Supported by:

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on the basis of a decision by the German Bundestag

BEAM-ME

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

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May 22nd 2019

DLR – German Aerospace Center, Department of Energy Systems Analysis

A PROJECT BY

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Overview

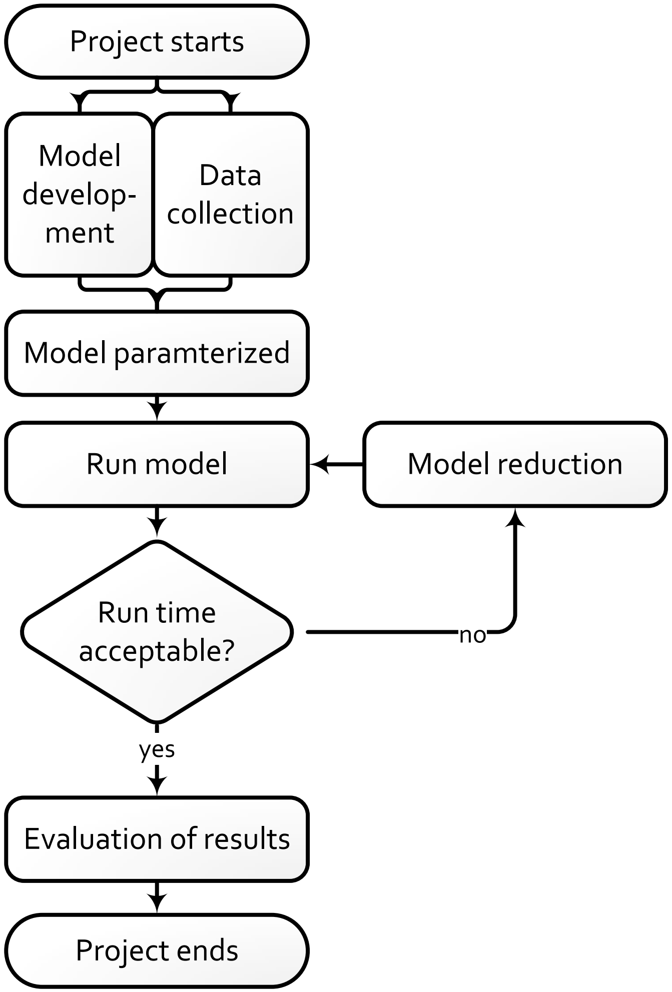
- Motivation
- Repetition: *Characteristics and dimensions of Energy system optimization models*
- Theory: *Classification of existing approaches*
- Evaluation methodology
- Results and major findings
- Conclusions

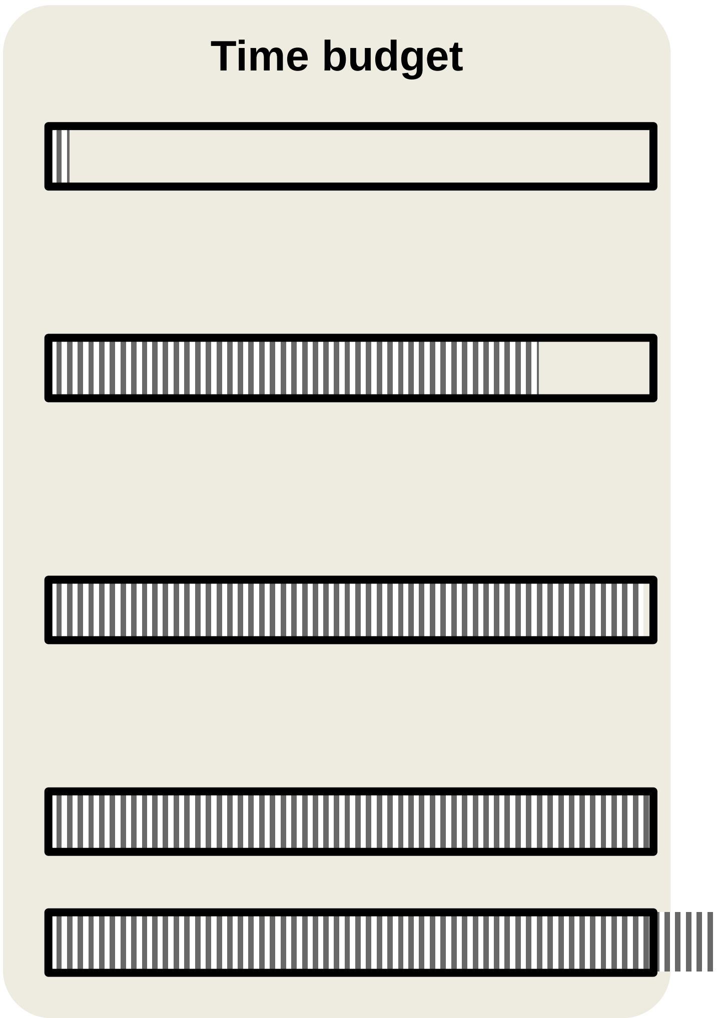
Motivation

What can modelers do by theirselves?

What have modelers done by theirselves?

Everyday‘s Energy Systems Analysis





Research Question

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

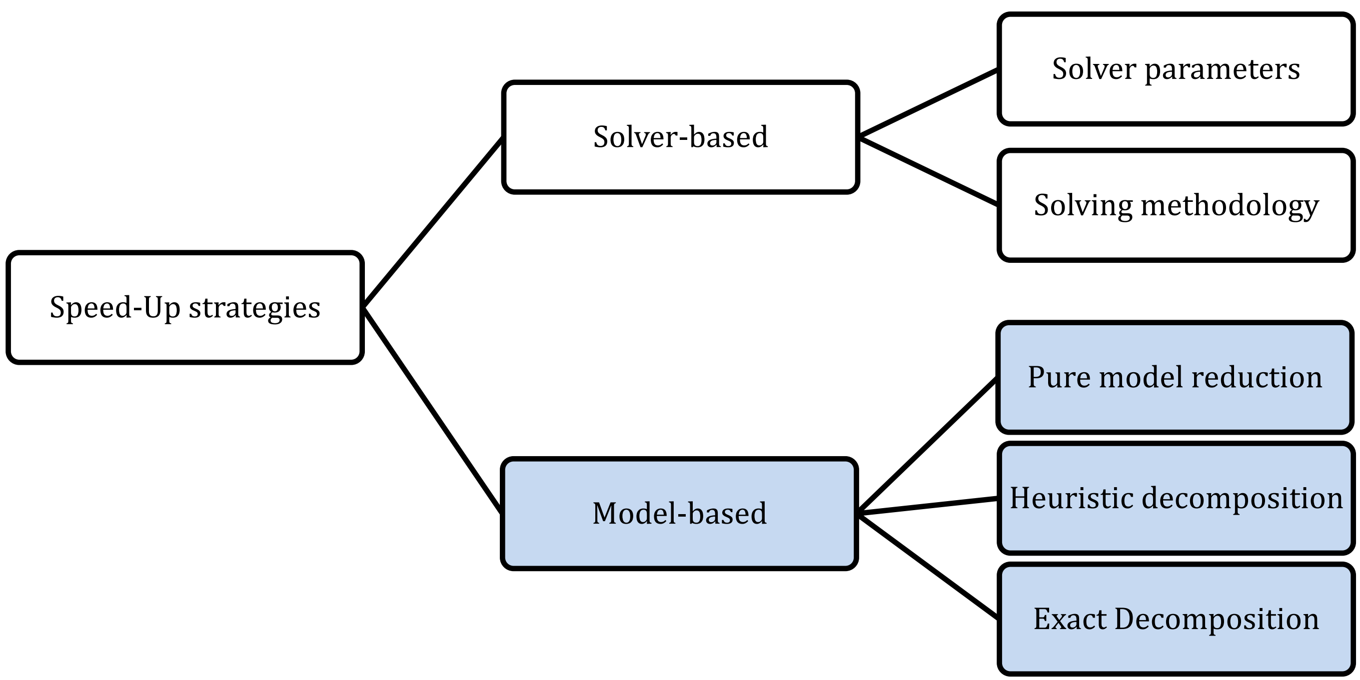
Framework

- Large applied Energy System Optimization Models
  - LPs
  - Computing time: >12h (dominated by solver)
  - Storage and transmission

- Shared memory hardware
- Use of standard solvers

Approach I (the probably most popular one)

