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Rolling Horizon Planning Methods in Long-Term Energy System Analysis MILP Models

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Agenda

- Background and motivation
- Methodological approach for urban energy system modeling
- Temporal decomposition methods
- Computational results
- Critical reflection
- Conclusions and outlook

Background and motivation

- optimizing decision support tools that can cope with complexity are required
  - complex interactions between energy carriers and technologies in energy systems

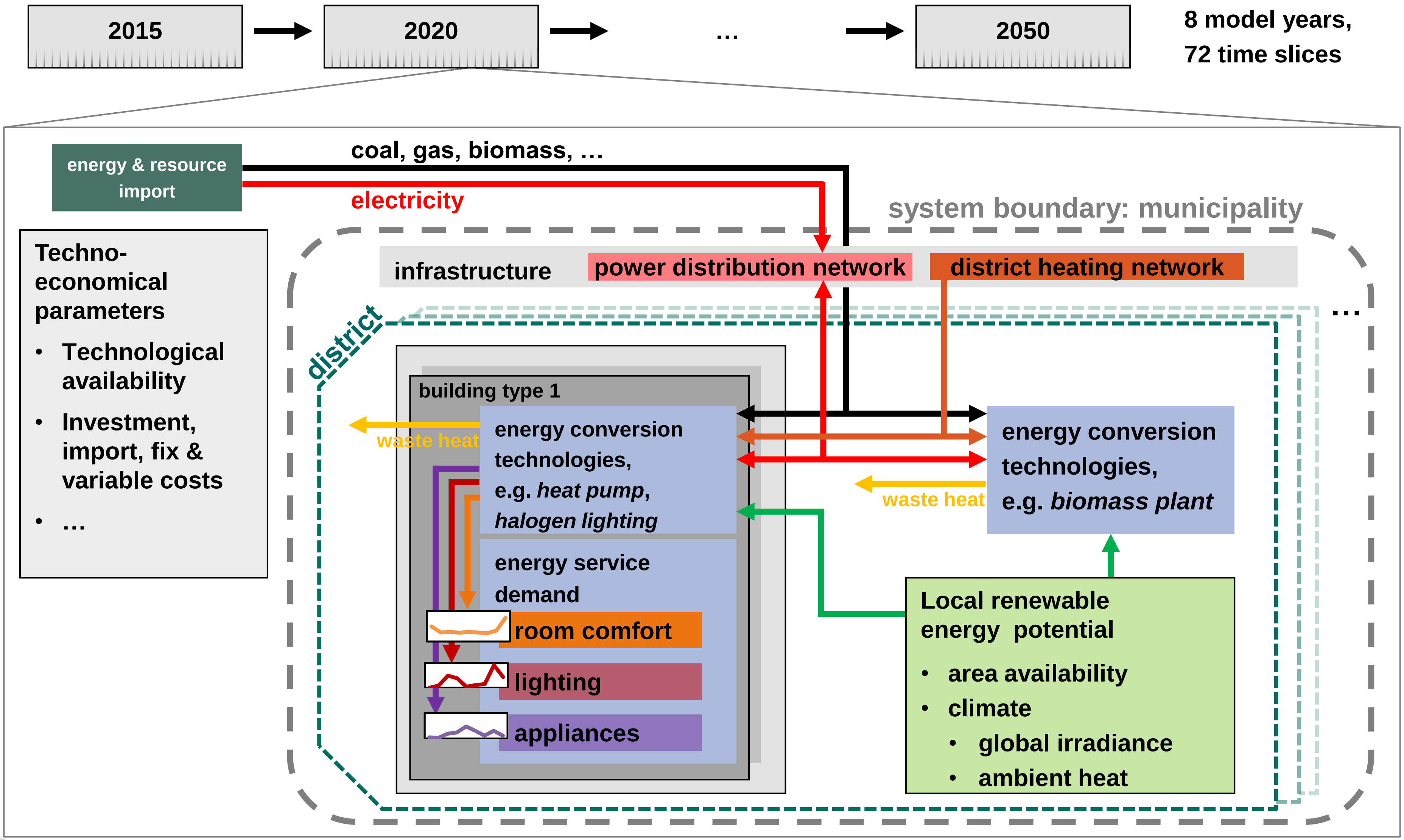
- growing significance of regional/urban modeling
  - decentralized generation from renewable energies (RE)
  - local stakeholders get involved in energy-related topics
  - provision of heat in buildings accounts for a large share of energy demand

