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# Speeding up energy system optimization models – lessons learned from heuristic approaches, parallel solvers and large scale models

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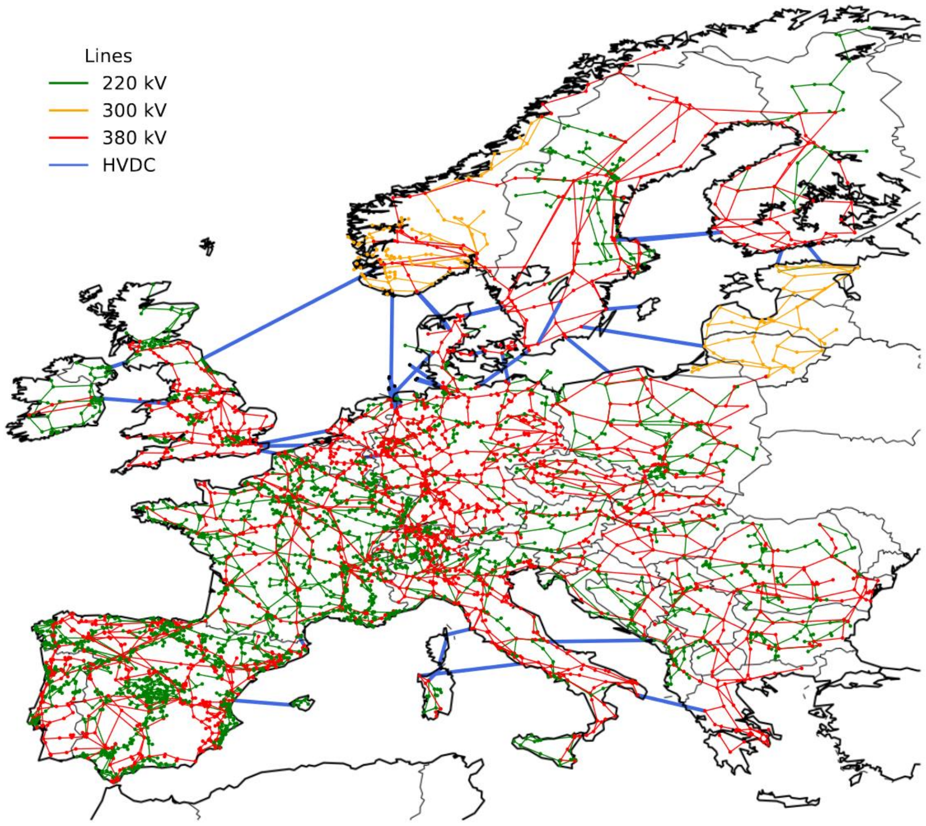
# The case for large scale energy system models

- Renewable energy is an intermitted sources of energy
- High temporal resolution is required to capture sufficient variation
- Sector coupling will further increase the share of renewable energy

- Overall system will rely on spatial and temporal flexibly options
- Low spatial scale models overestimate spatial concurrency
- Detailed grid representation necessary