Approach II: Model-based speed-up strategies



Characteristics and dimensions of Energy system optimization models

Typical model dimensions

Time

Planning horizon

Operation

Investment

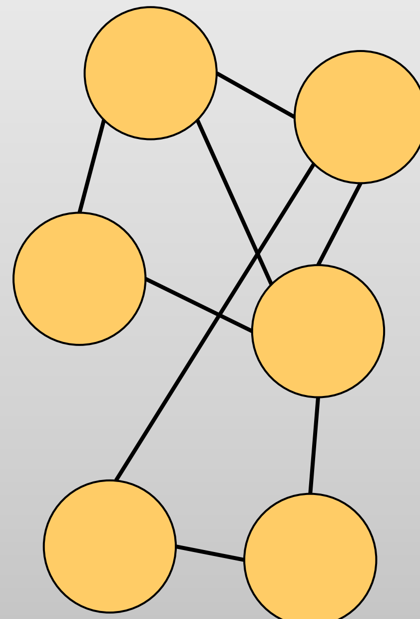
Short term → Long term

Discretisation

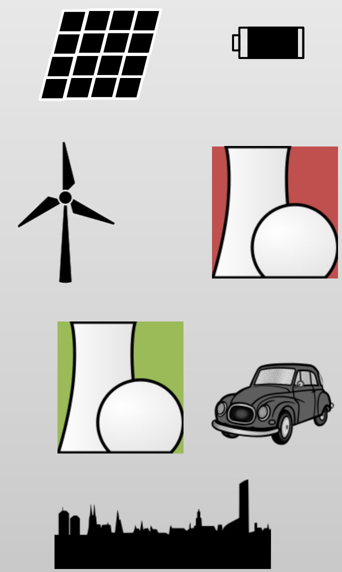
coarse

fine

Regions



Technology



Linking variables & constraints

Storage energy balance:

$$\boldsymbol{p}_{s+}(t,n,u_s) - \boldsymbol{p}_{s-}(t,n,u_s) - \boldsymbol{p}_{ls}(t,n,u_s) = \frac{E_s(t,n,u_s) - E_s(t-1,n,u_s)}{\Delta t}$$

$$\forall t \in T; n \in N\ ; \forall u \in U_s;\ U_s \subset U$$

$\boldsymbol{p}_{s+}/\boldsymbol{p}_{s-}$:	storage charge/discharge power
$\boldsymbol{p}_{ls}$:	storage self-discharge (losses)
$\boldsymbol{E}_s$:	stored energy
U_s:	set of storage facilities

DC power flow:

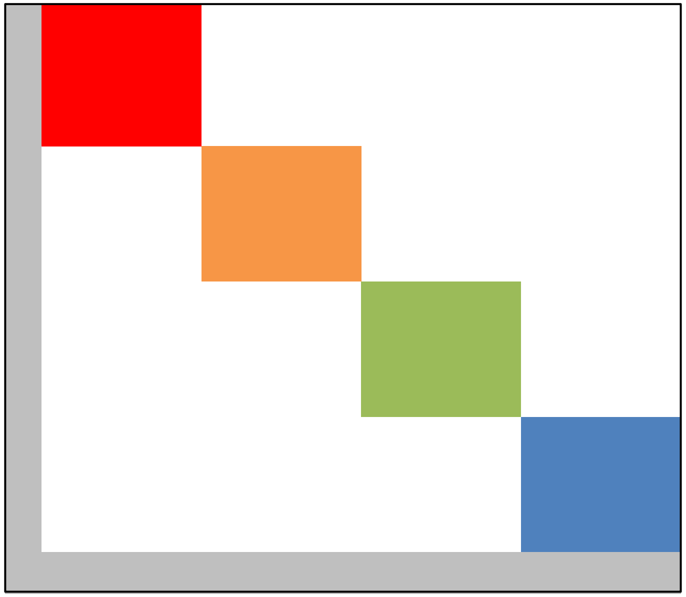
$$\boldsymbol{p}_{im}(t,n) - \boldsymbol{p}_{ex}(t,n) - \boldsymbol{p}_{lt}(t,n) = \sum_{n'} B(n,n') \cdot \boldsymbol{\theta}(n',t)$$

$$\forall t \in T,; \forall n \in N$$

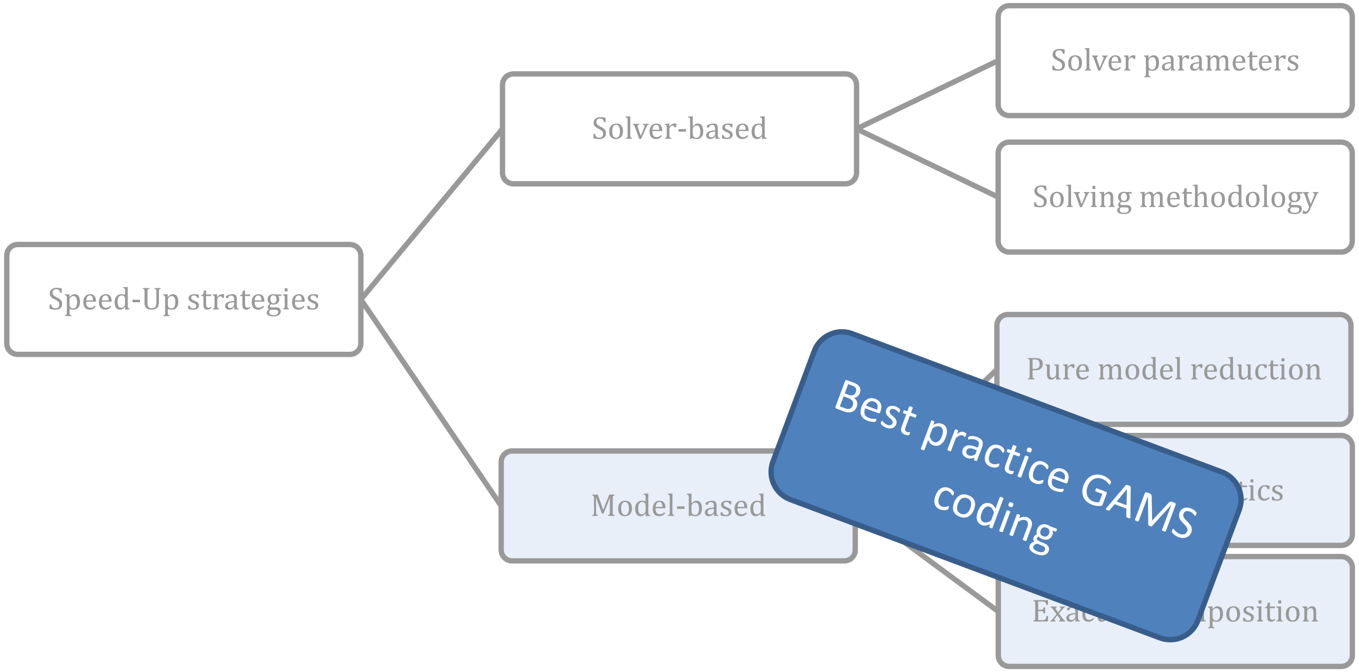
$$\boldsymbol{p}_{f+}(t,l) - \boldsymbol{p}_{f-}(t,l) = \sum_{l}\sum_{n} B_{diag}(l,l') \cdot K^T(l,n) \cdot \boldsymbol{\theta}(n,t)$$

$$\forall t \in T,; \forall l \in L$$

$\boldsymbol{p}_{im}/\boldsymbol{p}_{ex}$:	power import/export
$\boldsymbol{p}_{lt}$:	transmission losses
$\boldsymbol{p}_{f+}/\boldsymbol{p}_{f-}$:	active power flow along/against line direction
$\boldsymbol{\theta}$:	voltage angle
B:	susceptances between regions
B_{diag}:	diagonal matrix of branch susceptances
K:	incidence matrix



