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BEAM-ME

Model-based methods to improve computing times in linear energy system optimization models

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24th of June 2019

DLR – German Aerospace Center, Department of Energy Systems Analysis

a project by

GAMS

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DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

ZIB

Overview

- Motivation
- Repetition: *Characteristics and dimensions of Energy system optimization models*
- Theory: *Classification of existing approaches*
- Evaluation methodology
- Results and major findings
- Conclusions

Motivation

Overview

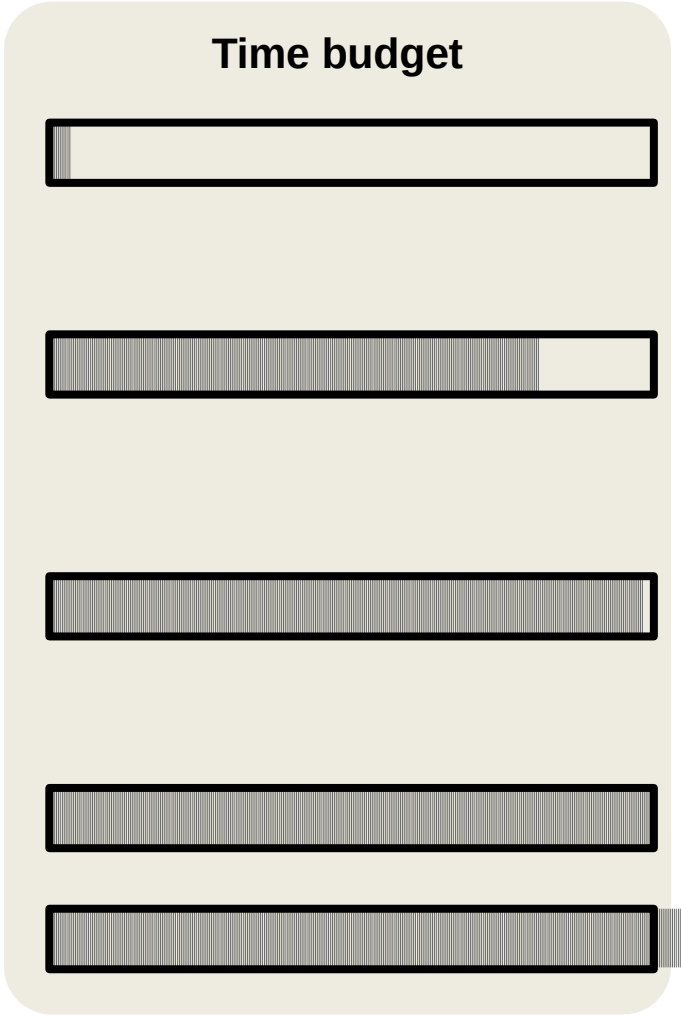
What can modelers do?

Overview

What have modelers done themselves?

Everyday‘s Energy Systems Analysis

Project starts



Research Question

Which **speed-up** is possible using measures that can be influenced by „normal“ model developers?

Framework

- Large applied Energy System Optimization Models
  - LPs
  - Computing time: >12h (dominated by solver)
  - Storage and transmission
- Shared memory hardware
- Use of standard solvers

Basic approaches (try that first)

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- Speed-Up strategies
  - Solver-based
    - Solver parameters
    - Solving methodology
  - Model-based
    - Pure model reduction
    - Exact Dec…
    - Best practice GAMS coding

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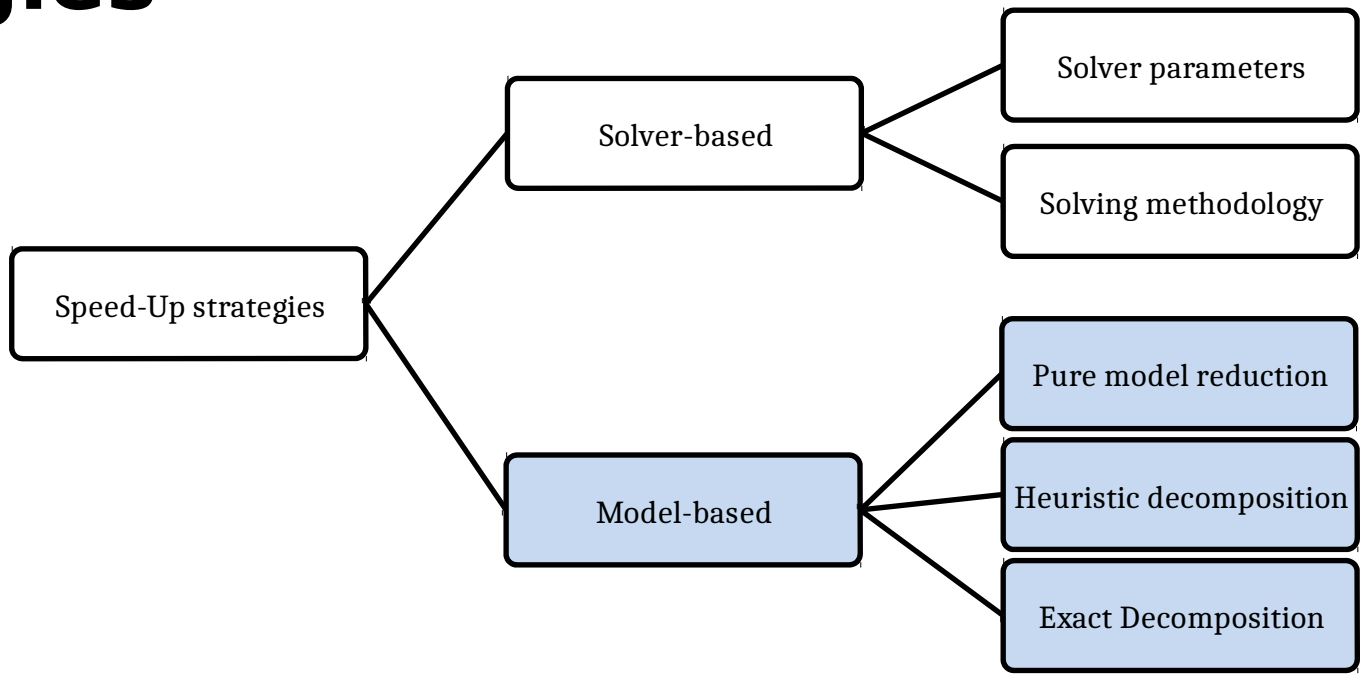
?

Source code improvement

- **Selection of measures (also useful for decrease memory need):**
  - **Input data should not differ much in its order of magnitude**
  - **Index order influences computing time**
    - **Useful, but not necessarily faster**
    - **Assignment statements with a different set order can be faster**
    - **It can be better to place large index sets at the beginning**
  - **Use of “option kill” , e.g. for long time-series input parameters saves memory**
  - **Abundant use of “Dollar Control over the Domain of Definition”**
  - **Consistent (and limited) use of defined variables**
  - **Avoidance of the consideration of technologies providing the same service at the same costs**
  - **Consideration of alternative formulation of model constraints (dense vs. sparse)**

- **Helpful references**: “Speeding up GAMS Execution Time” by Bruce A. McCarl https://www.gams.com/mccarl/speed.pdf

