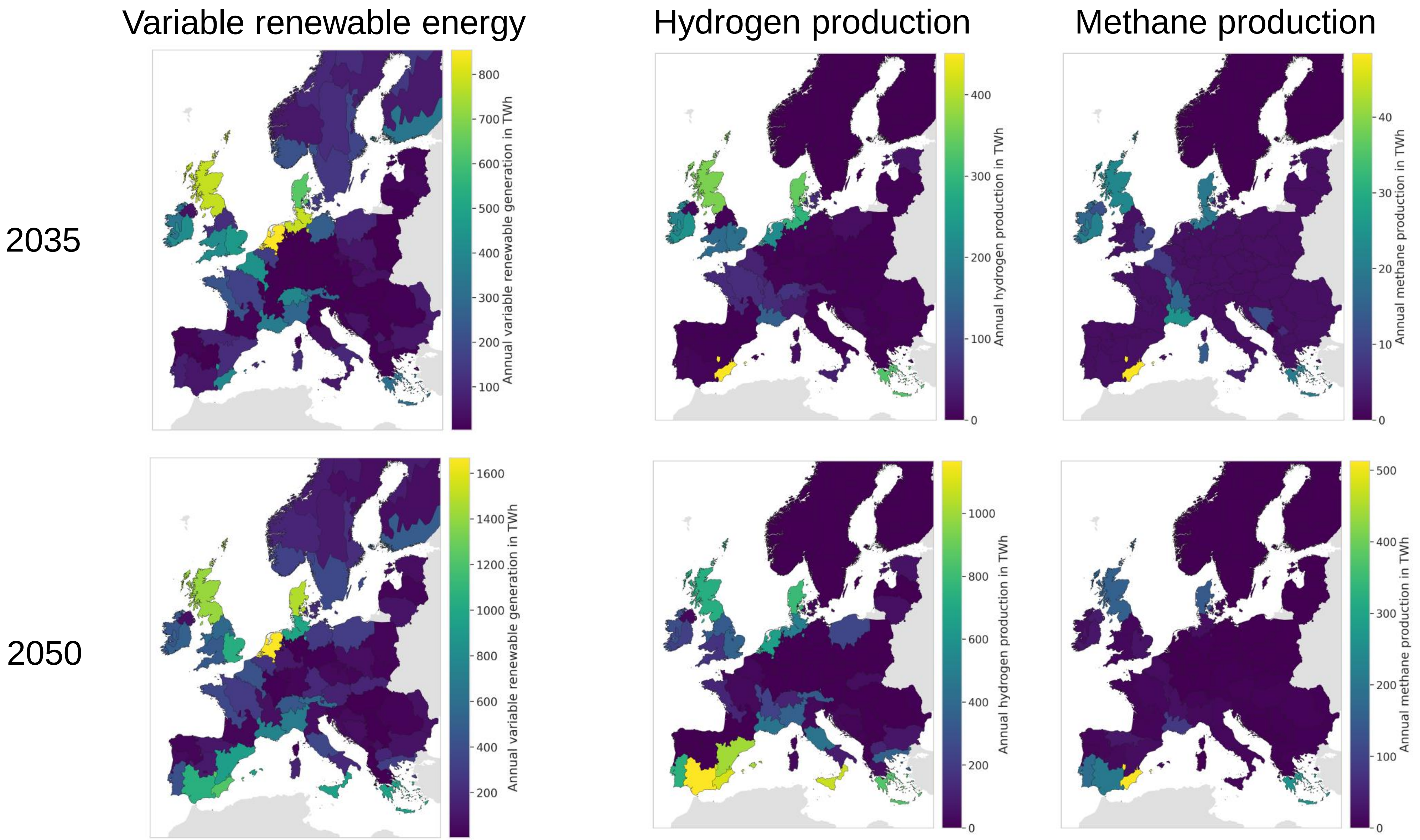
Concentrated solar | Photovoltaics | Onshore wind | Offshore wind