„Low Hanging Fruits“

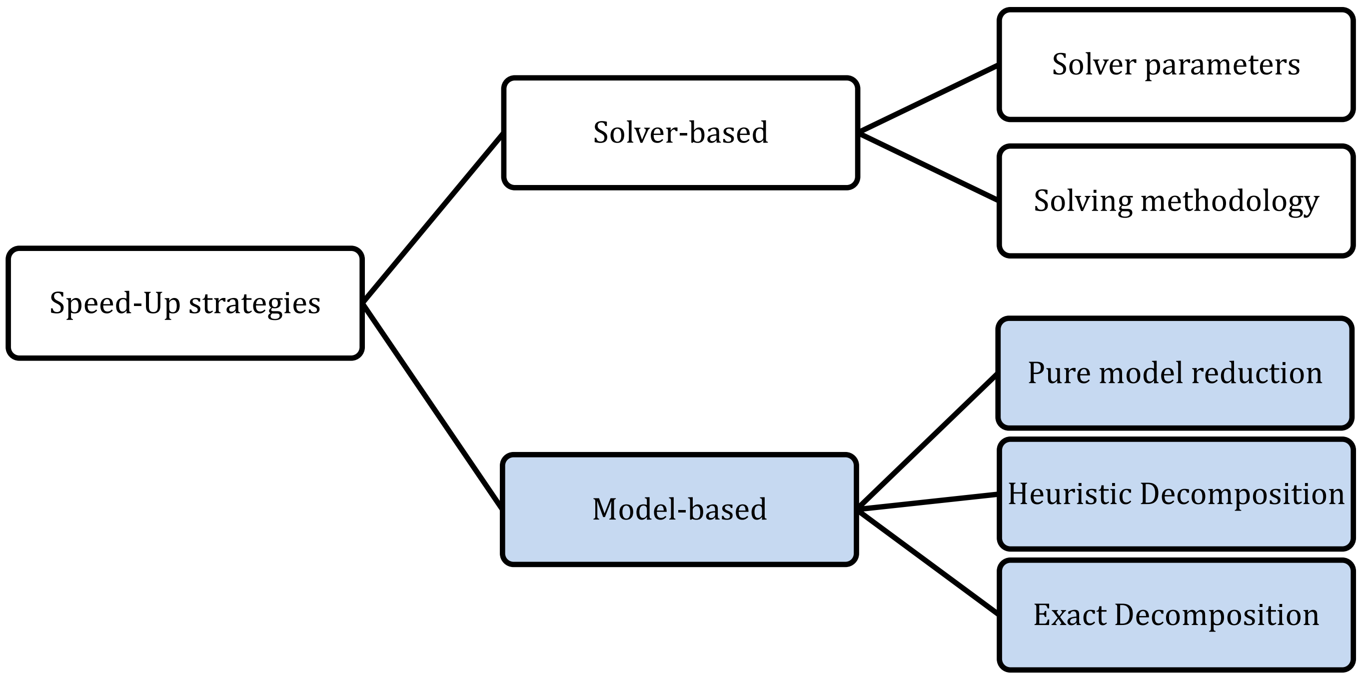


Source code improvement

- 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

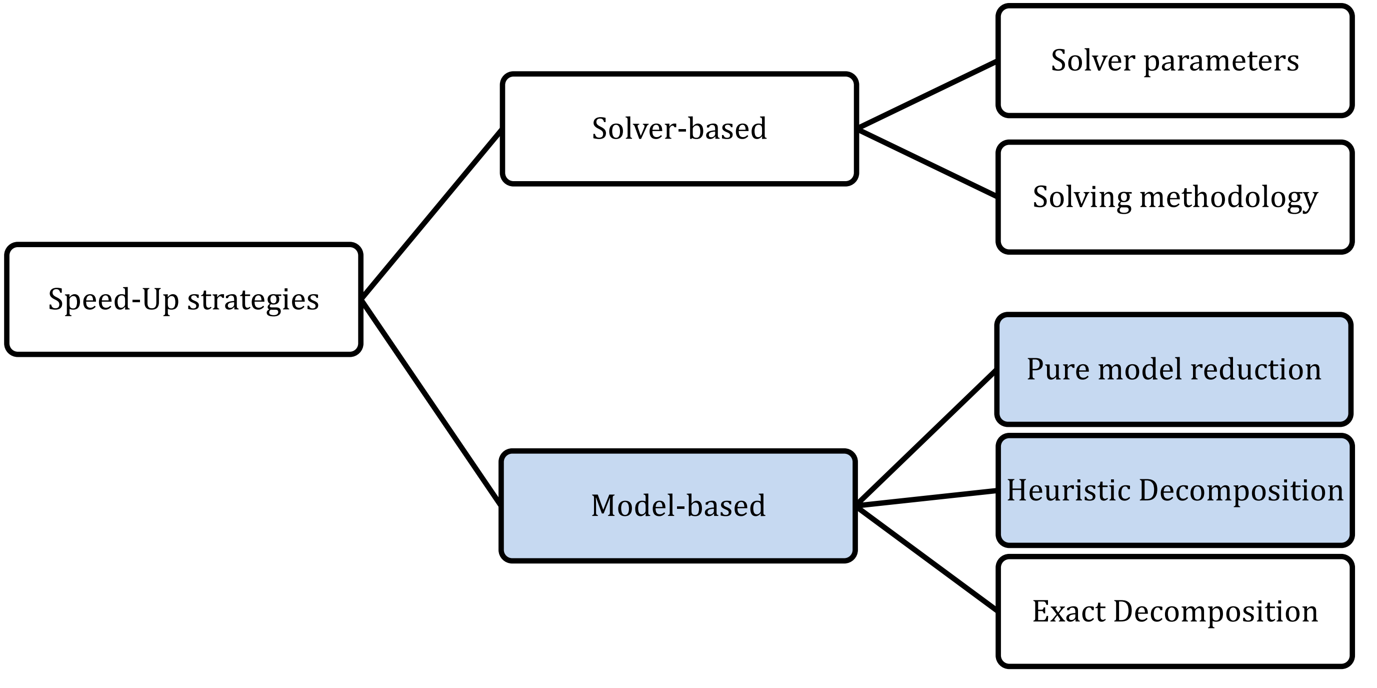
Model-based speed-up strategies



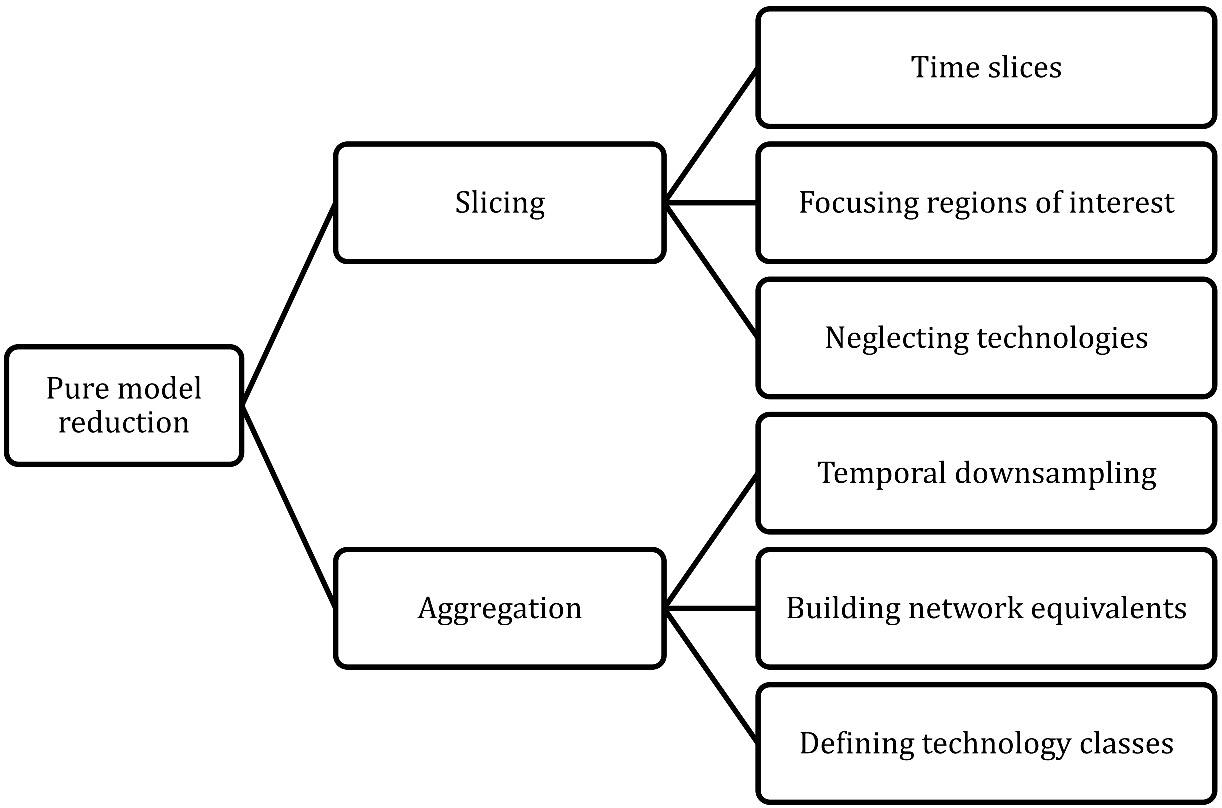
Literature Review

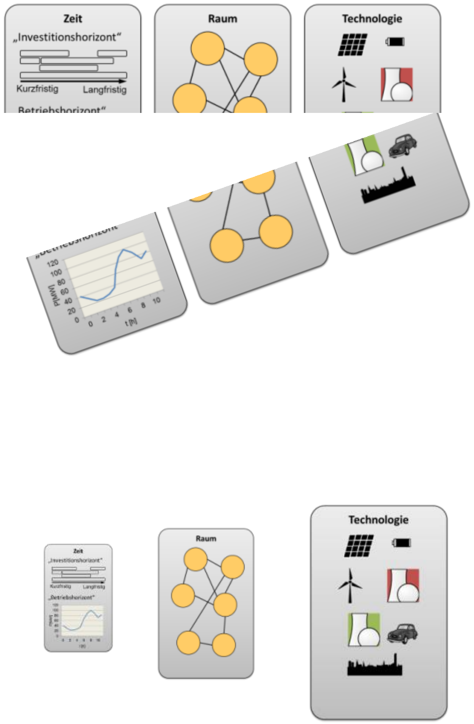
Authors	Math. problem type	Descriptive problem type	Decomposed model scale	Decomposition technique
Alguacil and Conejo [56]	MIP/NLP	Plant and grid operation	Time, single sub-problem	Benders decomposition
Amjady and Ansari [57]	MIP/NLP	Plant operation		Benders decomposition
Binato et. al [58]	MIP/LP	TEP		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