Approach II: Model-based speed-up strategies



Typical model dimensions

Time

Planning horizon

Operation

Investment

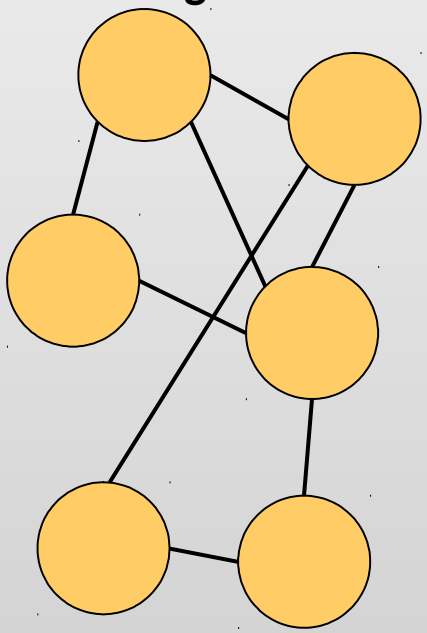
Short term — Long term

Discretisation

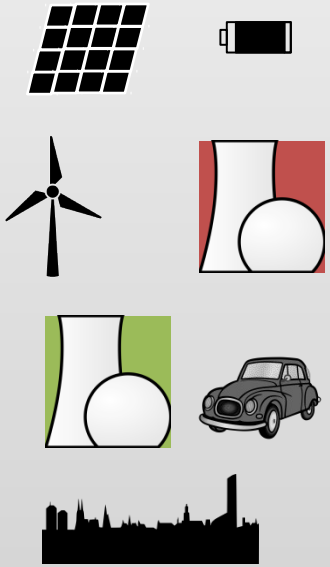
coarse

fine

Regions



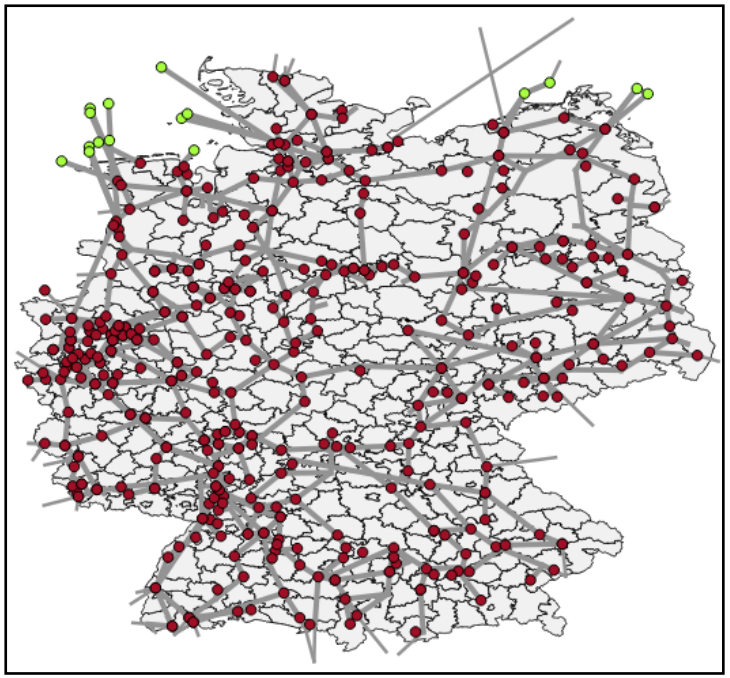
Technology



Characteristics and dimensions of Energy system optimization models

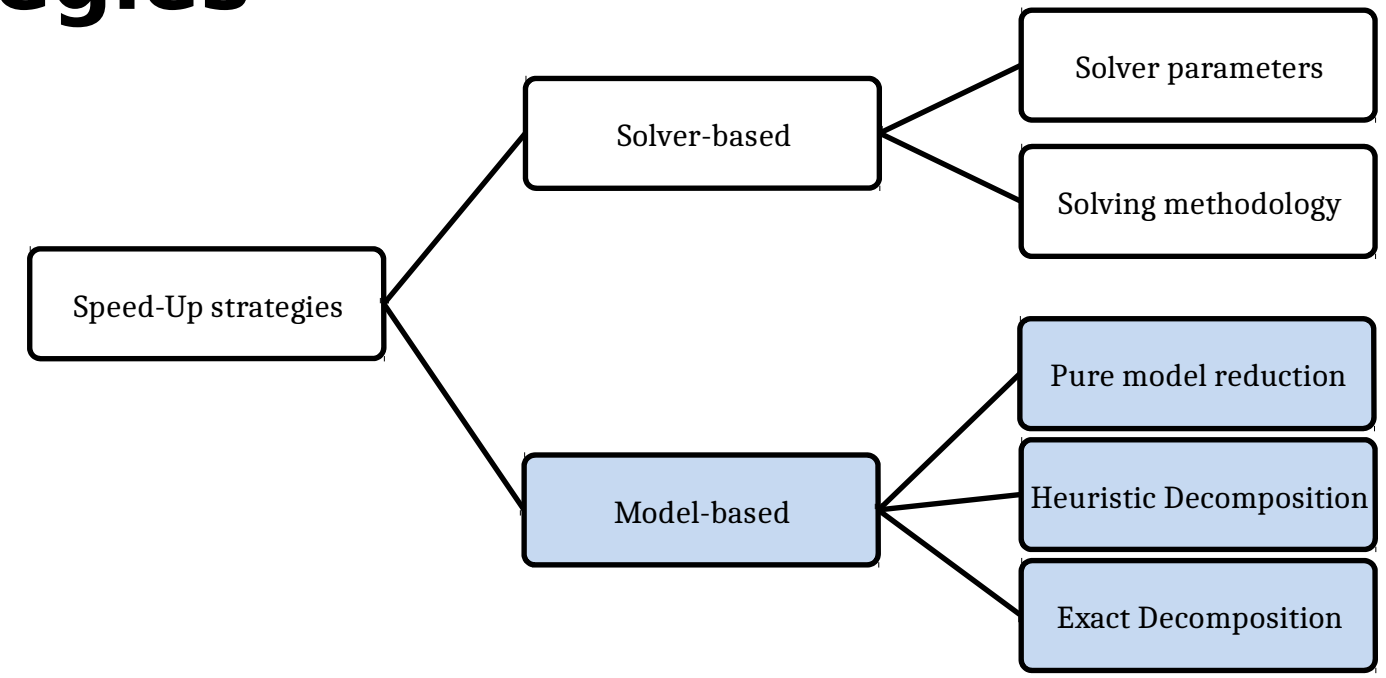
Overview

Model name	REMix
Author (Institution)	German Aerospace Center (DLR)
Model type	Linear programing minimization of total costs for system operation **economic dispatch** / optimal dc power flow with **expansion of storage and transmission capacities**
Sectoral focus	Electricity
Geographical focus	Germany
Spatial resolution	> 450 nodes (reference model)
Analyzed year (scenario)	2030
Temporal resolution	8760 time steps (hourly)



Solver	Commercial
Algorithm	Barrier
Cross-over	Disabled
Max. parallel barrier threads	16
Scaling	Aggressive