High spatial and temporal resolution required

→ Complexity of models increases exponentially with size



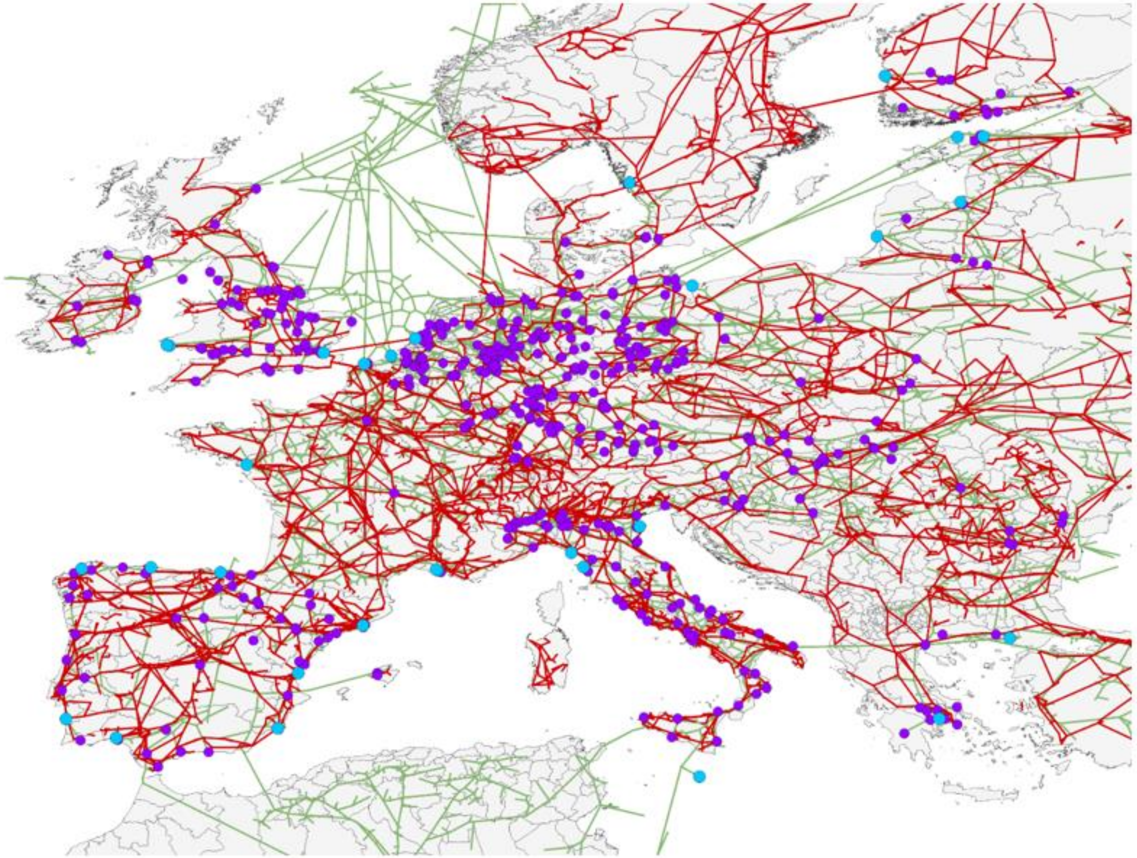

Hörsch et al., PyPSA-Eur: An Open Optimisation Model of the European Transmission System

# Sector integration and gas infrastructure

- Future models need to address gas pipelines for methane and hydrogen in addition to power grids
- Gas infrastructure such as LNG terminals and storage needs to be included in energy system models
- More degrees of freedom for the optimization

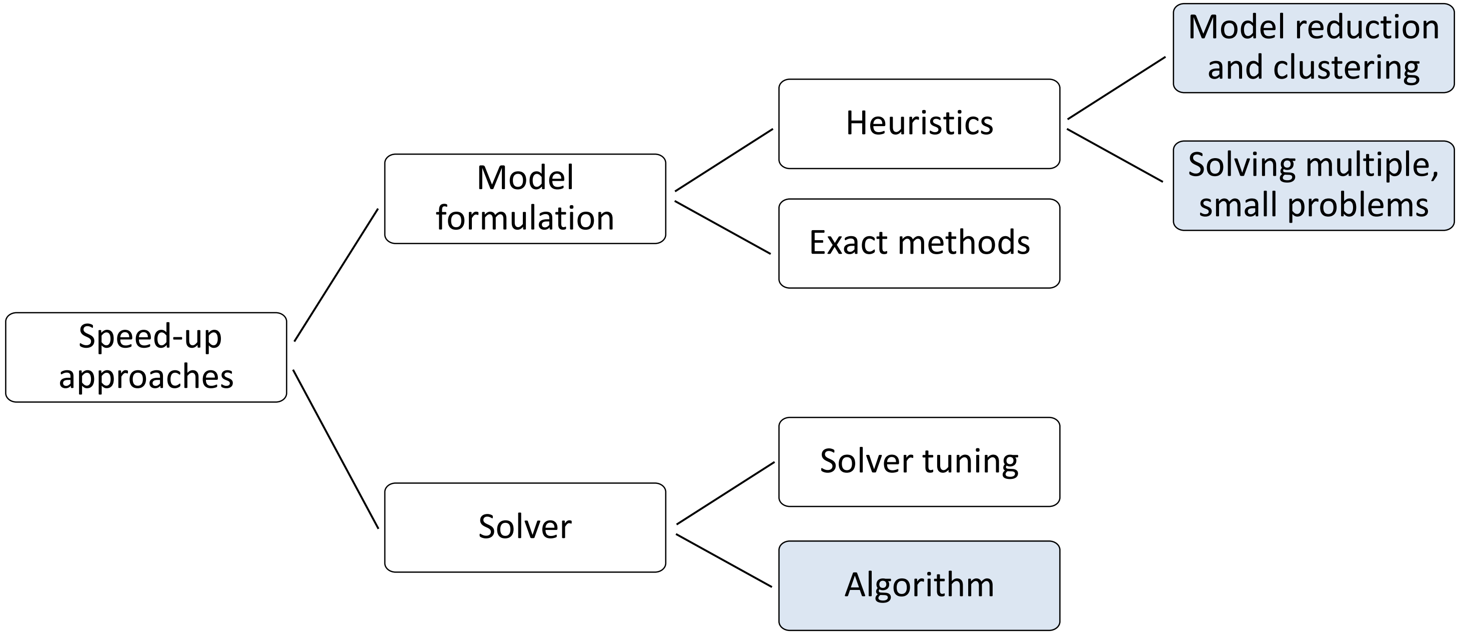
Trend towards large scale energy system models continues