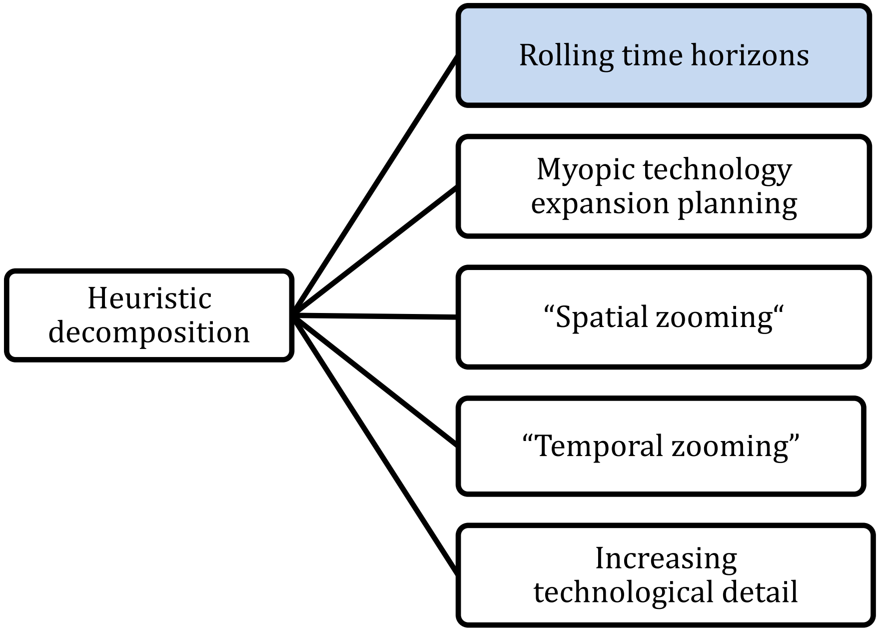


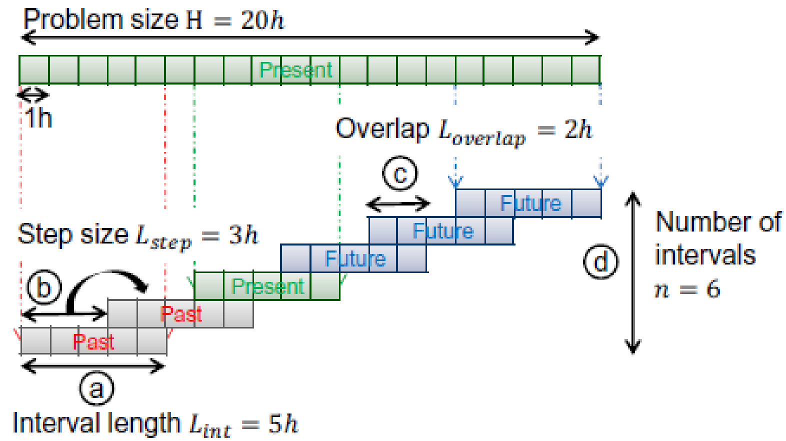
Types of model reductions in ESM



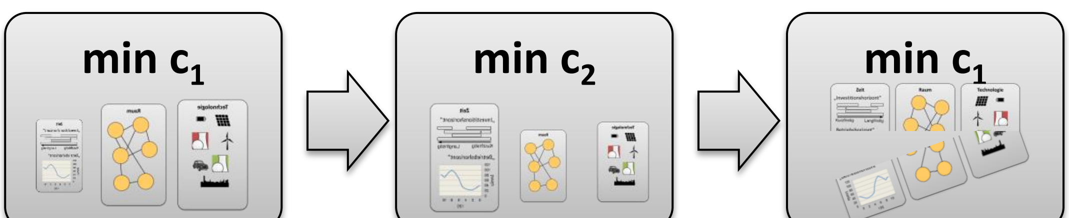


Meta heuristics



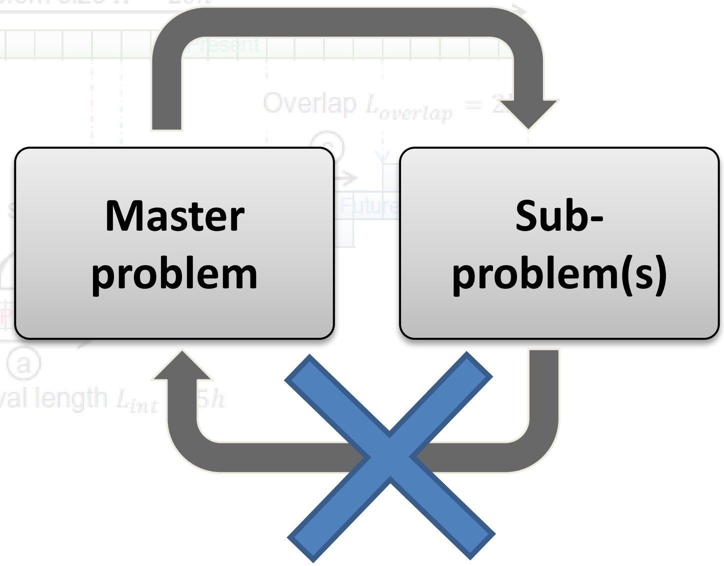


Stepwise solving reduced models

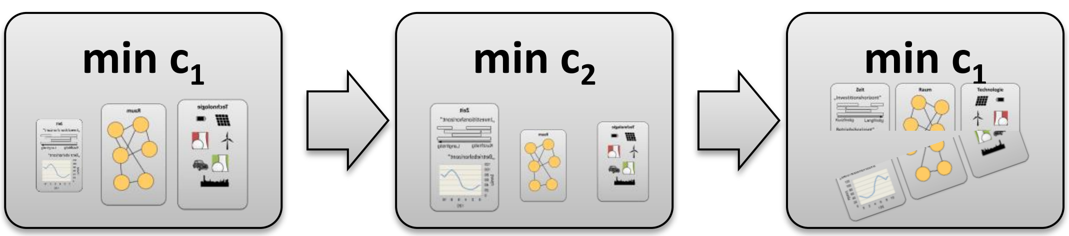


Meta heuristics

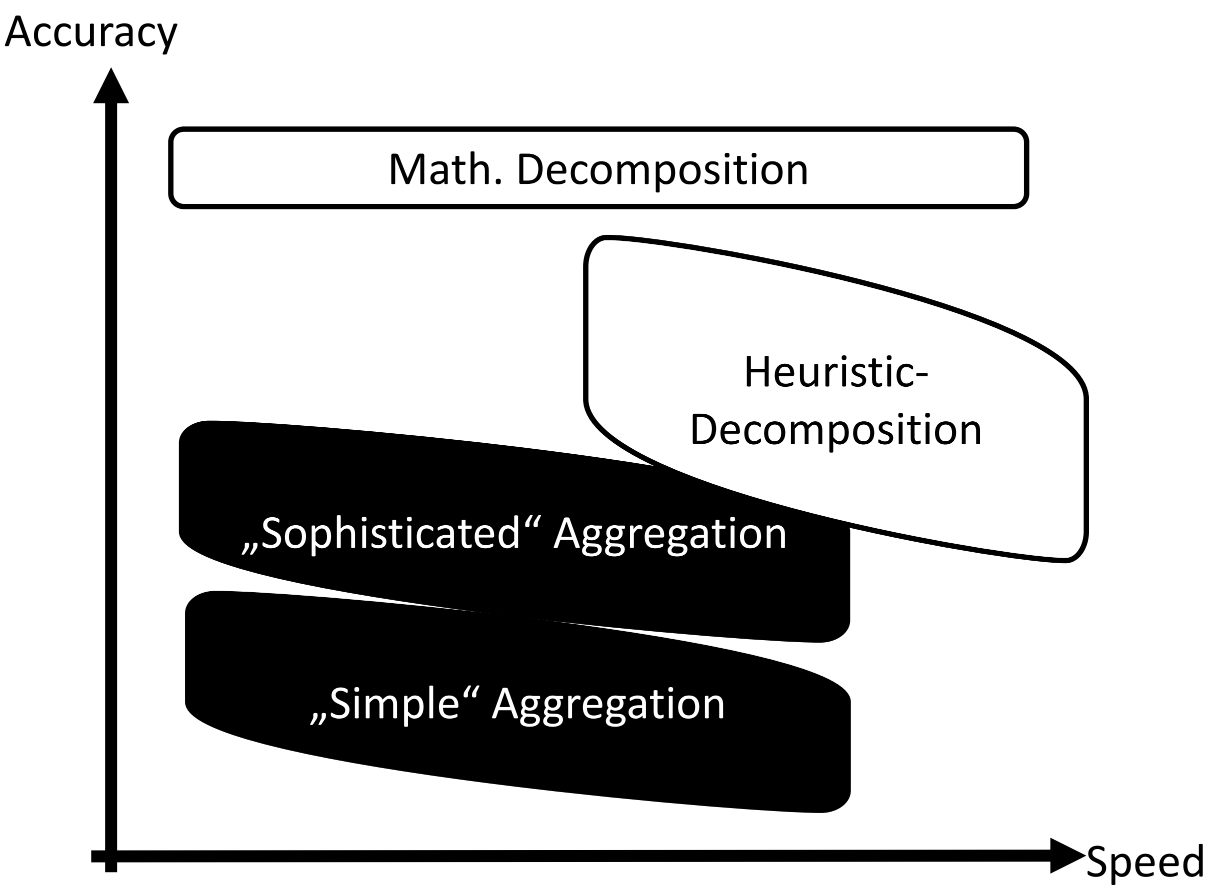
„Decomposition which is ***similar*** *to exact decomposition approaches that are stopped within the first iteration“*