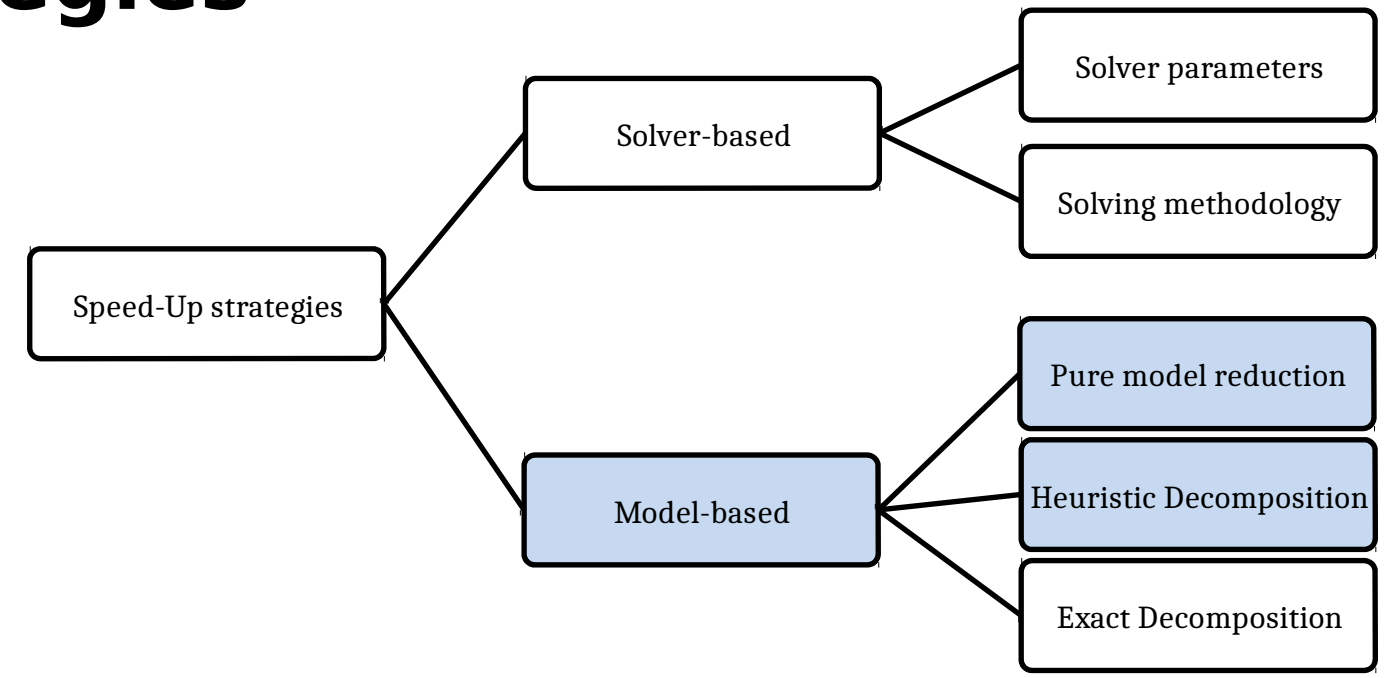
Model-based speed-up strategies



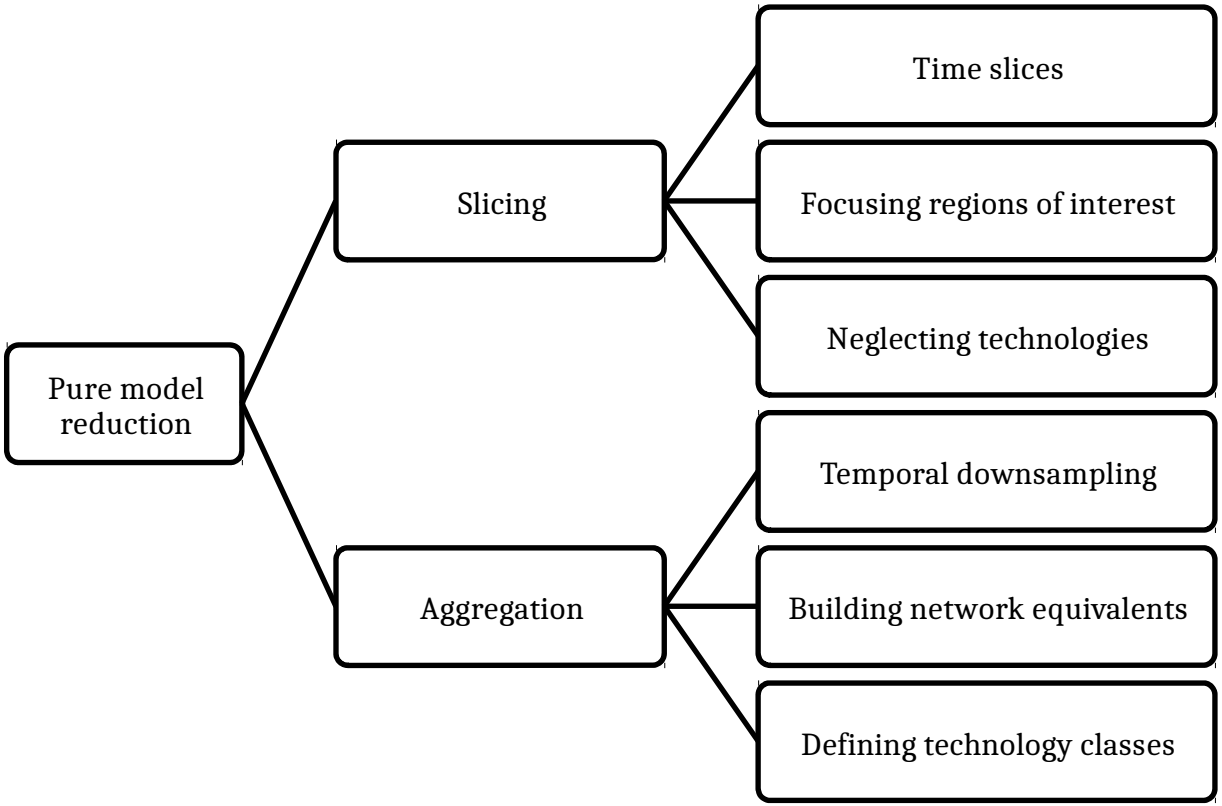
Literature Review

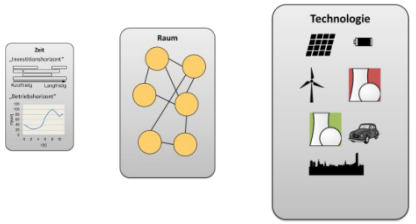
Authors	Math. problem type	Descriptive problem type	Decomposed model scale	Decomposition technique
Alguacil and Conejo [56]	MIP/NLP	Plant and grid operation	Time, single sub-problem	Benders decomposition
Amjady and Ansari [57]	MIP/NLP	Plant operation		Benders decomposition
Binato et. al [58]	MIP/LP	TEP		Benders decomposition
Esmaili et. al [59]	NLP/LP	Grid operation		Benders decomposition
Flores-Quiroz et. al [60]	MIP/LP	GEP	Time, 1-31 sub-problems, sequentially solved	Dantzig-Wolfe decomposition
Habibollahzadeh et. al [61]	MIP/LP	Plant operation		Benders decomposition
Khodaei et. al [62]	MIP/LP	GEP-TEP	Time, 2 sub-problem types, sequentially solved	Benders decomposition
Martinez-Crespo et. al [63]	MIP/NLP	Plant and grid operation	Time, 24 sub-problems, sequentially solved	Benders decomposition
Roh and Shahidehpour [64]	MIP/LP	GEP-TEP	Time, up to 10 • 4 sub-problems, sequentially solved	Benders decomposition and Lagrangian Relaxation
Virmani et. al [65]	LP/MIP	Plant operation	Technology (generation units), up to 20 sub-problems, sequentially solved	Lagrangian Relaxation
Wang et. al [66]	LP/MIP	Plant and grid operation	Space, 26 sub-problems, sequentially solved	Lagrangian Relaxation
Wang et. al [67]	MIP/NLP	Plant and grid operation	Scenarios and time, 10 • 4 sub-problems, sequentially solved	Benders decomposition
Wang et. al [68]	LP	Plant and grid operation	Technology (circuits) and time (contingencies), 2 sub-problem types, sequentially solved	Lagrangian Relaxation and Benders decomposition

Model-based speed-up strategies

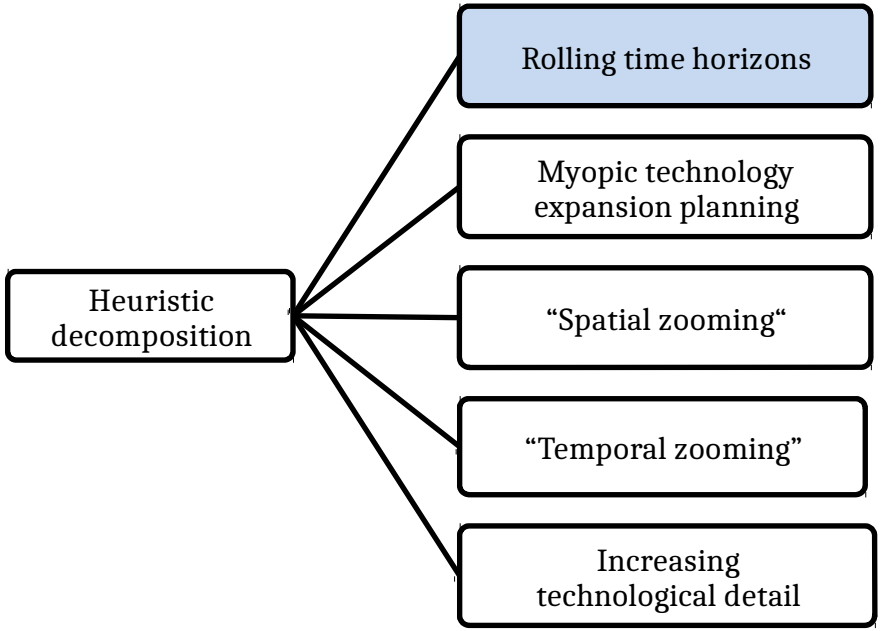


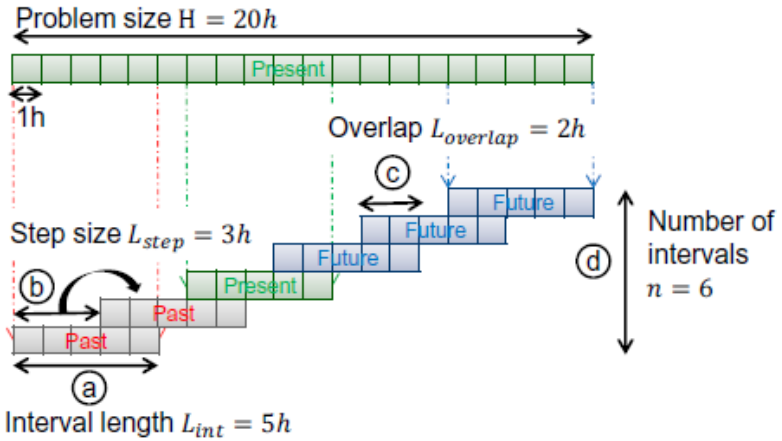
Types of model reductions in ESM



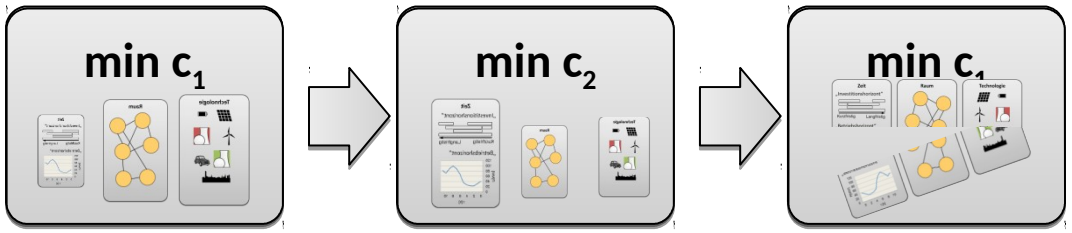


Meta heuristics



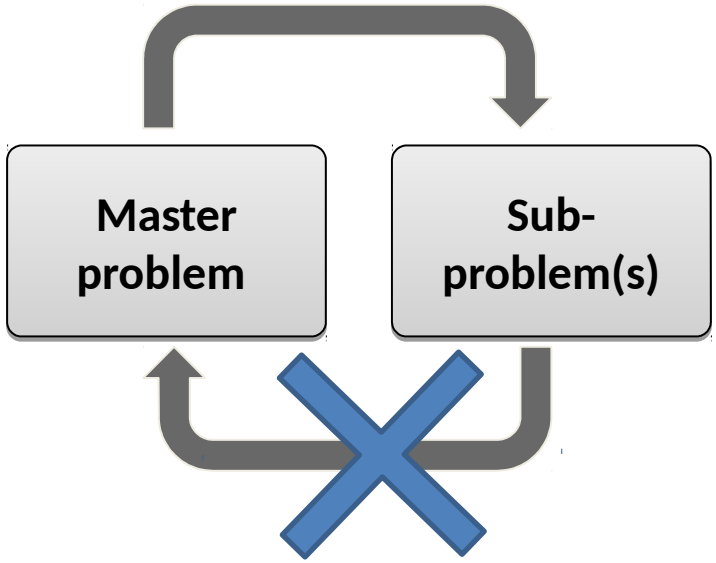


Stepwise solving reduced models

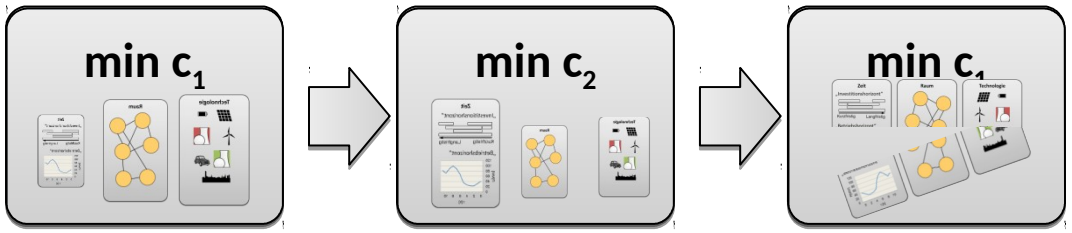


Meta heuristics

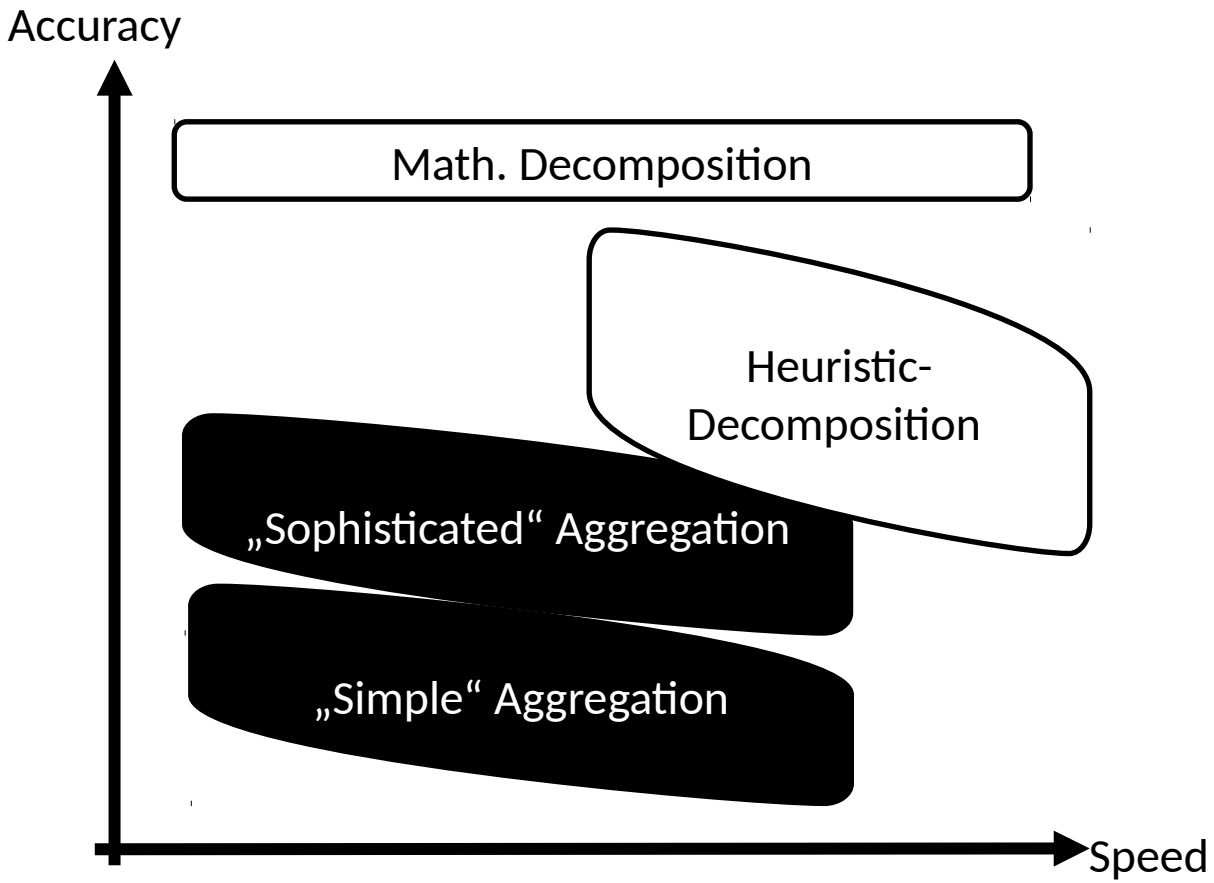
*„Decomposition which is **similar** to exact decomposition approaches that are stopped within the first iteration“*