→ Model speed-up methods are urgently needed



Own depiction based on ENTSO-E GridKit and SciGrid_gas

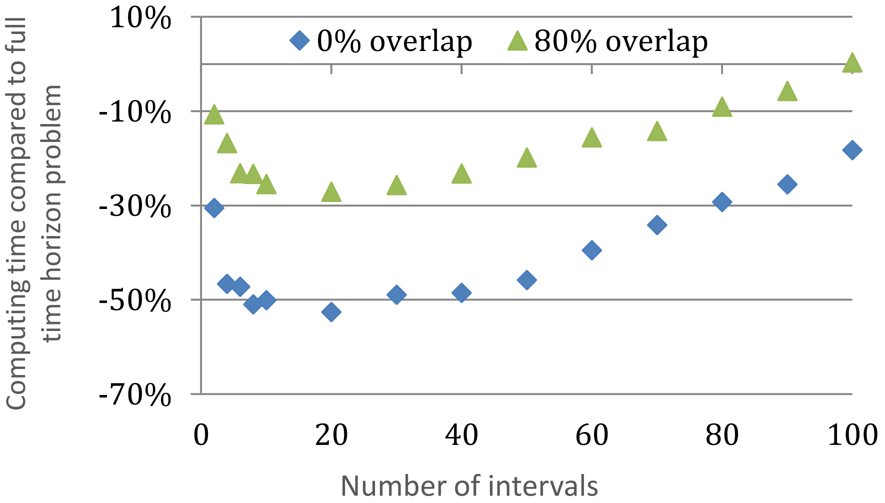
# Classification of speed-up methods

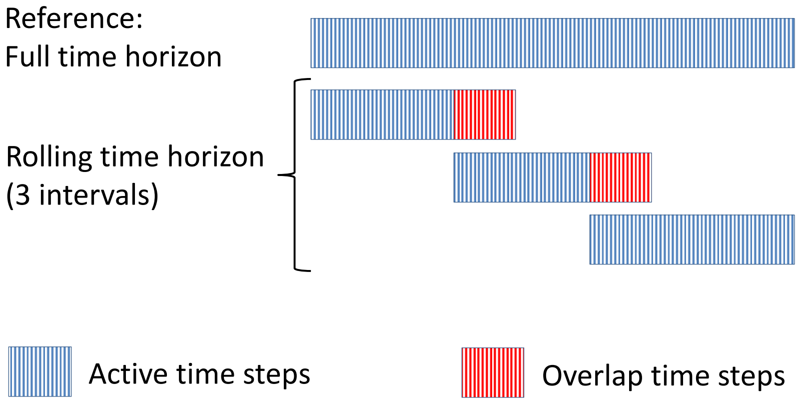



- Speed-up measured in comparison to solving the original optimization problem with commercial solvers
- Both reduction techniques and decomposition methods can target either the spatial or temporal dimension
- Model based methods heavily rely on understanding the mathematical formulation
- Solver based methods require less domain specific knowledge

# Rolling horizon

- Hourly optimisation time horizon split up into several intervals
- Previous time steps are fixed to match the continuity of the variables
- Long term storage levels and annual constraints differ from perfect foresight



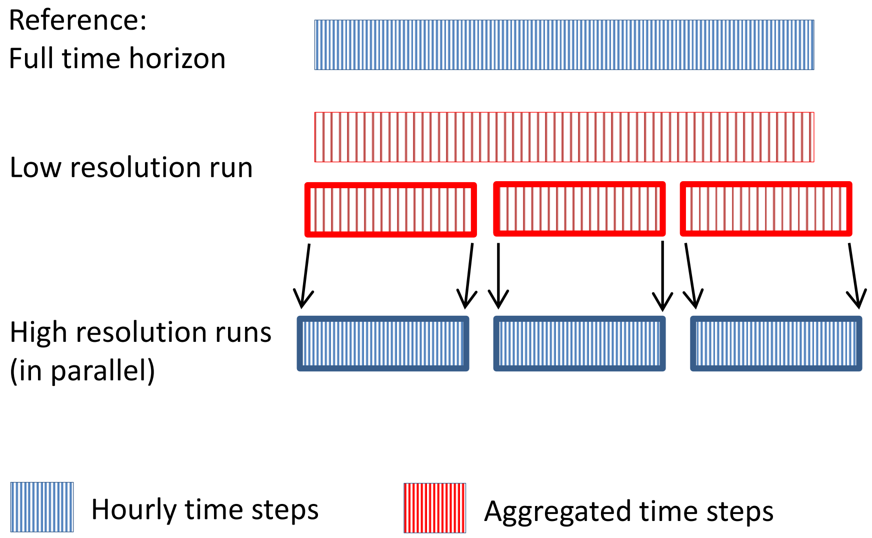

| Overlap-size [%] \ Number of intervals | 2 | 4 | 6 | 8 | 10 | 20 | 30 | 40 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.13 | 0.98 | 1.02 | 1.03 | 1.48 | 1.69 | 2.30 | 2.76 | 2.90 | 3.19 |
| 20 | 0.09 | 0.06 | 0.24 | 0.28 | 0.32 | 0.59 | 1.02 | 1.17 | 1.46 | 1.54 |
| 40 | 0.10 | 0.05 | 0.07 | 0.10 | 0.12 | 0.28 | 0.47 | 0.64 | 0.78 | 0.81 |
| 60 | 0.03 | 0.04 | 0.06 | 0.08 | 0.10 | 0.21 | 0.34 | 0.52 | 0.54 | 0.58 |
| 80 | 0.02 | 0.04 | 0.05 | 0.07 | 0.09 | 0.19 | 0.30 | 0.38 | 0.56 | 0.61 |
| 100 | 0.02 | 0.03 | 0.05 | 0.06 | 0.07 | 0.18 | 0.28 | 0.30 | 0.48 | 0.54 |