Stepwise solving reduced models



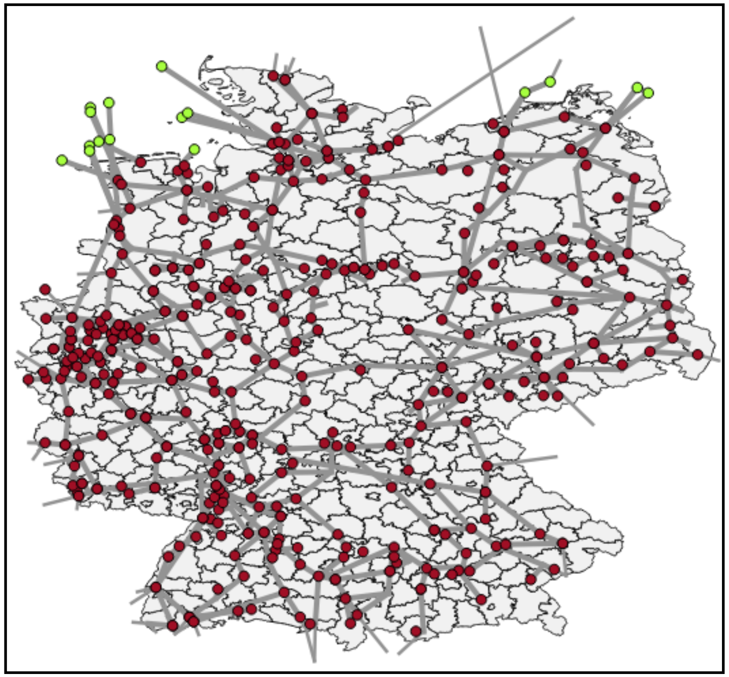
Hypothesis


Accuracy
Math. Decomposition
PIPS
Heuristic-
Decomposition
„Sophisticated“ Aggregation
„Simple“ Aggregation
Speed

Evaluation methodology

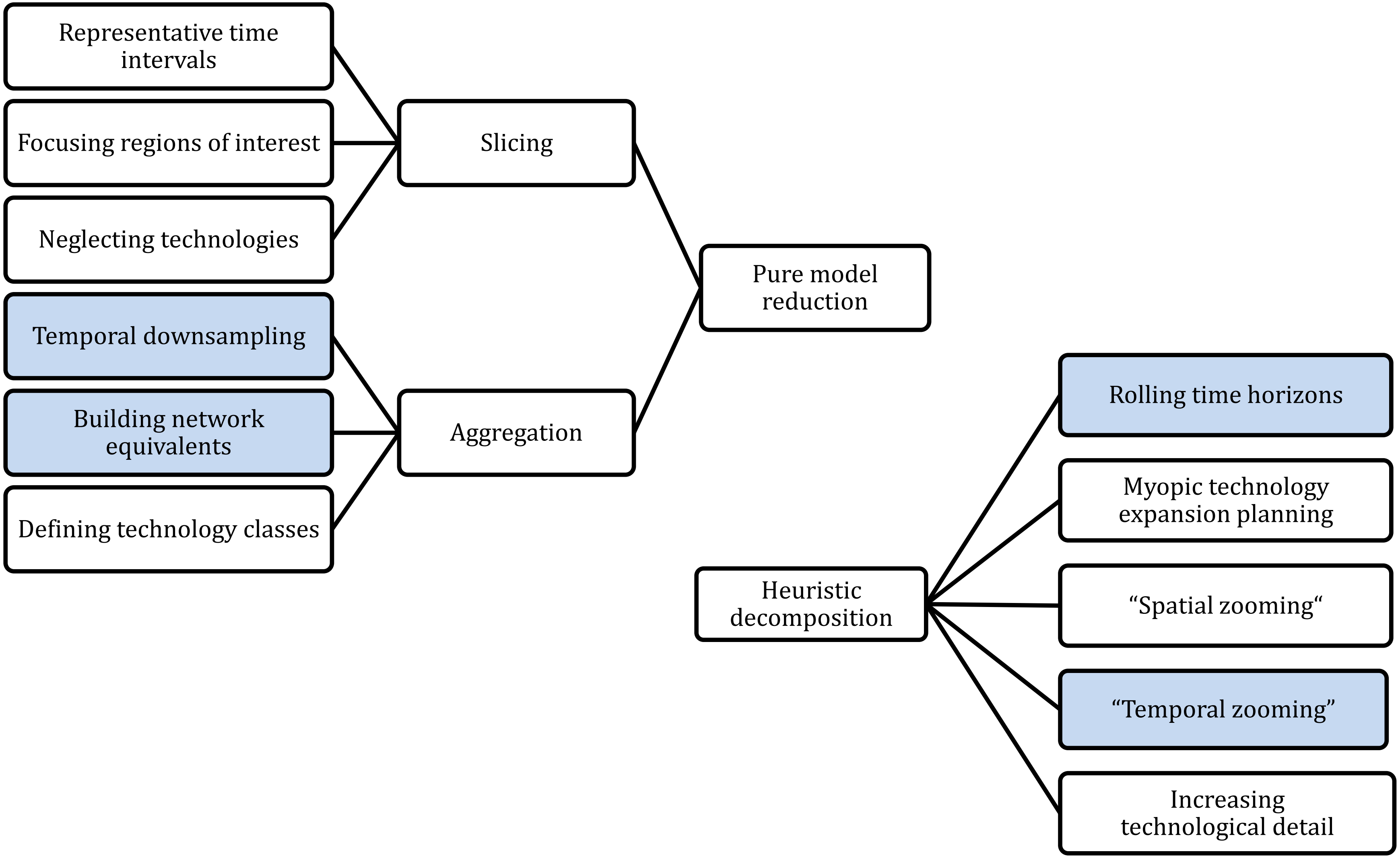
Overview

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)



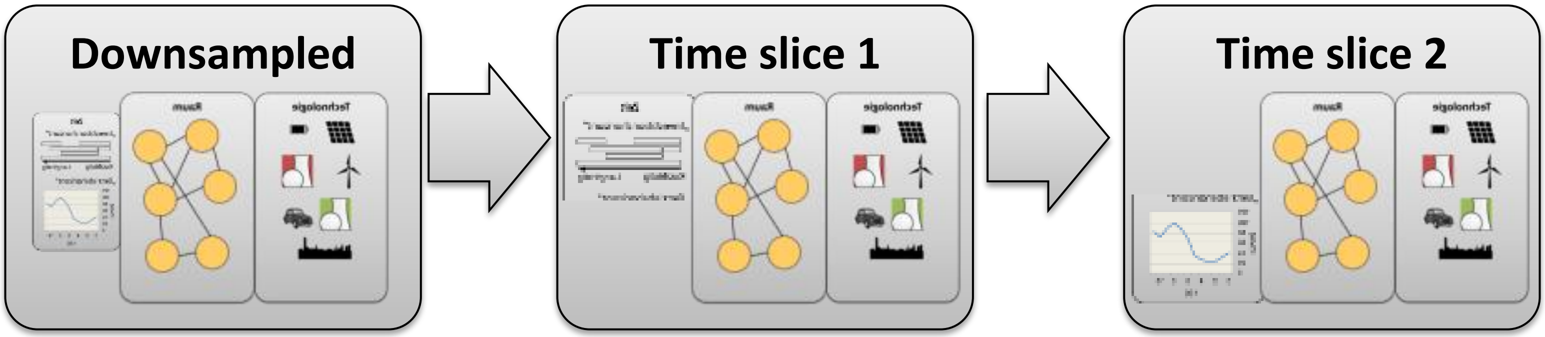
Solver	Commercial
Algorithm	Barrier
Cross-over	Disabled
Max. parallel barrier threads	16
Scaling	Aggressive