Stepwise solving reduced models



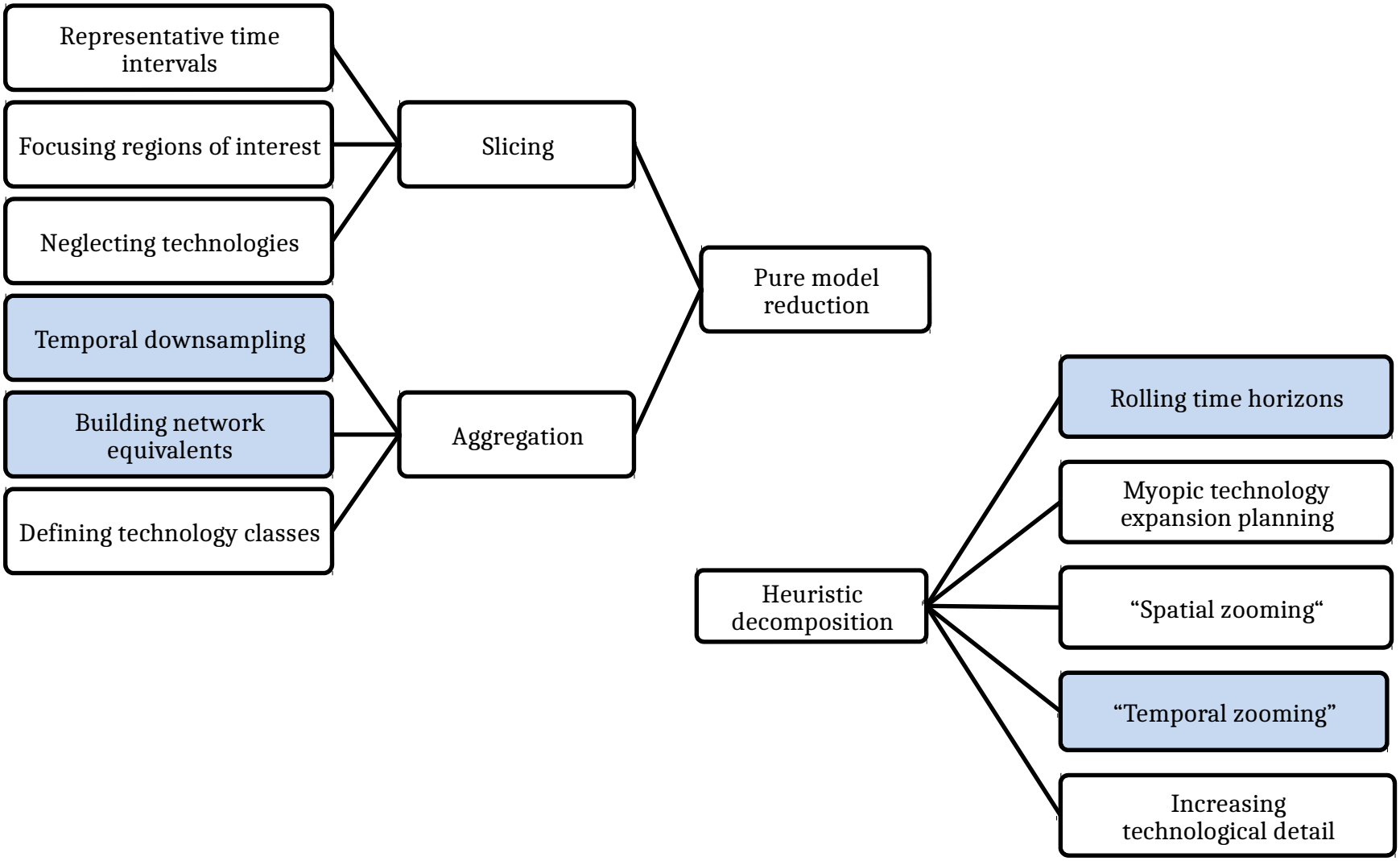
Hypothesis



PIPS

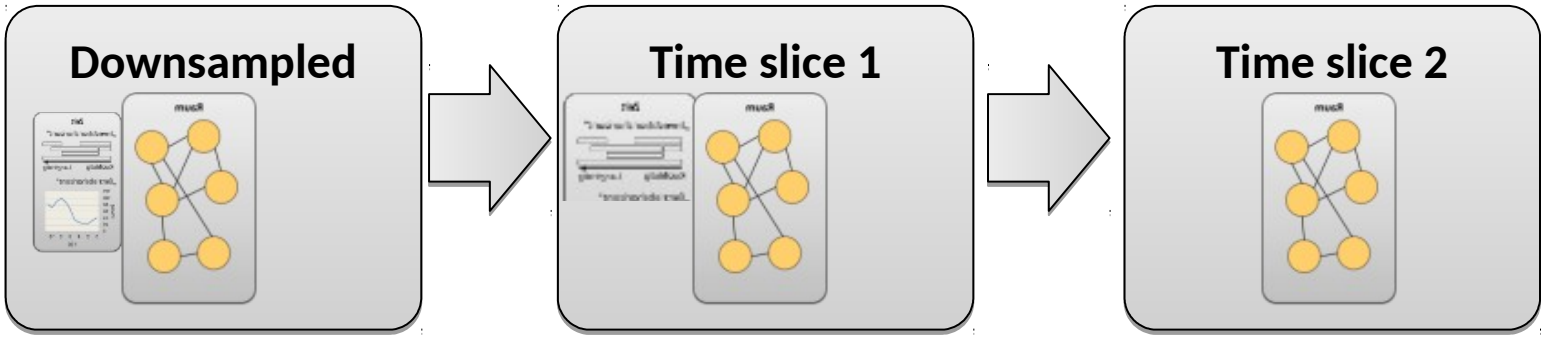
Evaluation methodology

Evaluated speed-up approaches

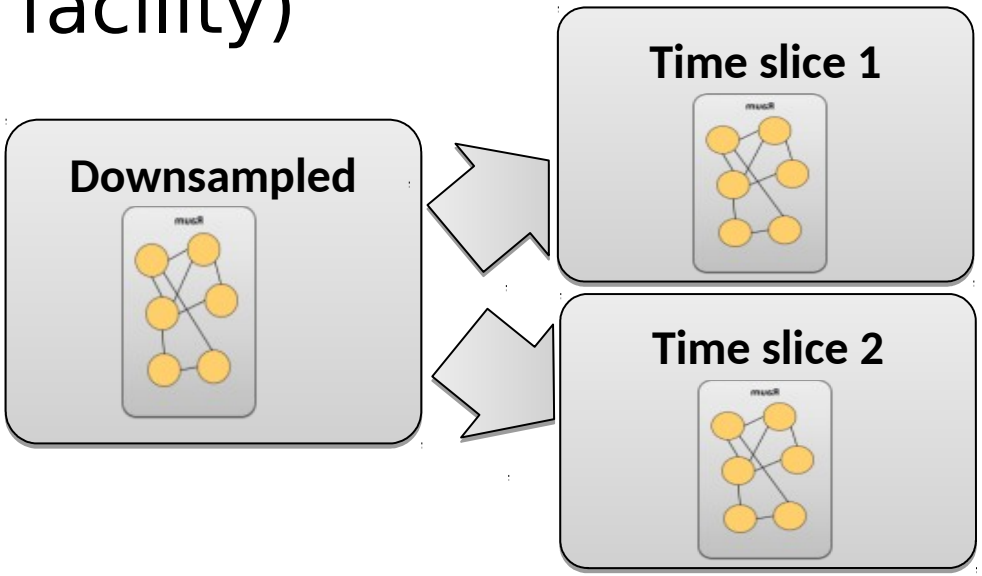


„Temporal zooming“ implementations

- Sequential



- Parallel (using GAMS‘s grid computing facility)