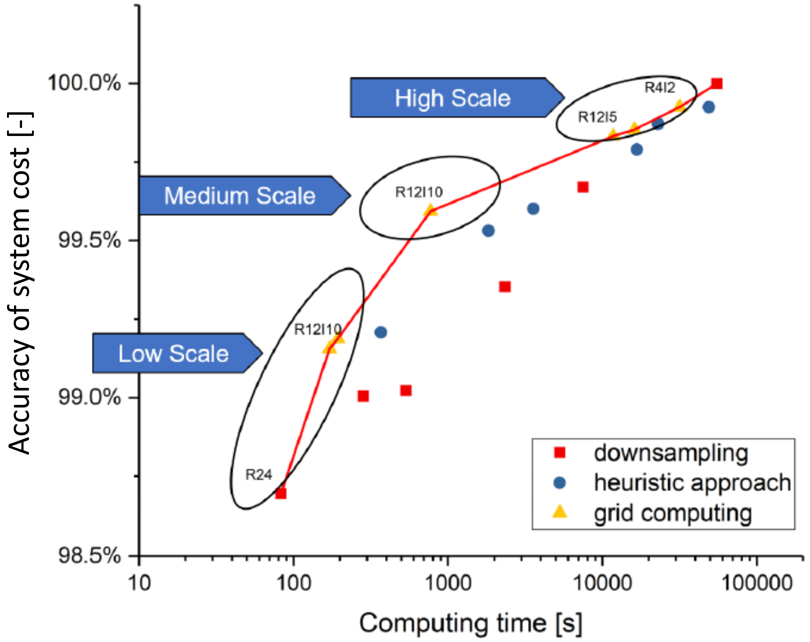
Number of intervals

Schreck, S: “Implementation and Analysis of a Rolling Horizon Approach for the Energy System Model REMix”, University Stuttgart, 2016

# Temporal zooming

- Hourly optimisation time horizon split up into several intervals
- Run with low temporal resolution allocates the storage utilization and CO2 emission
- High resolution runs with take into account the intermittency of renewable energy sources




- Approach can be easily adjusted to trade off relative error against solution speed up

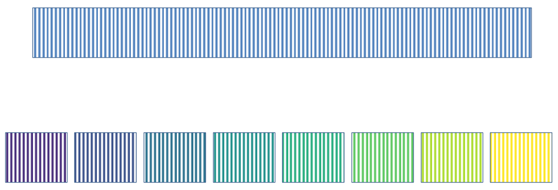
Schreck, S: “Implementation and Analysis of a Rolling Horizon Approach for the Energy System Model REMix”, University Stuttgart, 2016
Chen, C: “Assessment of speed-up methods for optimizing energy system models”, Technical University Berlin, 2018

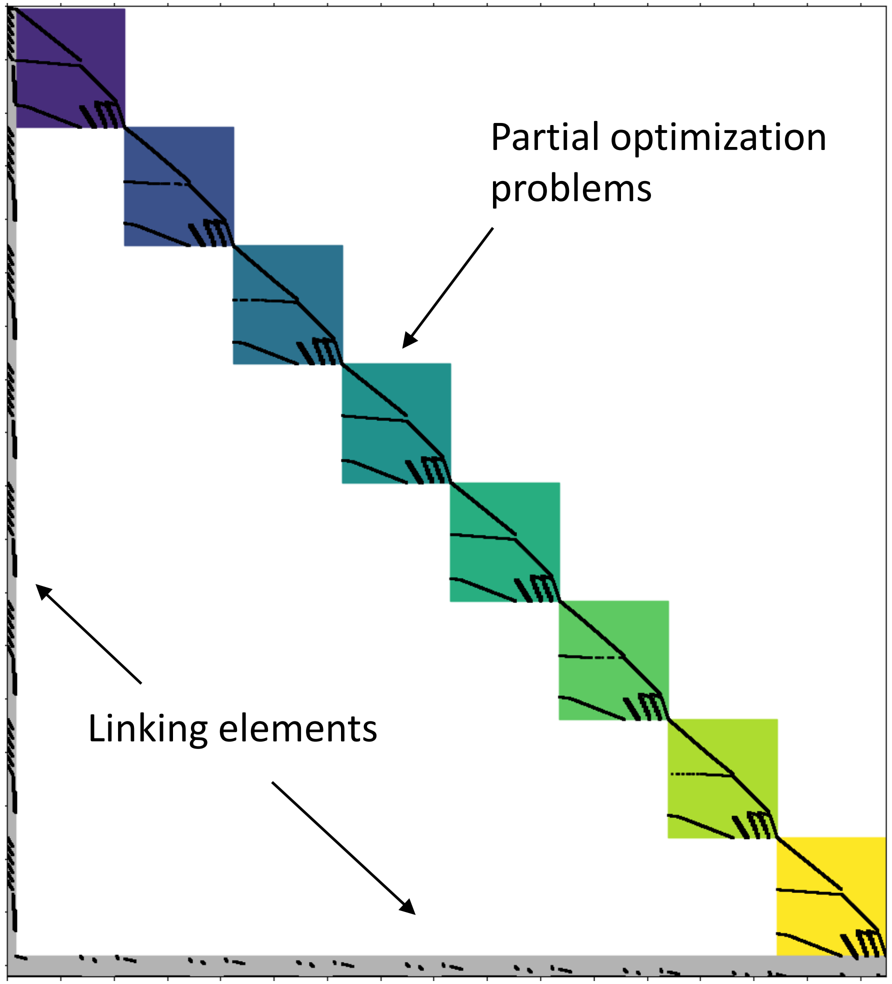
# Parallel solving with PIPS-IPM++

- Enhanced version of the parallel solver PIPS-IPM[1]
- PIPS-IPM++ will be published as open source by Zuse Institute Berlin (ZIB) later this year
- Optimization model is decomposed into time slices which are solved fully parallel on HPCs via MPI