Evaluated speed-up approaches

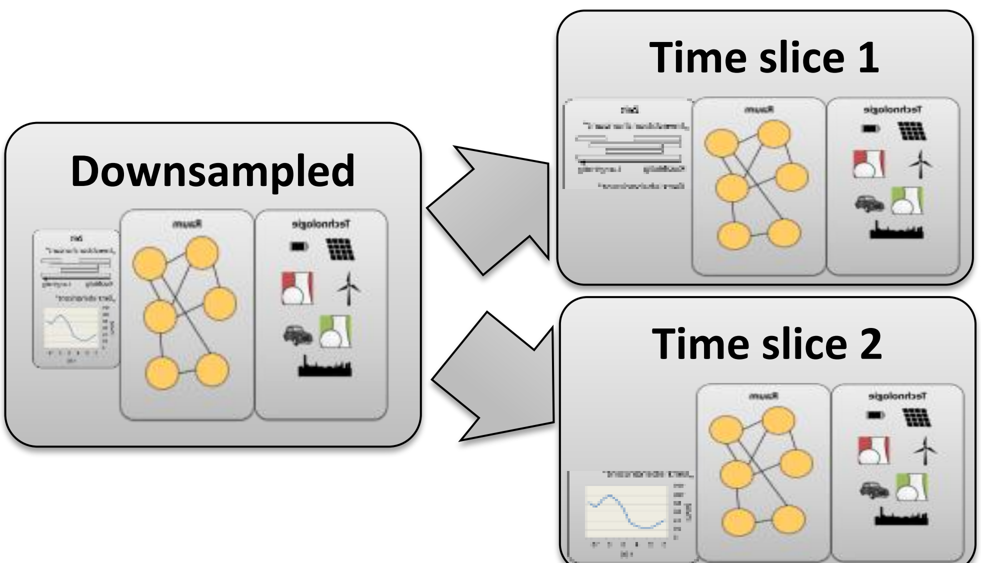


„Temporal zooming“ implementations

- Sequential



- Parallel (using GAMS‘s grid computing facility)



„Temporal zooming“ implementations

- Sequential

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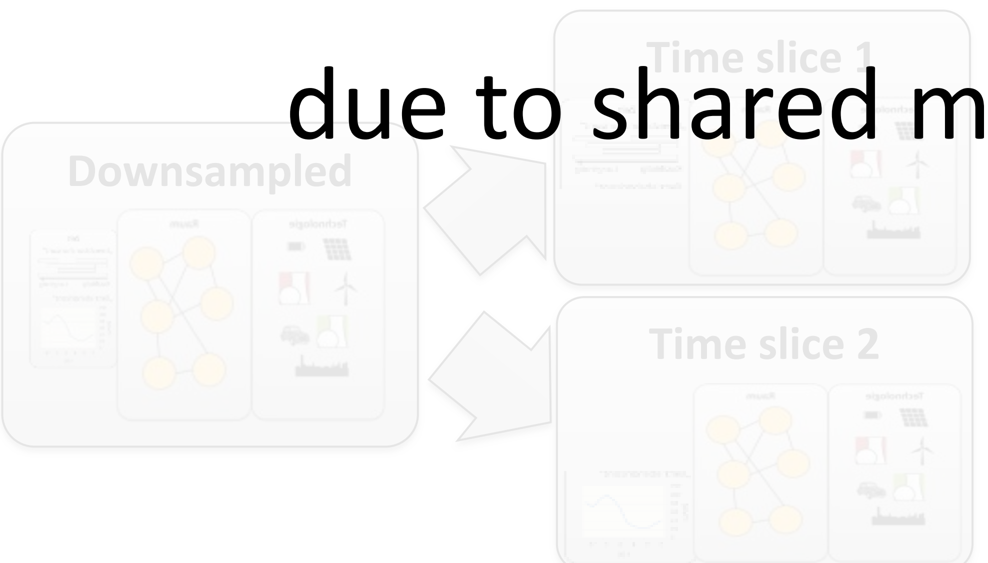
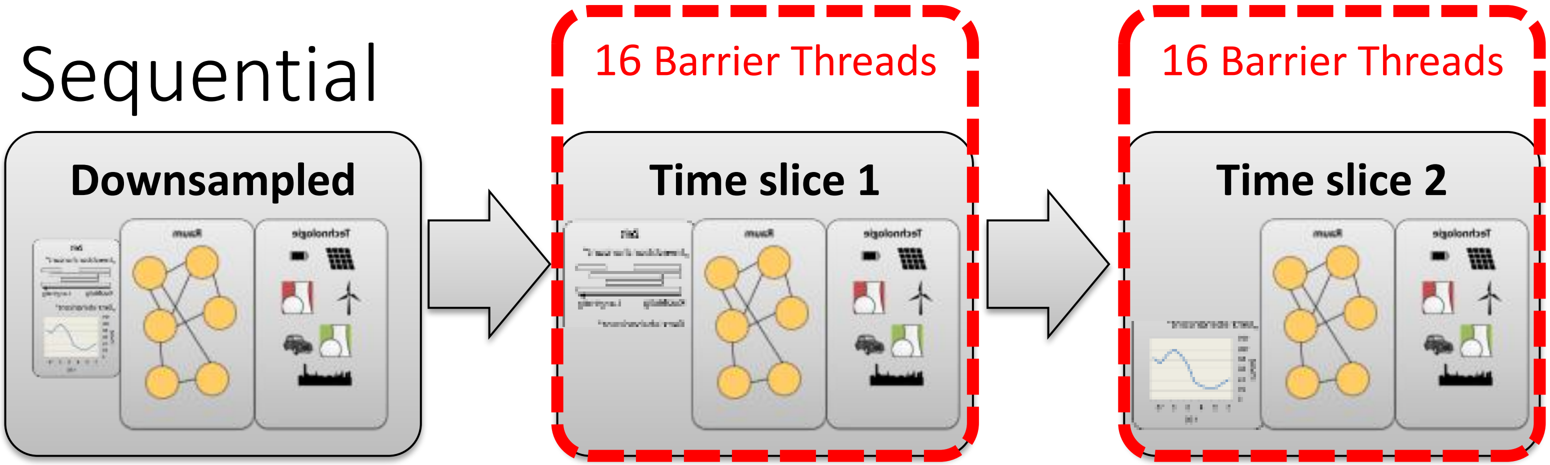


Parallelization limited

due to shared memory!

„Temporal zooming" implementations

- Sequential



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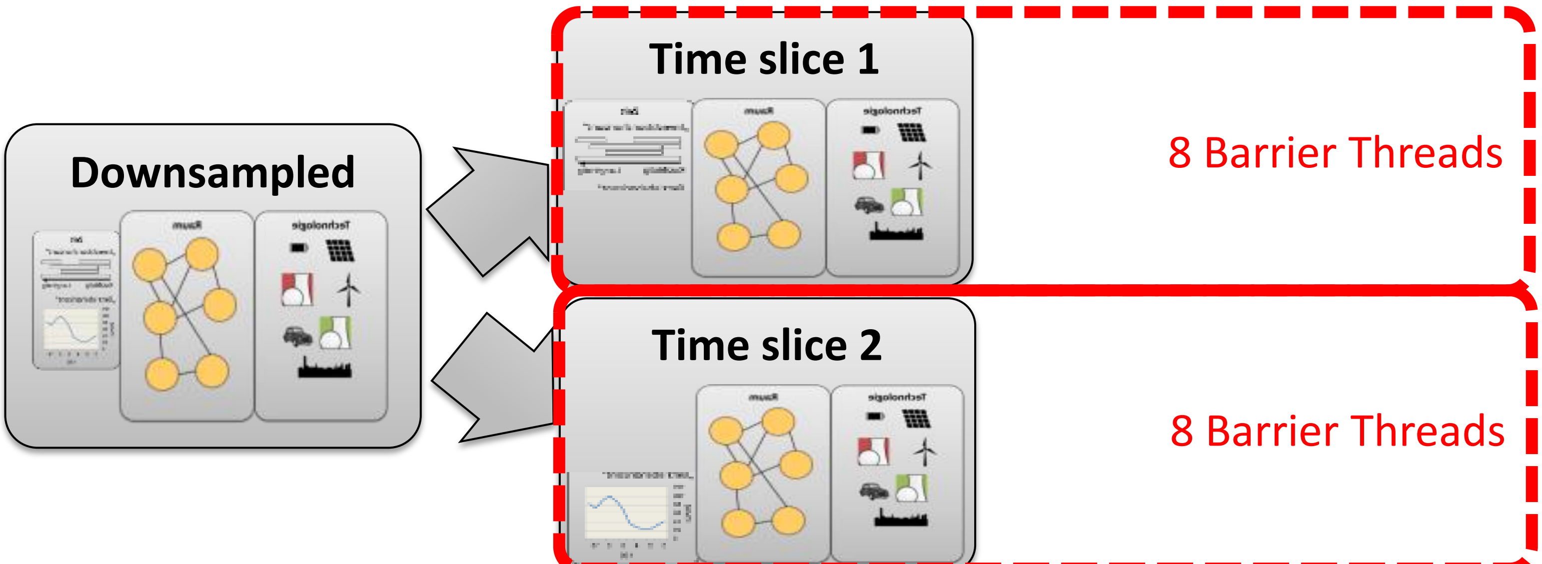