- complexity of (urban) energy system models is increasing
  - high spatial and temporal resolutions are needed for meaningful results
  - local renewable energy potentials have to be considered
  - large number of technologies: RE, heat, supply & demand side technologies, …

- computational time of MILP can grow exponentially with number of variables
- speed can be increased by compromising solution quality
  - reducing details
  - applying heuristics

➢ How can the computational speed for solving optimizing urban energy system models be increased without compromising the solution quality?

Methodological approach: optimizing energy and material flow model



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Methodological approach: optimizing energy and material flow model

- objective function: minimization of all decision relevant system expenditures, discounted to base year

$$
\min \sum_{my \in \text{YEARS}} \left(\alpha_{my} * N_{my} * \begin{pmatrix} ImportFlowsCosts_{my} \\ +TransmissionGridCosts_{my} \\ +IntermediaryFlowsCosts_{my} \\ +UnitsInvestmentAnnuities_{my} \\ +UnitsFixCosts_{my} \\ +ProcessActivitiesVarCosts_{my} \\ +EmissionsCosts_{my} \\ +LandUseCosts_{my} \\ +LocalSourcingCosts_{my} \end{pmatrix} \right)
$$

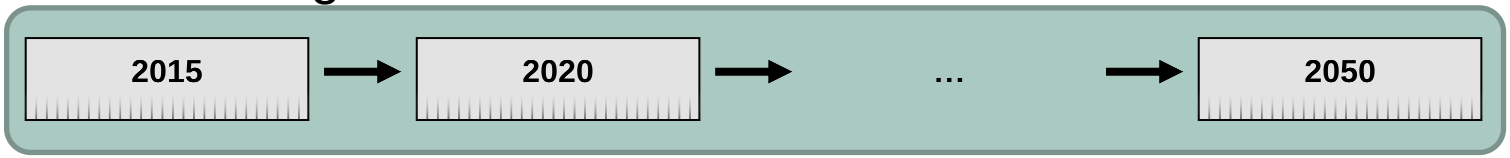
- constraints
  - energy balance
  - flow restrictions
  - land use constraints
  - emission restrictions
  - …

Methodological approach: optimizing energy and material flow model

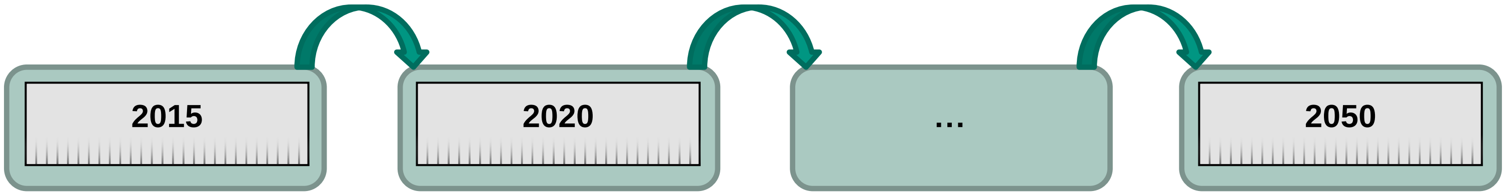
- parameters
  - energy service demand
  - fuel & technology prices
  - technological characteristics (conversion efficiency, emissions, …)
  - infrastructure
  - renewable energy potentials
  - technologies in stock
- decision variables
  - unit commitment for each time slice
  - yearly investment decisions (binary)
- model size (reduced form):
  - 1.9 million equations, 1.8 million variables, 19,200 binaries
- implemented in GAMS, solved with CPLEX
- run on 64 bit machine, 11 Threads @ 3.5 GHz, 128 GB DDR3 RAM

Temporal decomposition in energy system models

- Perfect foresight



  - result: globally optimal pathway for all investment & unit commitment to cope with the given development (e.g. fuel prices)
  - exponential growth of solution space with number of variables
- Myopic approaches (e.g. Babrowski et al. 2014)