Reference:
Full time horizon

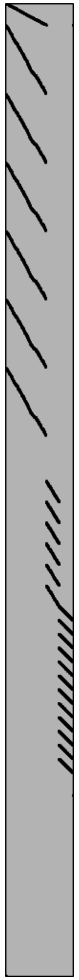
Block structured

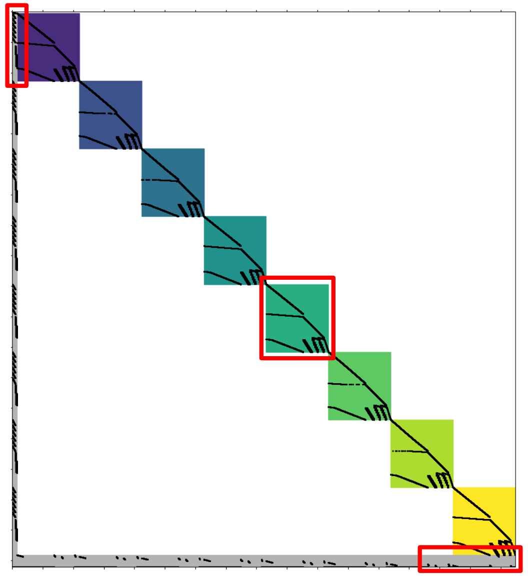


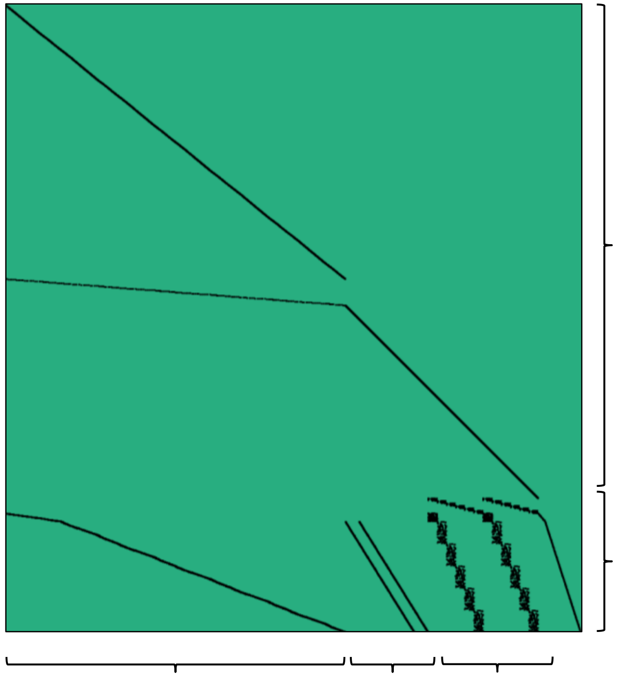



[1]https://github.com/Argonne-National-Laboratory/PIPS

# Understanding the block structure



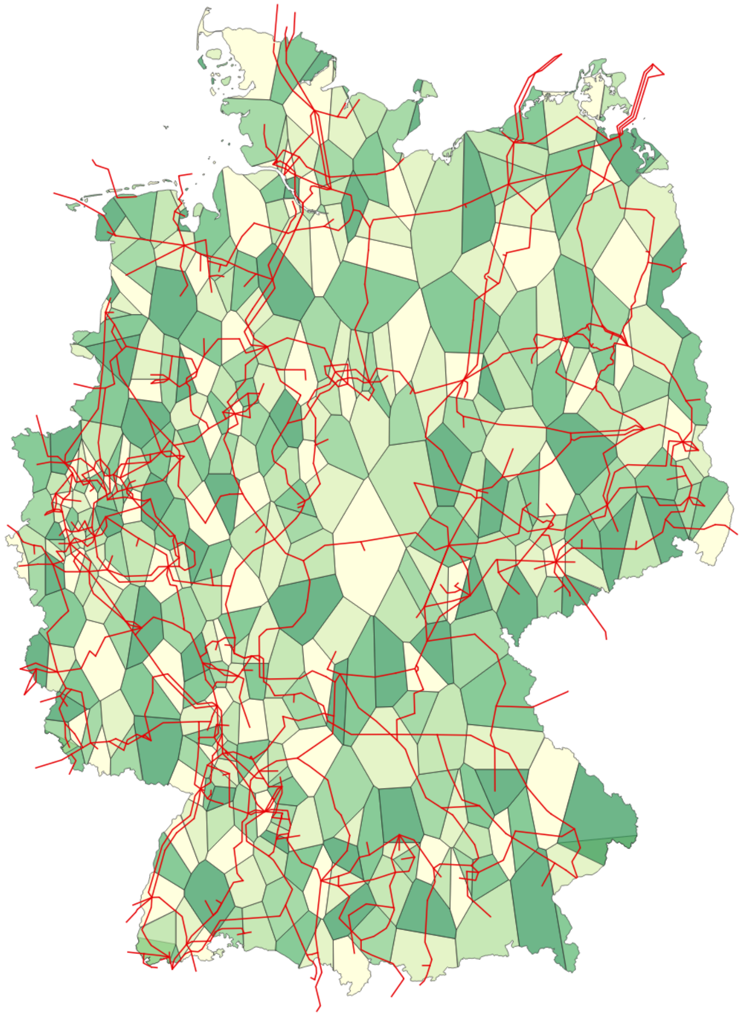



# Solving a German power system model with PIPS-IPM++

Large scale German power system model

- Economic dispatch and capacity expansion formulation
- Investment in renewable energy, storage and power lines
- Scalable between 1 and 488 model regions

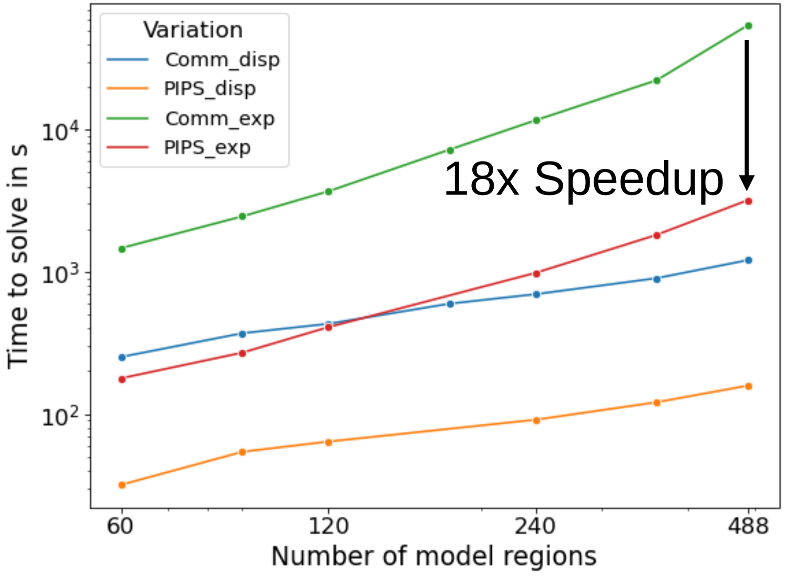
| regions | rows | cols | nnzs |
|---|---|---|---|
| 60 | 8.9 | 9.0 | 34.5 |
| 90 | 12.1 | 12.2 | 46.6 |
| 120 | 15.4 | 15.5 | 58.9 |
| 240 | 26.4 | 26.9 | 100.2 |
| 360 | 34.3 | 34.2 | 128.9 |
| 488 | 45.1 | 45.5 | 169.6 |



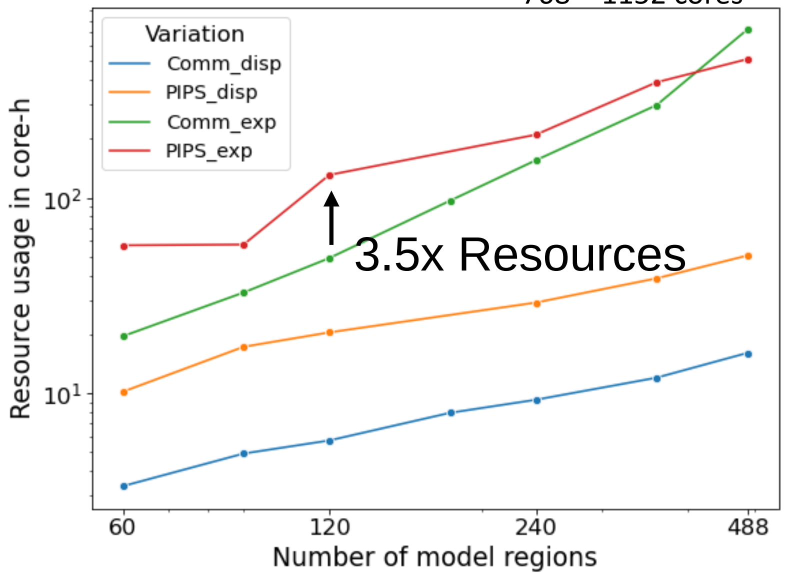
Cao et al., 2018, Incorporating Power Transmission Bottlenecks into Aggregated Energy System Models