Speed-up approach parameters

Speed-up approach	w*	wo*	Parameter: Name	Parameter: Evaluated range
Spatial aggregation	✓	✓	number of regions (clusters)	{1, 5, 18, 50, 100, 150, 200, 250, 300, 350, 400, 450, 488}
Temporal Downsampling	✓	✓	temporal resolution	{1, 2, 3, 4, 6, 8, 12, 24, 48, 168, 1095, 4380}
Rolling horizon dispatch	✗	✓	number of intervals	{4, 16, 52}
			overlap size	{1%, 2%, 4%, 10%}
Temporal zooming (sequential)	✓	✗	number of intervals	{4, 16, 52}
			resolution of down-sampled run	{4, 8, 24}
Temporal zooming (grid computing)	✓	✗	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

Speed-up approach parameters

BEAM-ME

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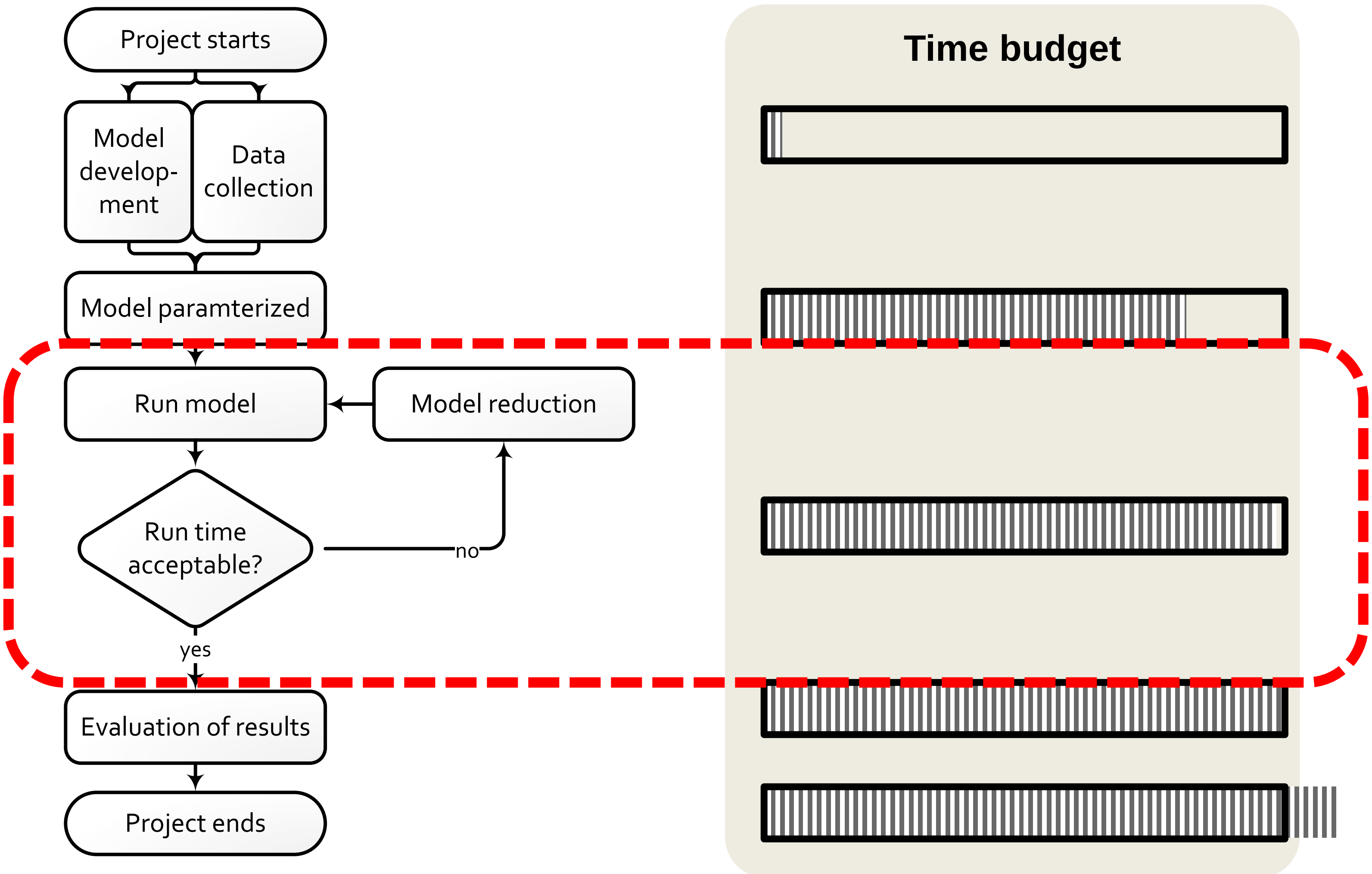
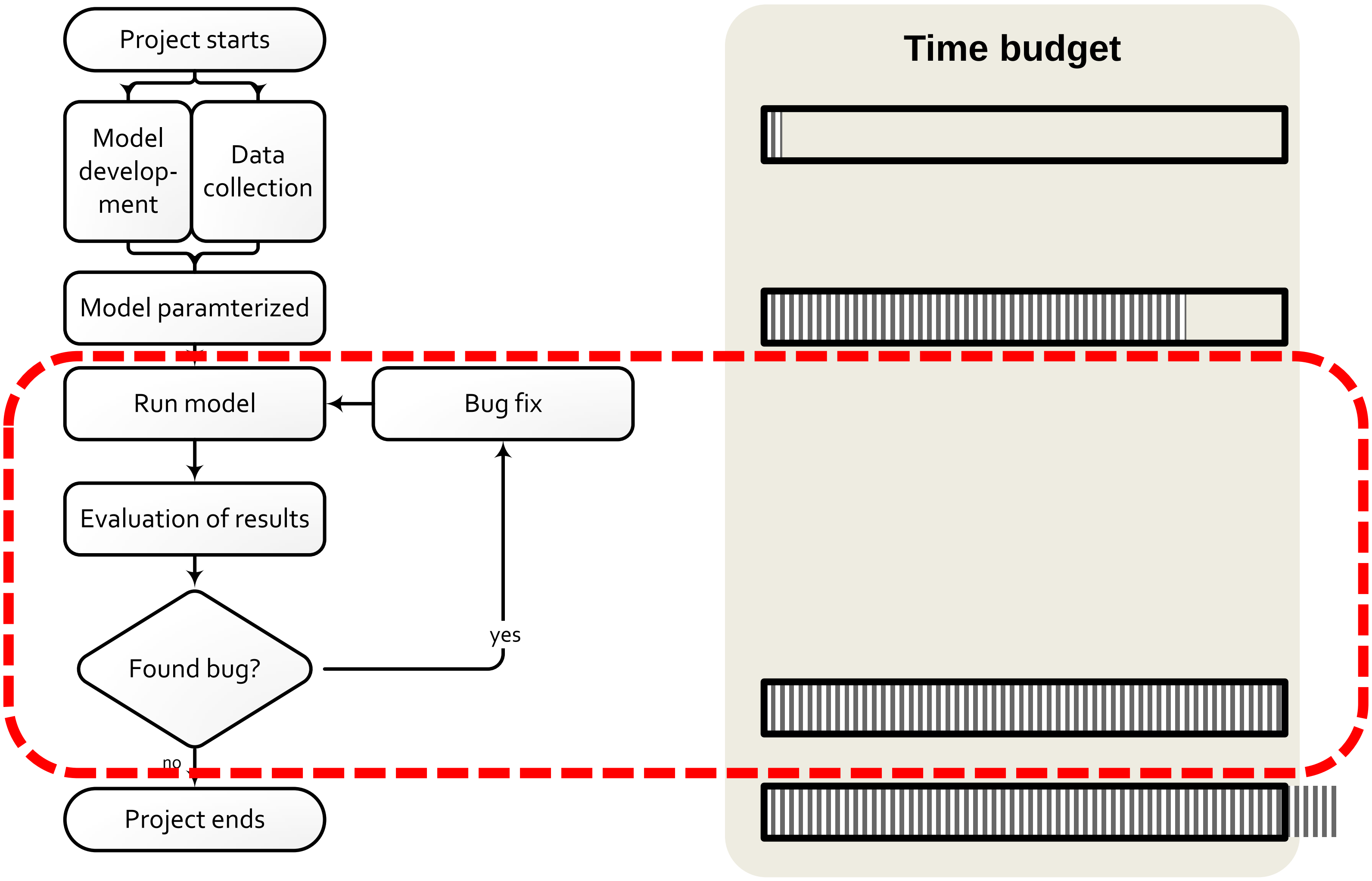
*w/wo: expansion of storage and transmission capacities

Results

Everyday's Energy Systems Analysis...