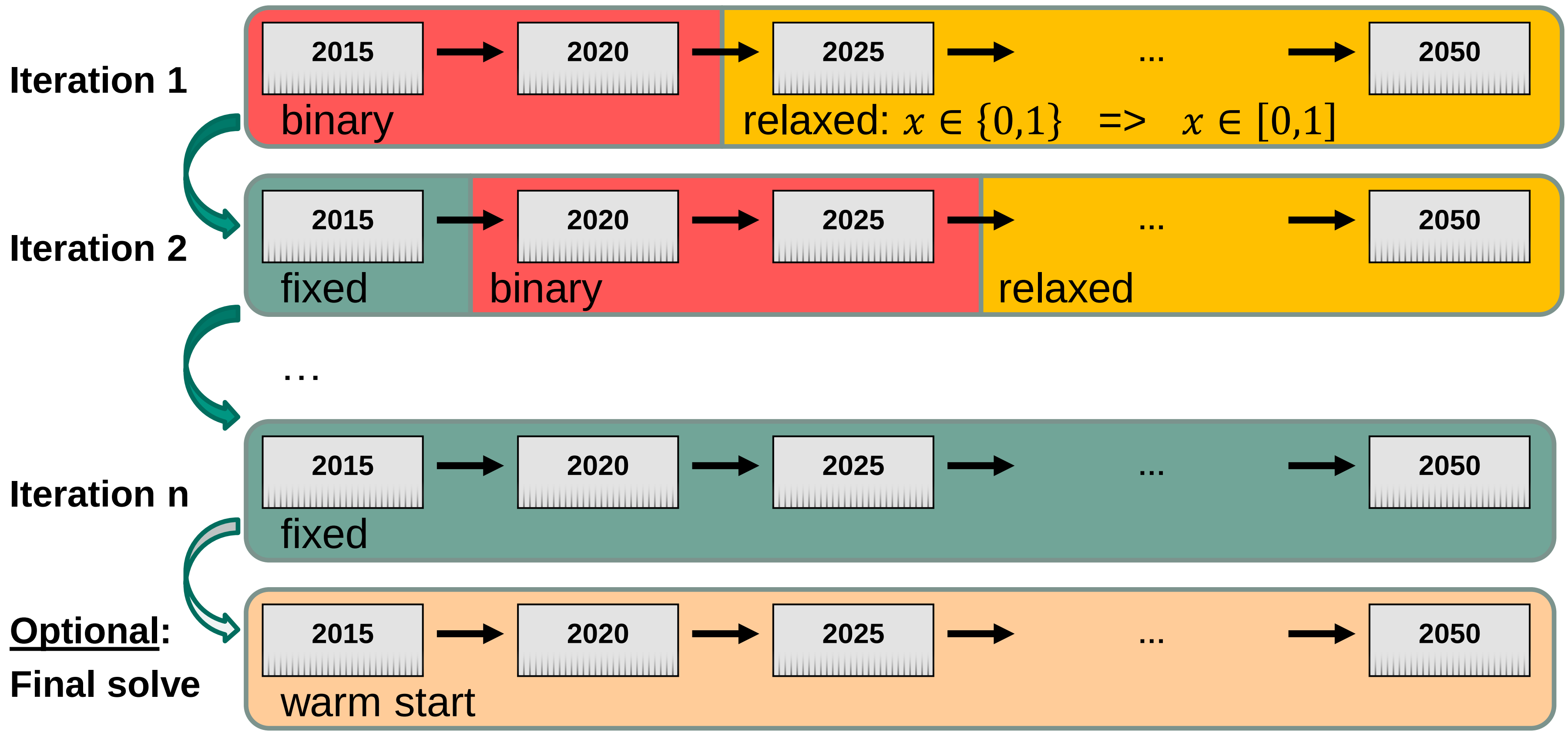


Each year's optimal investment planning is passed over to the next year

  - result: combination of each single year's optimal decisions
  - large reduction of complexity (about 90% less computational time)
  - blind for future developments: forecasts not considered
  - setting targets (e.g. -80% CO_2 in 2050) is not possible
  - tendency towards postponing investments