2035

2050



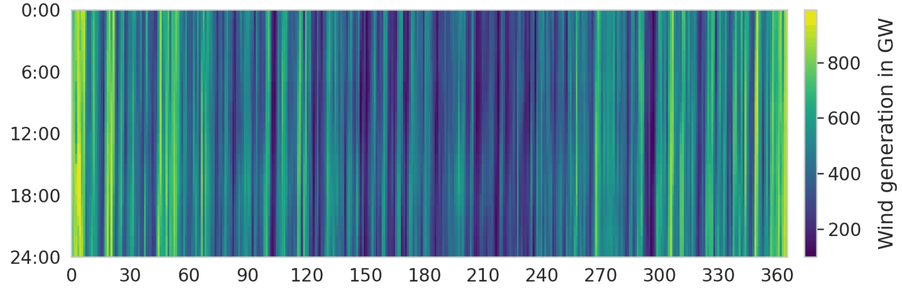
Preliminary results – Hydrogen and methane sites



Preliminary results – Temporal technology correlation

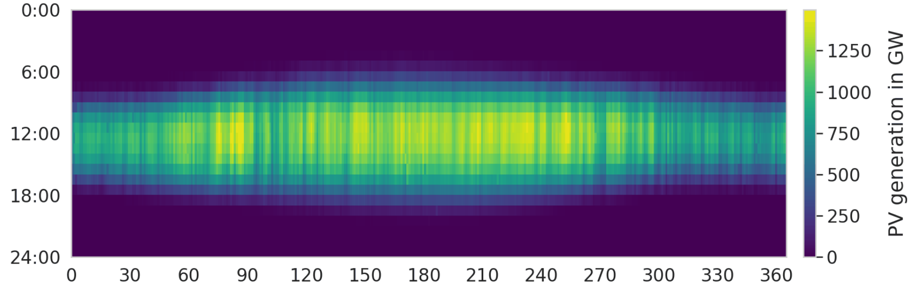
Onshore and offshore wind

pexels



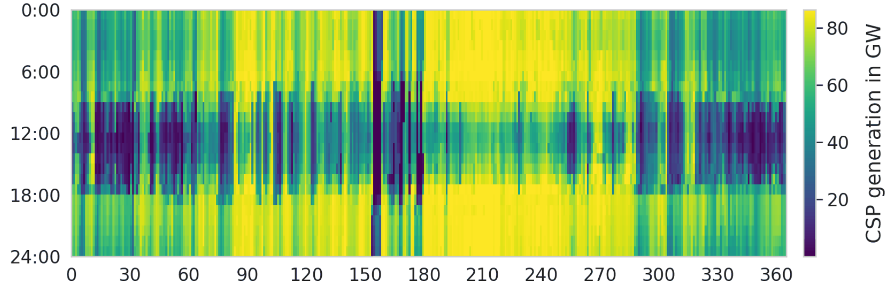
Photovoltaics

pexels

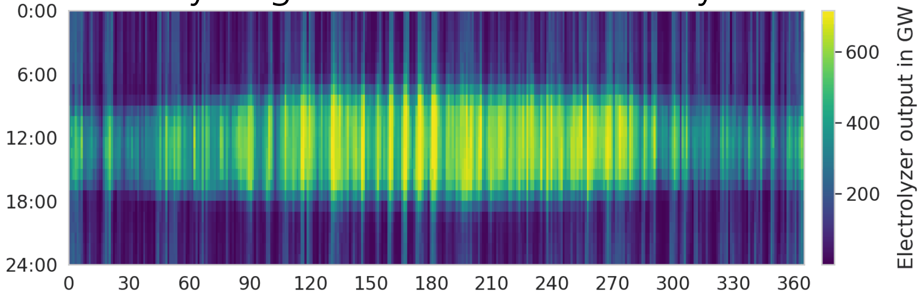