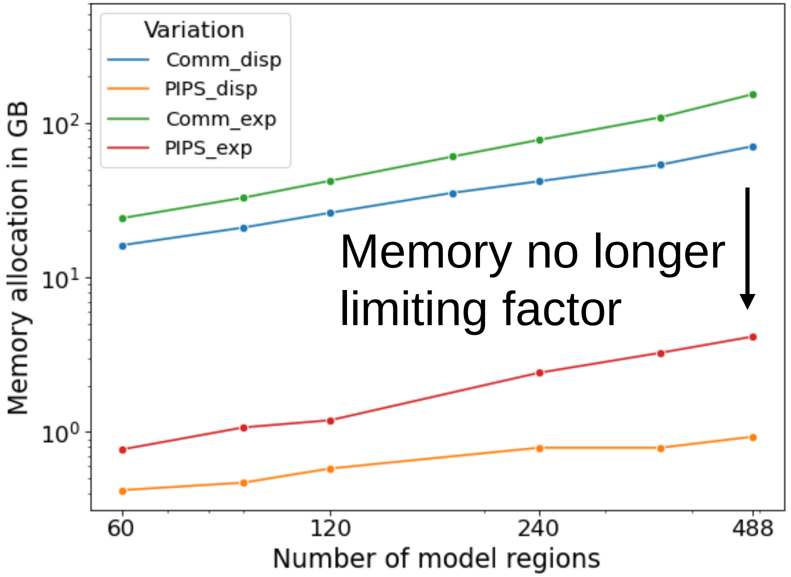
# Performance of parallel and commercial solvers