„Temporal zooming“ implementations

- Sequential

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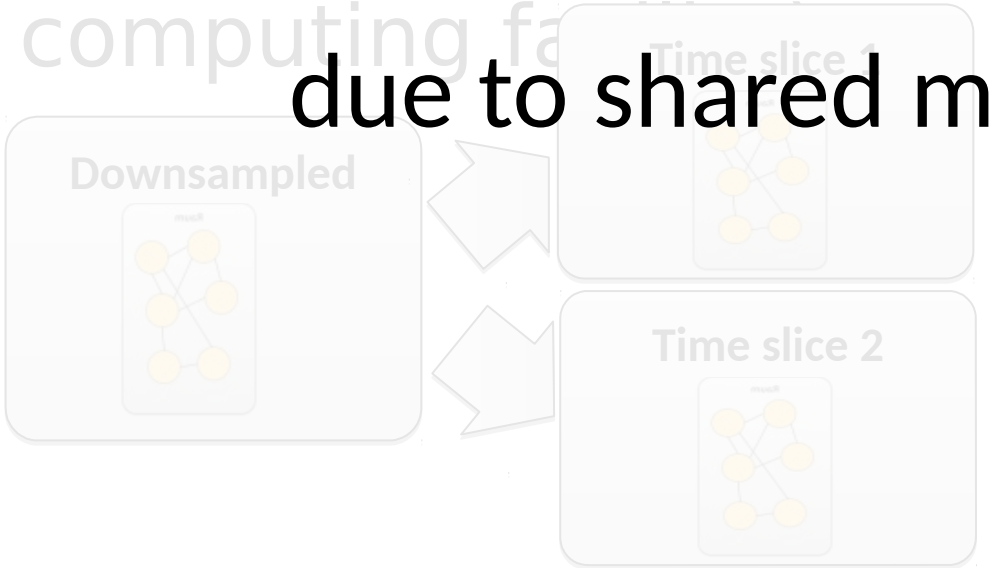
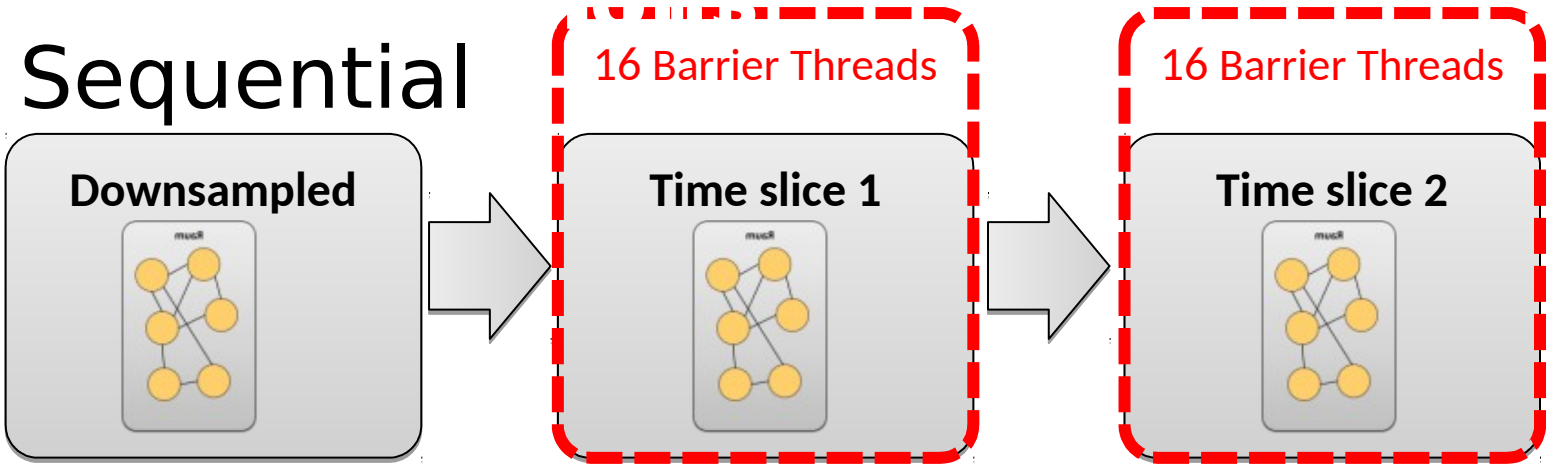


Parallelization limited

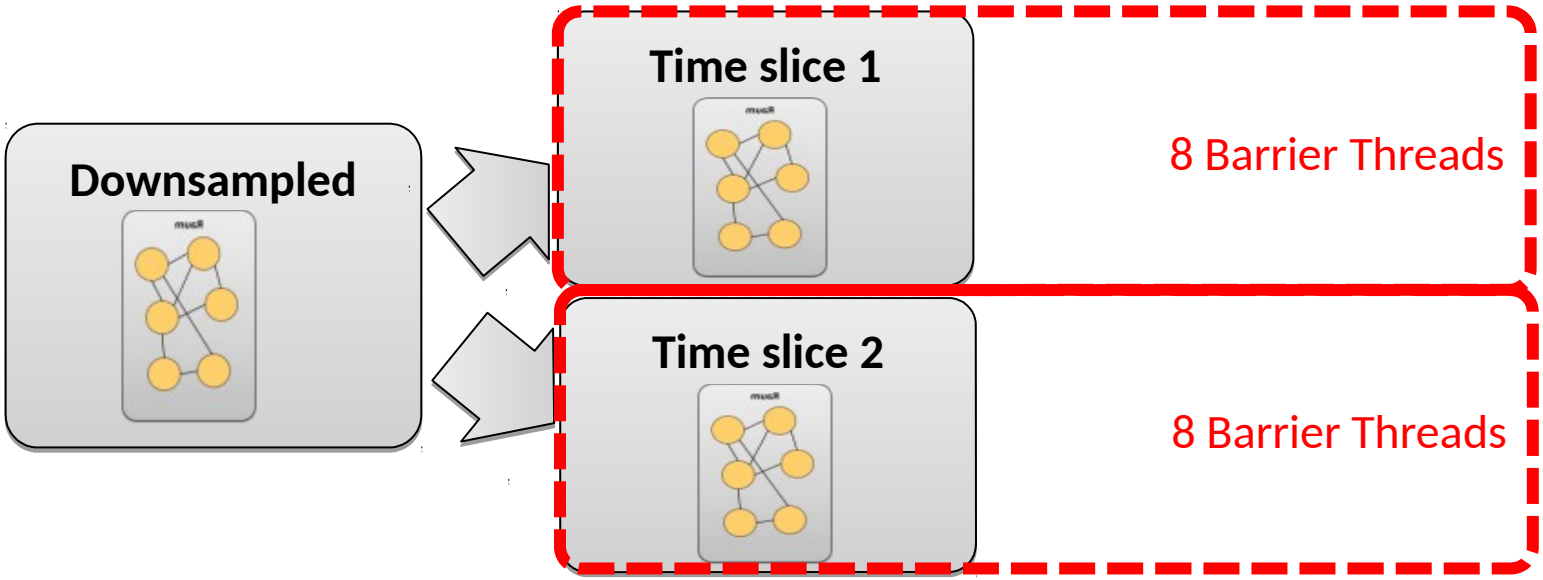
due to shared memory!

„Temporal zooming“

- Sequential



- Parallel (using GAMS‘s grid computing facility)



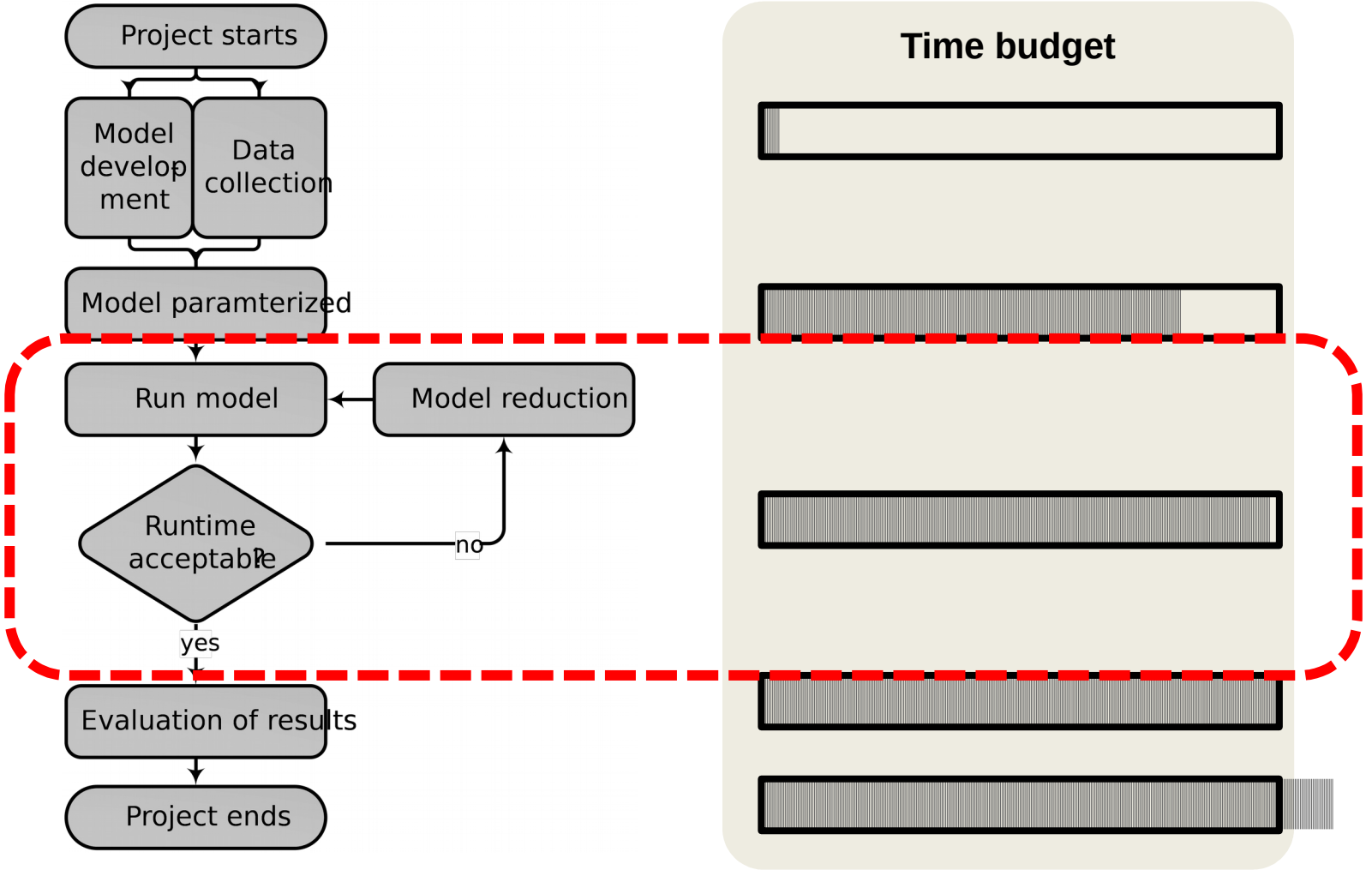
Speed-up approach parameters

Speed-up approach	w *	w o*	Name	Evaluated range
Spatial aggregation	P	P	number of regions (clusters)	{1, 5, 18, 50, 100, 150, 200, 250, 300, 350, 400, 450, 488}
Temporal Downsampling	P	P	temporal resolution	{1, 2, 3, 4, 6, 8, 12, 24, 48, 168, 1095}
Rolling horizon dispatch	O	P	number of intervals	{4, 16, 52}
			overlap size	{1%, 2%, 4%, 10%}
Temporal zooming (sequential)	P	O	number of intervals	{4, 16, 52}
			resolution of down-sampled run	{4, 8, 24}
Temporal zooming (grid computing)	P	O	number of intervals	{4, 16, 52}
			resolution of down-sampled run	{4, 8, 24}
			number barrier threads	{2, 4, 8, 16}
			number of parallel runs	{2, 4, 8, 16}