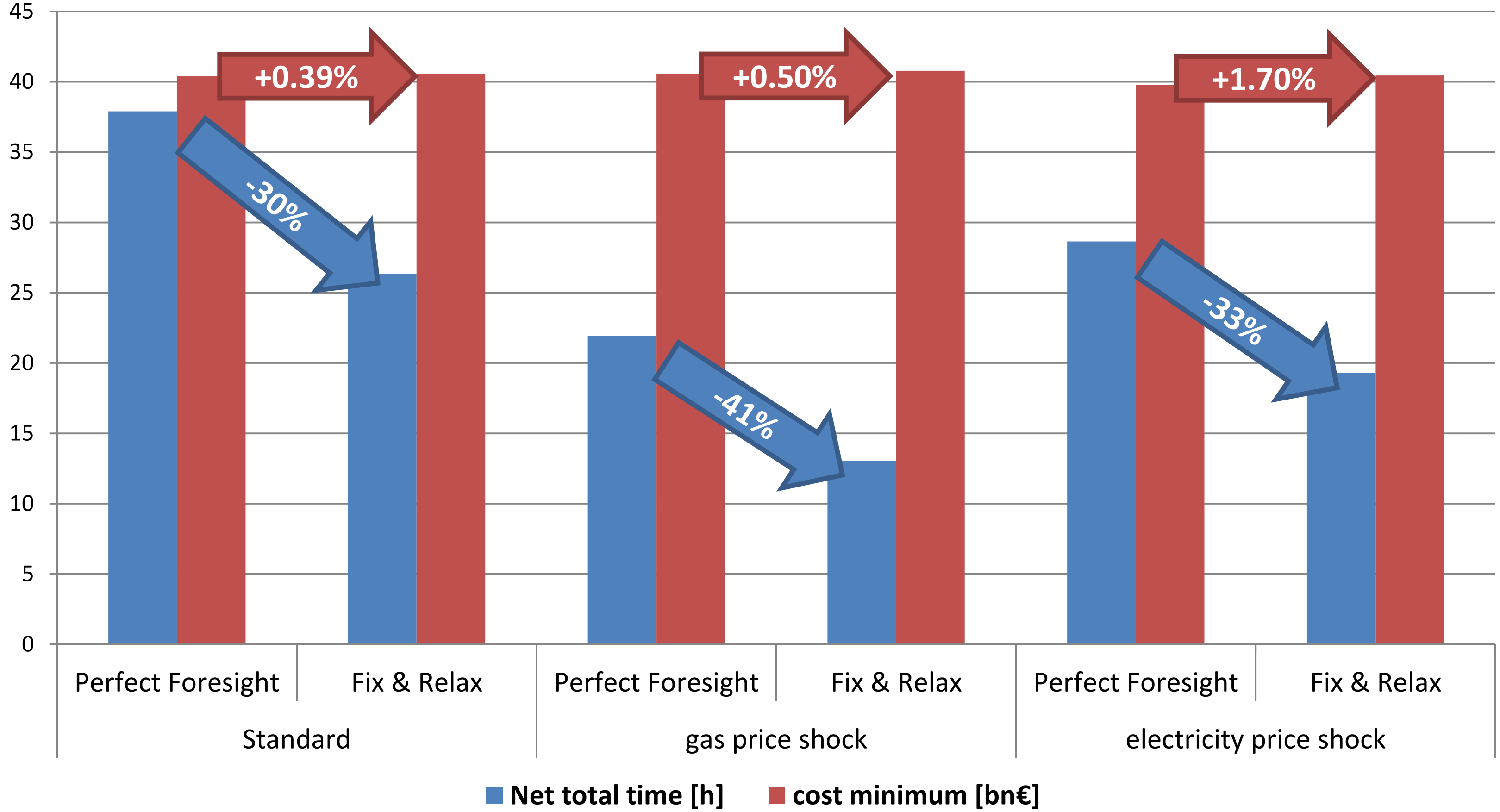
Temporal decomposition using rolling horizon planning

- Fix-and-relax technique, introduced by Dillenberger et al. (1994)



- overlap to mitigate end-of-horizon effects
- solution not guaranteed to be optimal (unless final solve is performed)

Results: analysis of result quality and runtimes of Fix & Relax without final solve



- computational time is reduced by 30-40%
- minor decrease of solution quality
- approach seems to cope well with price shocks