Concentrated solar power

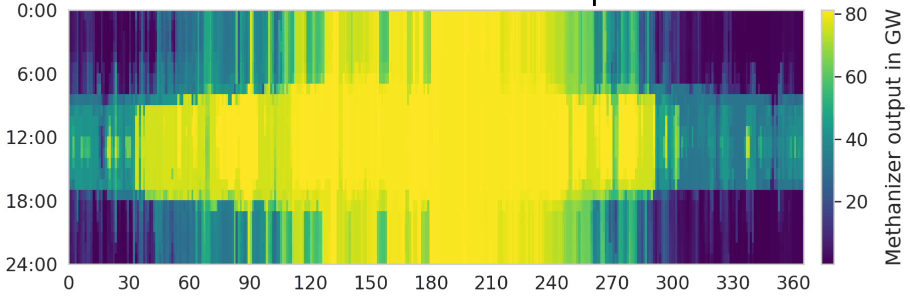
SENER



Hydrogen from water electrolysis



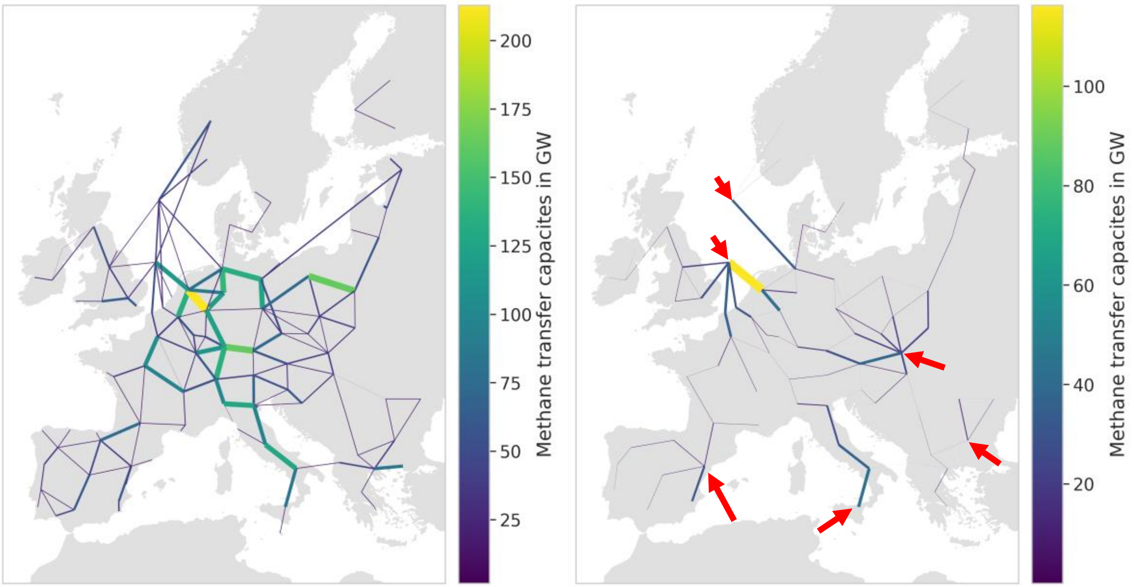
Methane from Sabatier processes



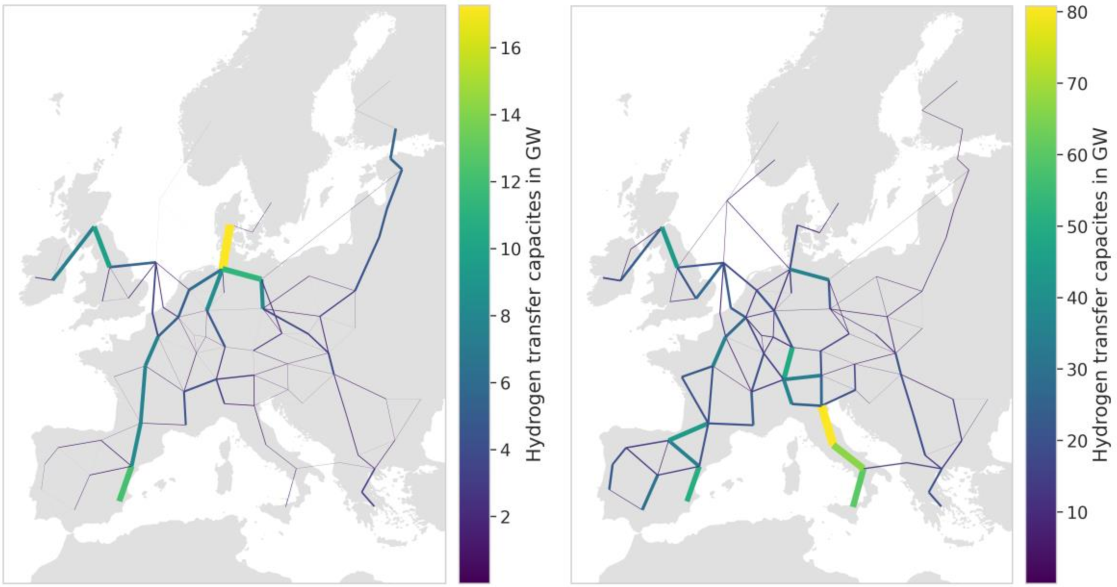
- Electrolyzers offer demand side flexibility
- Green methane requires seasonal storage