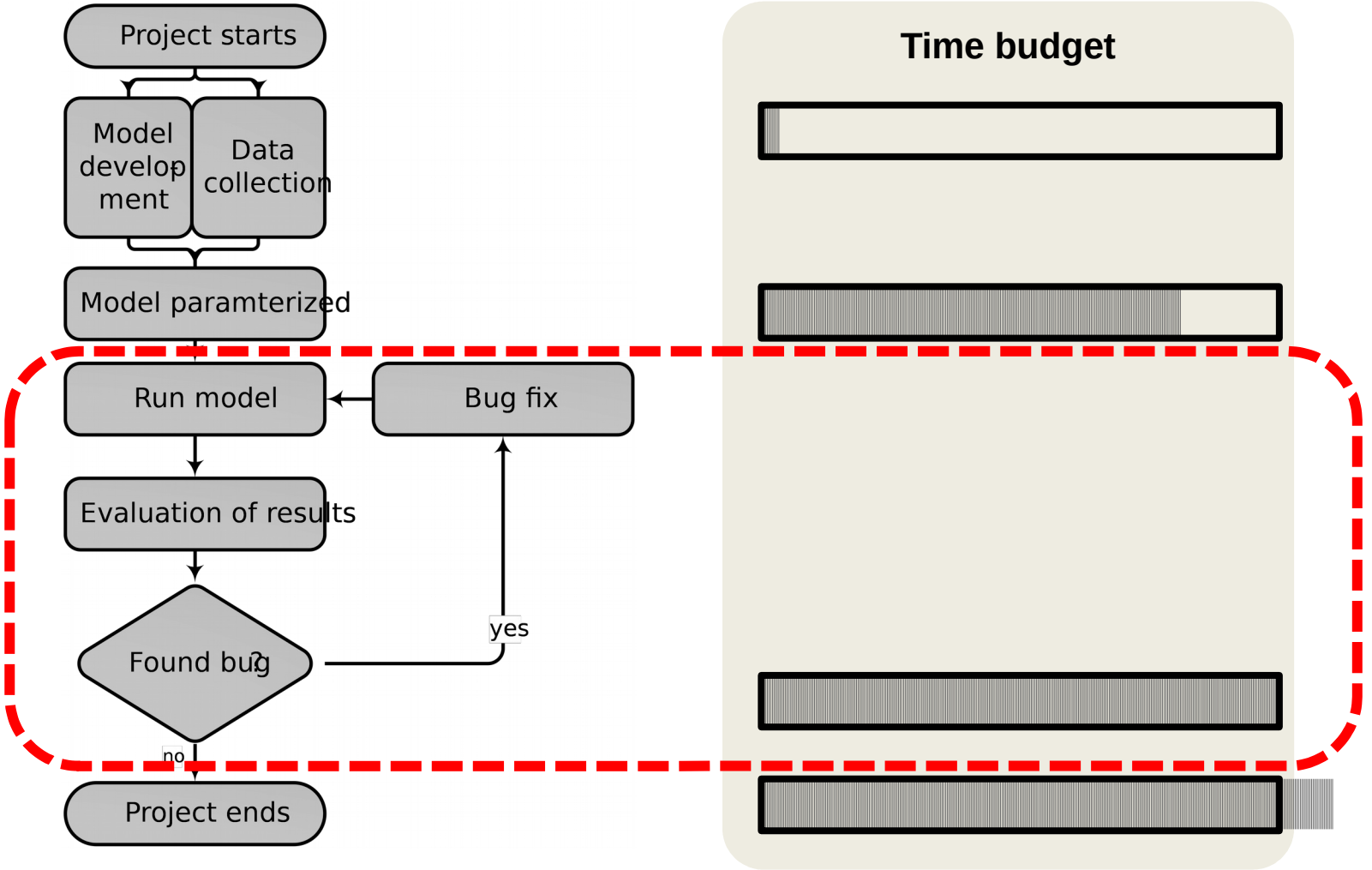
*w/wo: expansion of storage and transmission capacities

Results

Everyday‘s Energy Systems Analysis…

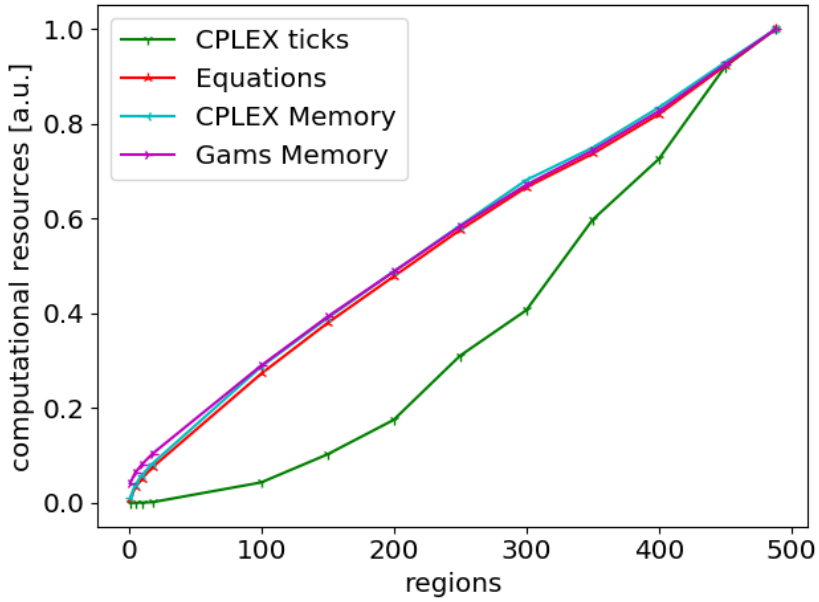


Everyday's Energy Systems Analysis



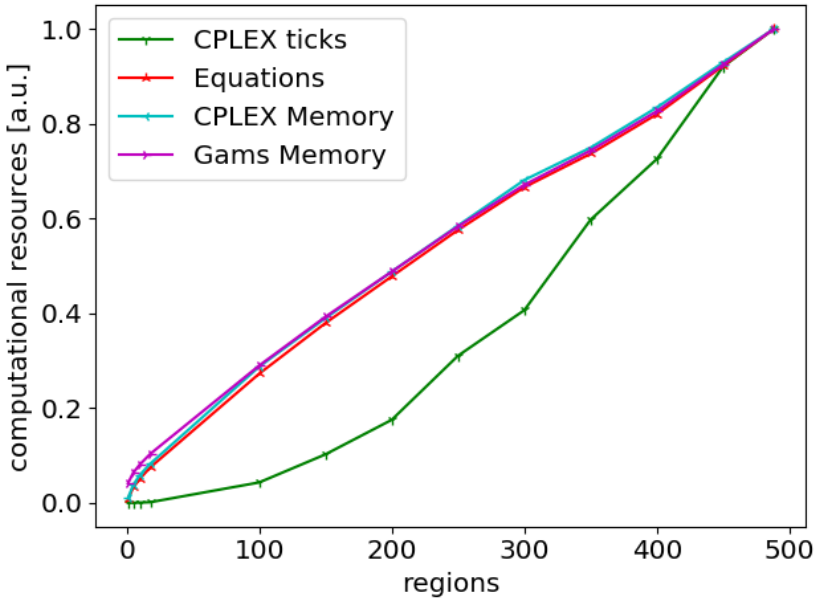
Spatial aggregation (w exp)

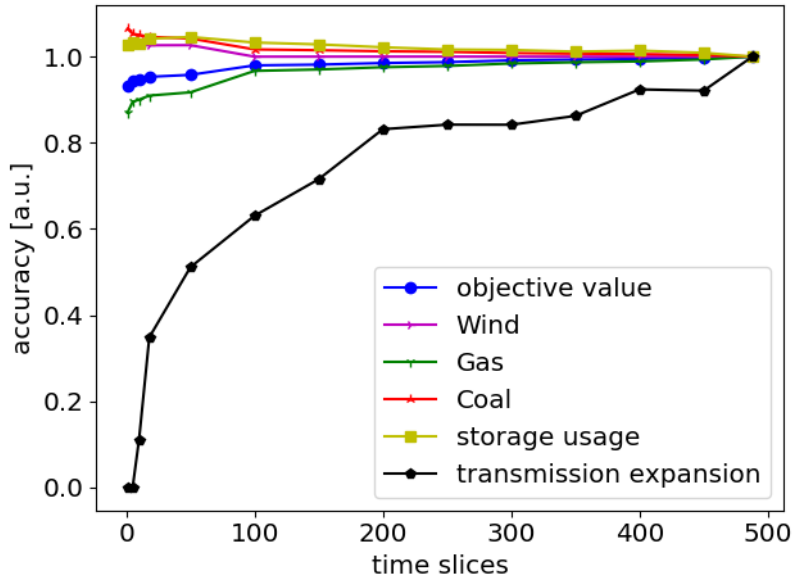
Performance



Spatial aggregation (w exp)