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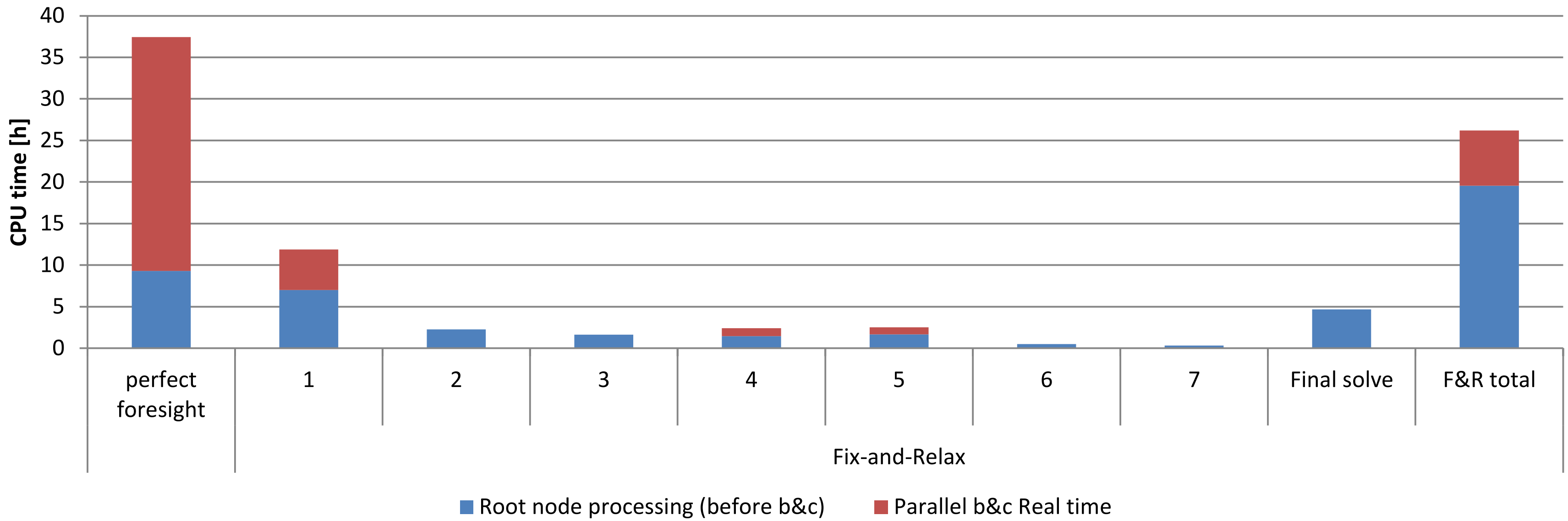
Results: effect of final solve (Preliminary)



- final solve with warm start is surprisingly fast (2-5 h), requires no new branching => solution already within optimality gap
- solution differs from perfect foresight solution (on average +0.66%)
- possible reasons for cost difference:
  - optimality gap too high (5%) => no new branching
  - opportunistic parallel mode => non-deterministic result
- Root node processing takes most time
- Taking this into consideration, a better decomposition could probably be constructed (e.g. [1]; [2-4]; [5-7]; [Final])

Critical reflection

- compared to perfect foresight, the model setup is more complex
- without final solve, result may be suboptimal
- with final solve, computational improvement is not guaranteed
- more tests needed to evaluate the benefits of this approach in energy system modeling
  - disable opportunistic parallel mode: yields deterministic results
  - decrease optimality gap
  - different decomposition periods & overlaps
  - more scenarios
  - different model sizes

Conclusions and outlook

- Conclusions
  - methods to reduce the computational effort, such as myopic approaches, gain a vast improvement in solution times over standard perfect foresight, at the cost of a degradation of solution quality
  - Fix-and-relax method gains a smaller improvement in solution times, but
    - enables model to consider future development
    - allows setting global objectives, e.g. emission targets
    - prevents lock-in effects
  - When warm start is used for a final solve, the solution should be globally optimal, while there still could be an improvement in computational times

- Outlook
  - Implement myopic approach for this model as comparison
  - compare solutions qualitatively
  - further tests with different parameters

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Thank you very much for your attention

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