## Key performance indicators




768 – 1152 cores



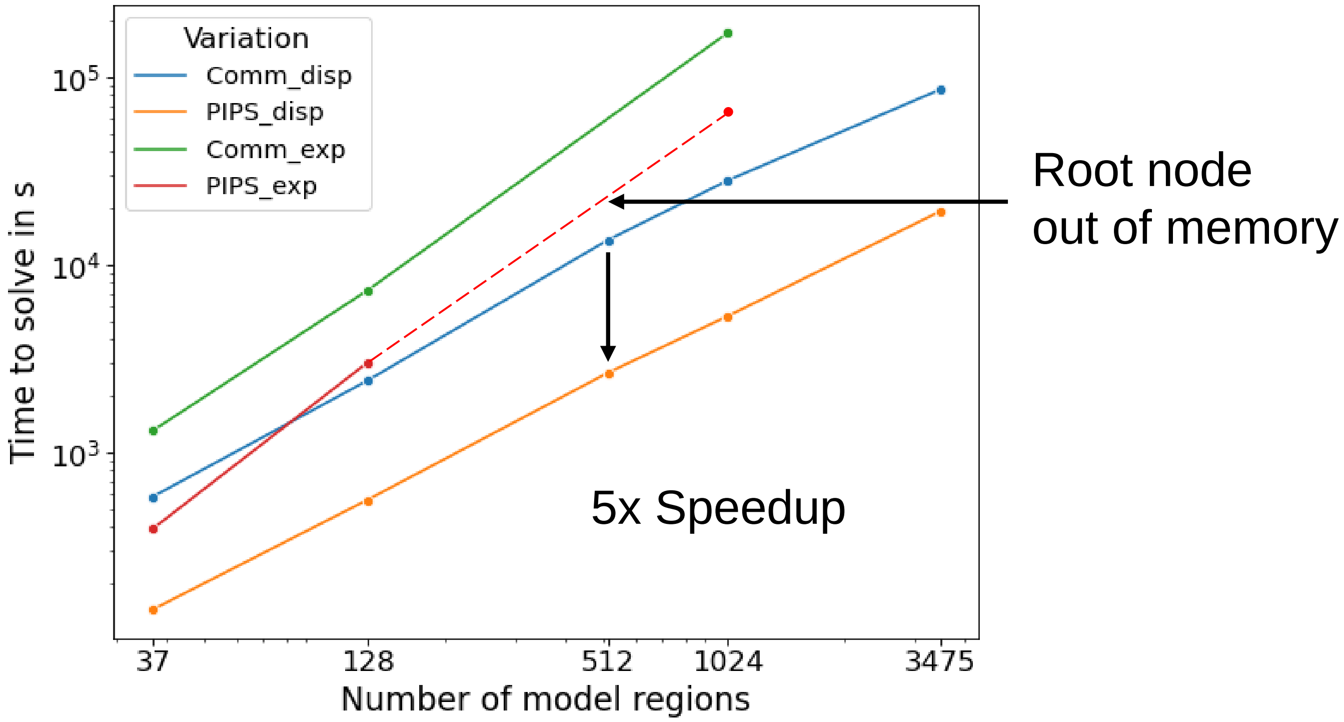



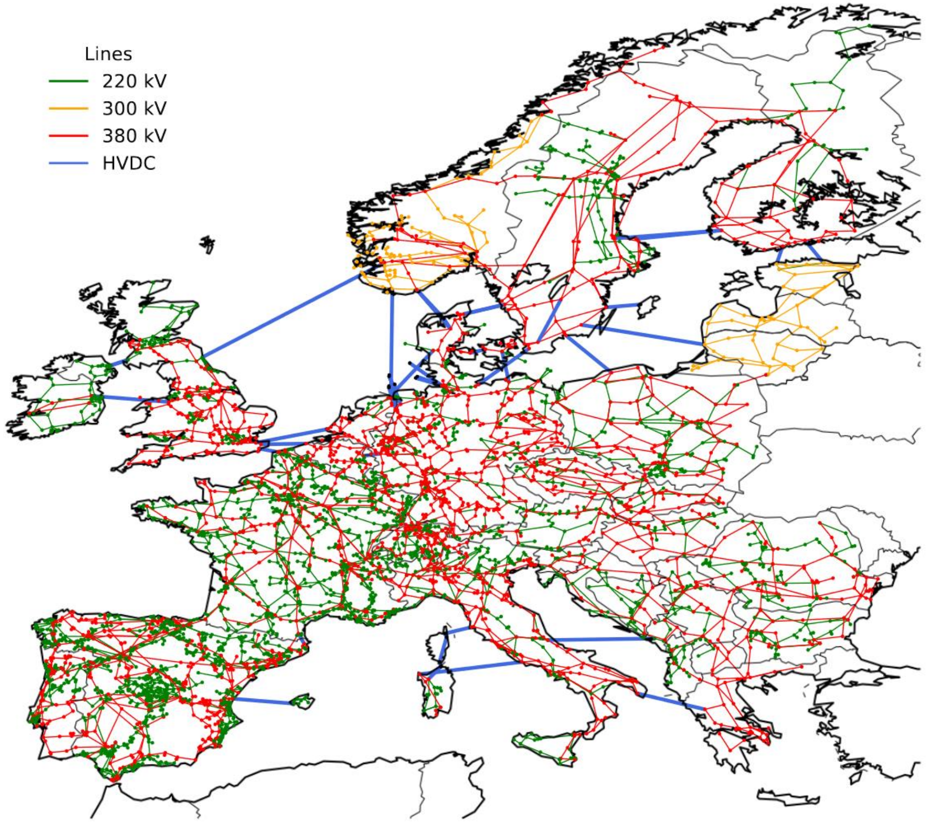

- Trade-off between faster time to solve and increased resource consumption
- Mitigation of both time and memory limits possible via compute node configuration on HPC systems

# Solving the PyPSA-eur dataset with PIPS-IPM++

An open large scale open European power system model

- Economic dispatch and capacity expansion formulation
- Investments into renewable energy, storage and power lines
- Prebuilt instances with 37 to 3475 model regions




Hörsch et al., PyPSA-Eur: An Open Optimisation Model of the European Transmission System

# Conclusions

- Heuristic approach trades off achievable speed up against relative error
  - up to 10 times faster for the German power system instances within reasonable error