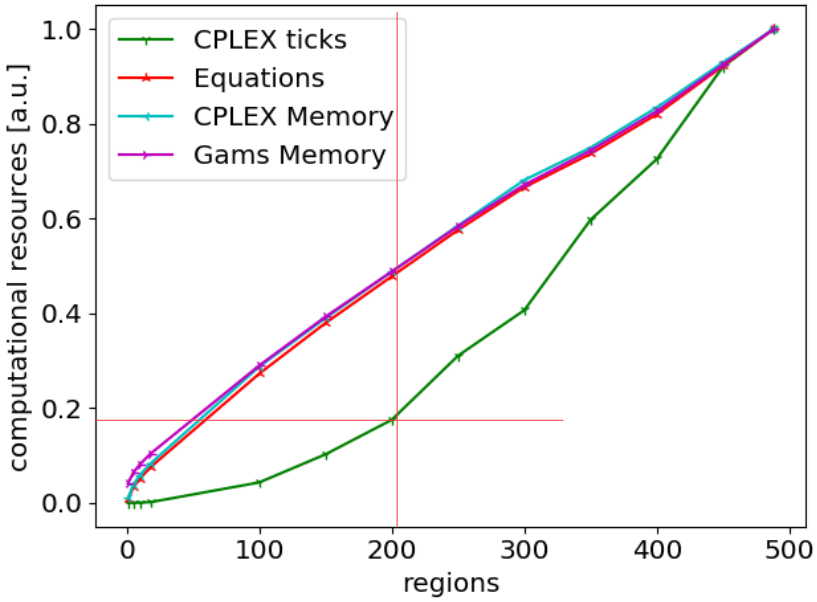
Performance

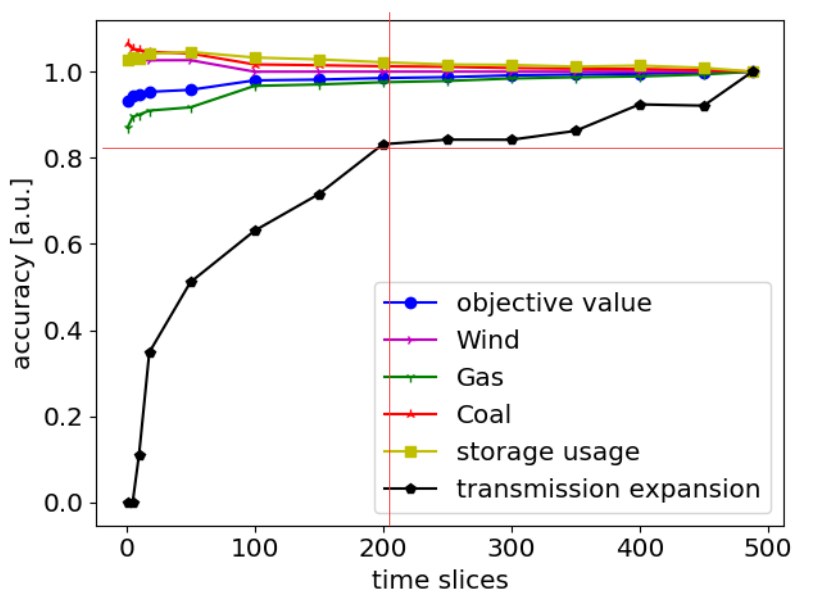




Spatial aggregation (w exp)

Performance



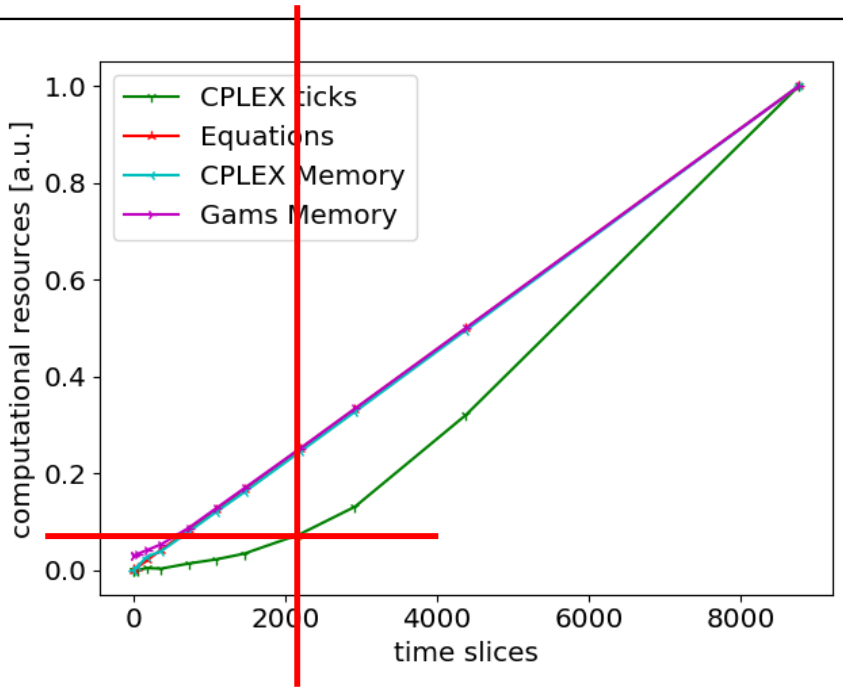


1 a) Speed-up factor: ≈5

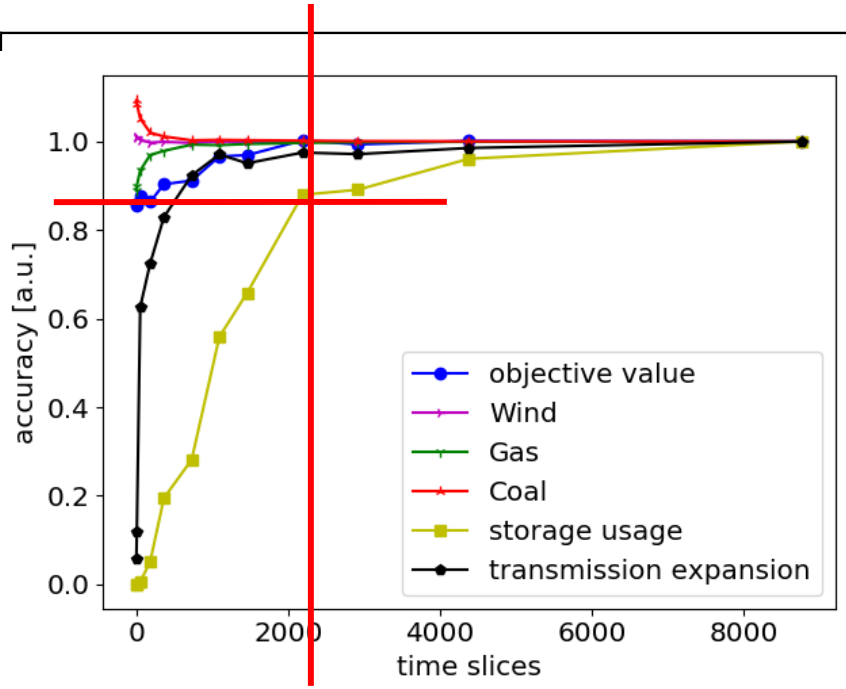
2 a) Accuracy error mainly < 10 % (grids: ≈20%)

Temporal downsampling (w exp)

Performance



Accuracy

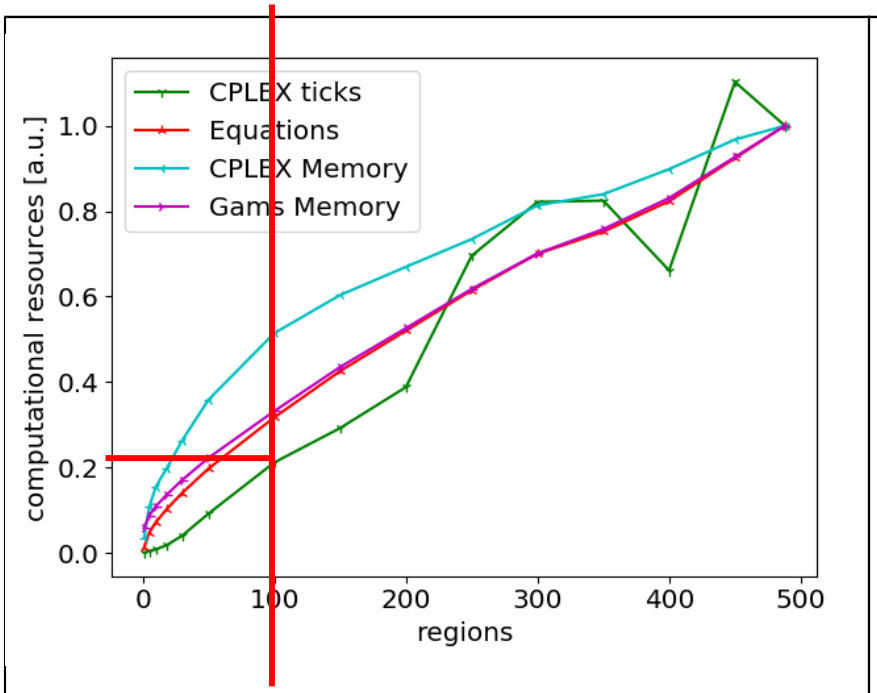


1 b) Speed-up factor: ≈10

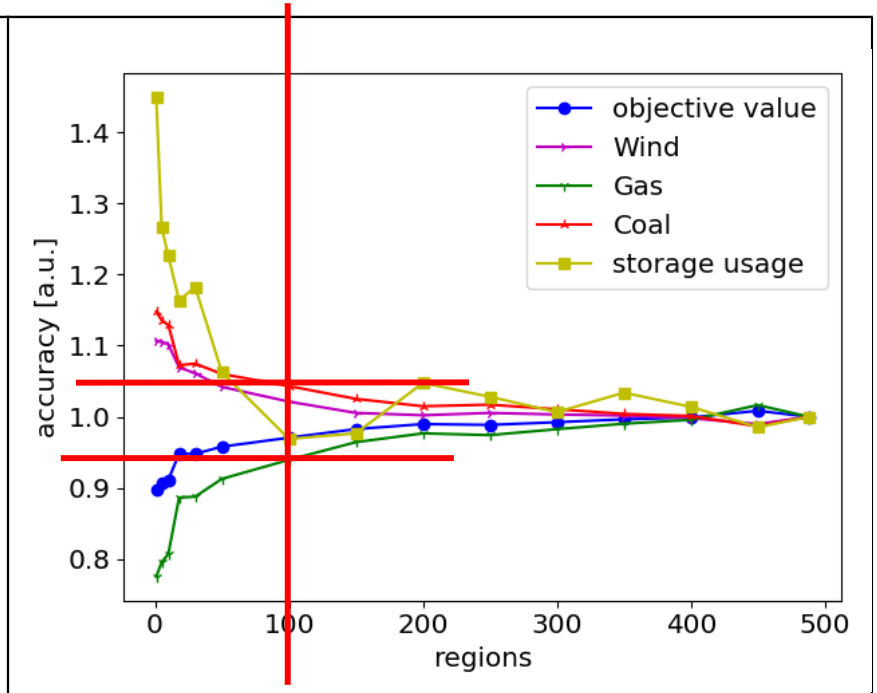
2 b) Accuracy error mainly < 10 % (storage: ≈20%)

Spatial downsampling (wo exp)