Preliminary results – Network topology (H2 scenario)

Methane network capacities 2025 - 2035



Hydrogen network capacities 2030 - 2050

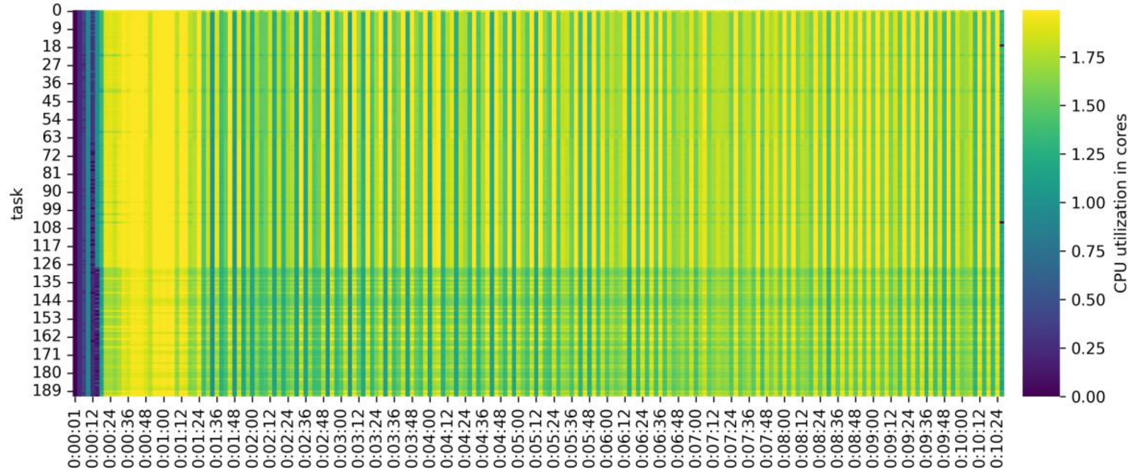


- Remaining gas network mainly focused on pipeline corridors for imports and gas rigs

- Initial hydrogen network focused on the North Sea area and Southern Europe
- Evolutionary development towards a highly meshed grid

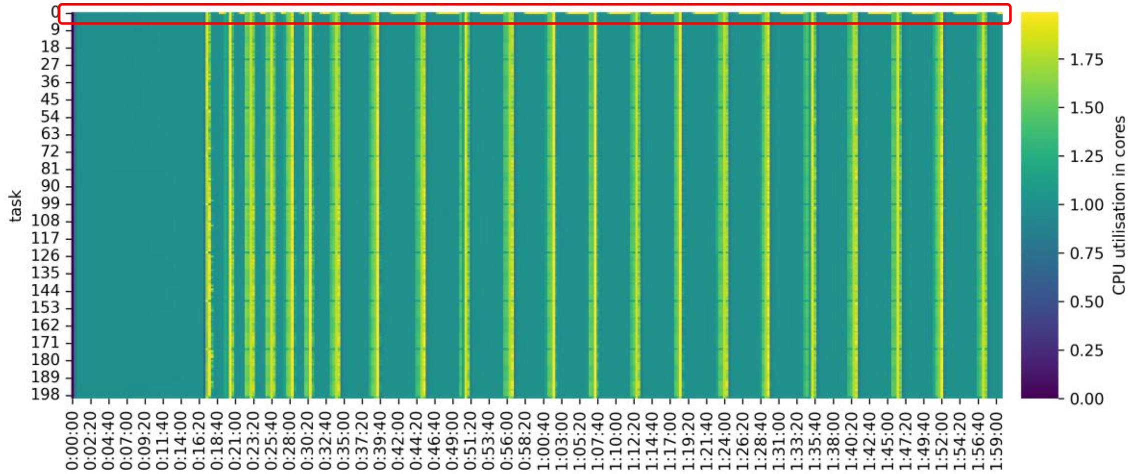
Computational challenges

Performance for medium sized problem



- Similar sized blocks to achieve load balancing across all parallel processes
- Full utilization of all compute nodes

Performance for large scale problem



- Significant time spent in updating of barrier bounds
- Exceedingly high memory demand of 4 x 800 GB

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