- Parallel solver provides exact solutions but trades off speed up against compute resources
  - up to 18 times faster for the German power system instances
  - up to 5 times faster for the PyPSA-eur instances
- Both approaches allow addressing future large scale energy system models, however a large number of expansion options can still lead to memory limitations with the current approaches

# Using neural networks for broad-scale scenario analysis

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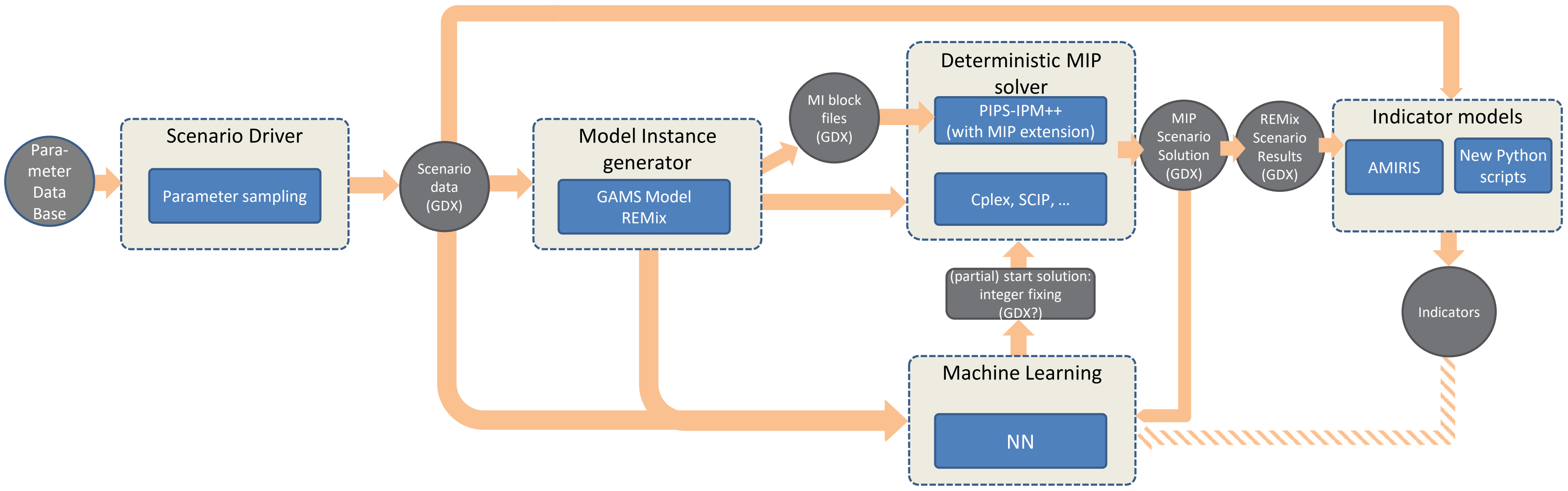
- Real world decisions require robust and discrete solutions
- Solving MIP problems takes significantly longer than solving their LP formulation
- Previously calculated similar solutions can help warm-start the MIP solver
- Integer solutions are proposed by a neural network based on reinforcement learning

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