Performance



Accuracy

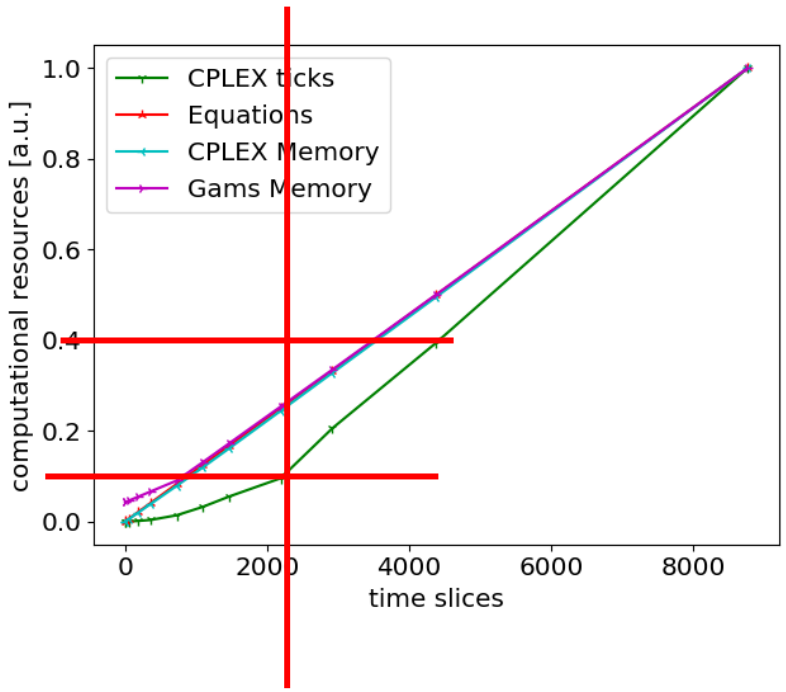


1 b) Speed-up factor: ≈5

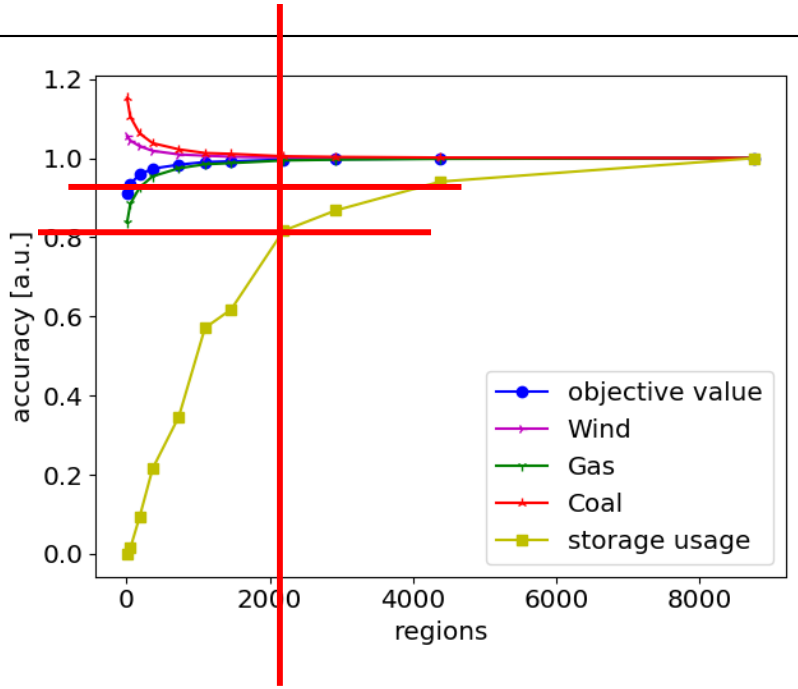
2 b) Accuracy error mainly < 10 %

Temporal downsampling (wo exp)

Performance



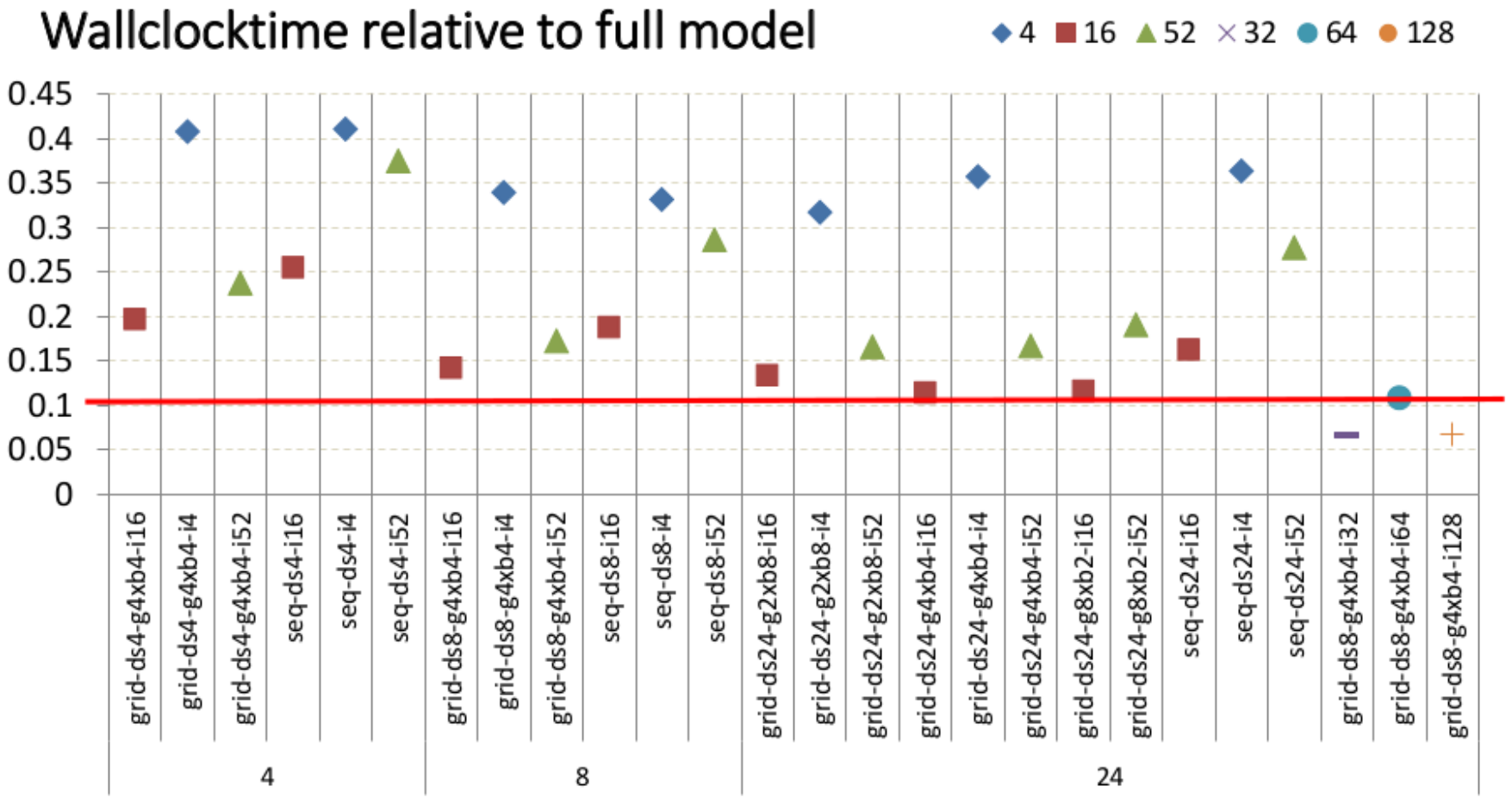
Accuracy



1 b) Speed-up factor: ≈10 (2.5)

2 b) Accuracy error mainly < 10 % (storage: ≈20%)

Temporal zooming



3) Speed-up factor: >10 reachable, at least >2

Conclusions

Research Question

Which **speed-up** is possible using measures that can be influenced by „normal“ model developers?

Short answer

Faktor 10!

Conclusions detailed

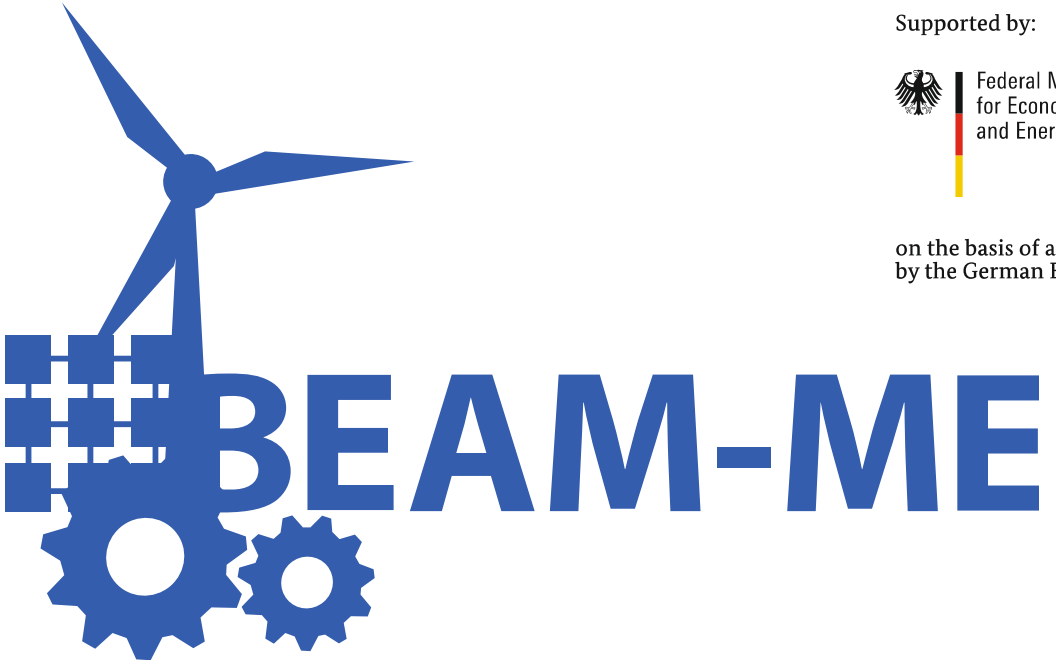
- 4 speed-up strategies evaluated
- 2 slightly different models

- Aggregation
  1) Speed up ≈5
  2) Accuracy error <10%*
- Temporal zooming
  3) Speed up ≈10

*except of indicators related to aggregated dimension

Project BEAM-ME

Thank you!



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