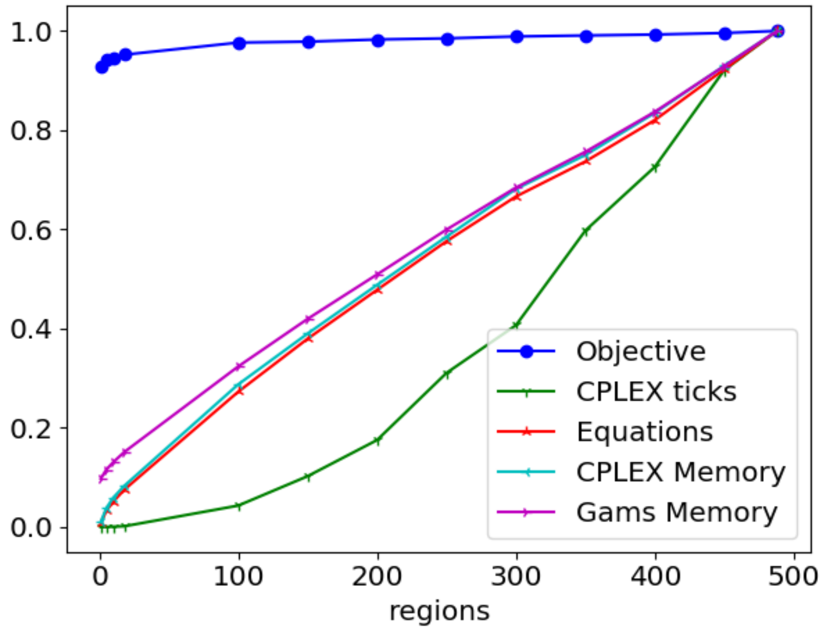


Everyday's Energy Systems Analysis...

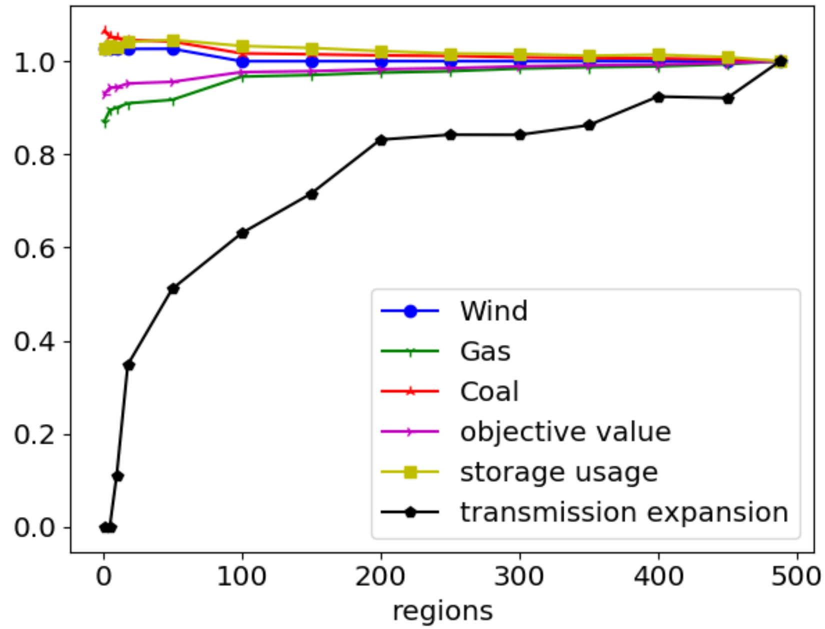


Spatial aggregation

Performance



Accuracy



Spatial aggregation

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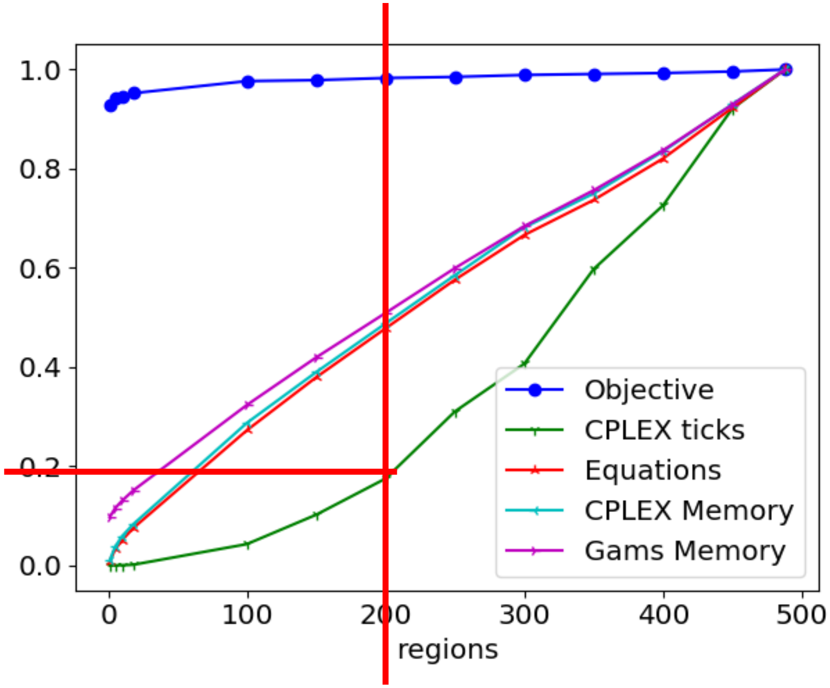
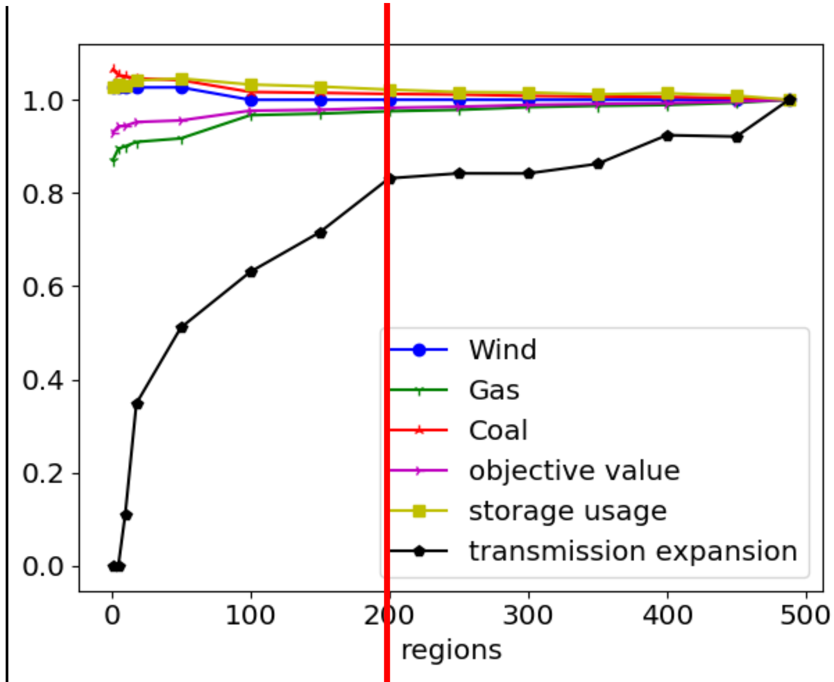
Performance



Accuracy

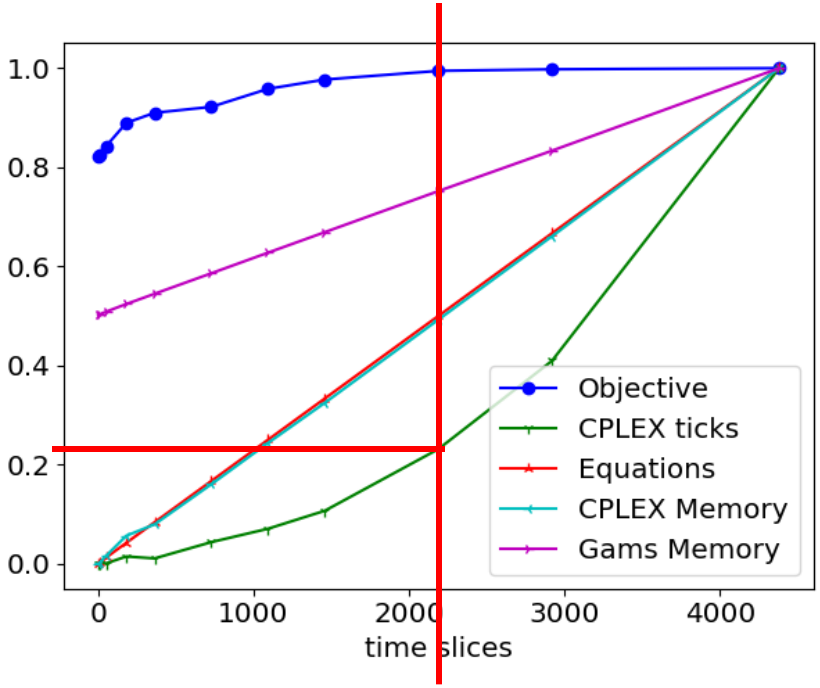


1 a) Speed-up factor: ≈5

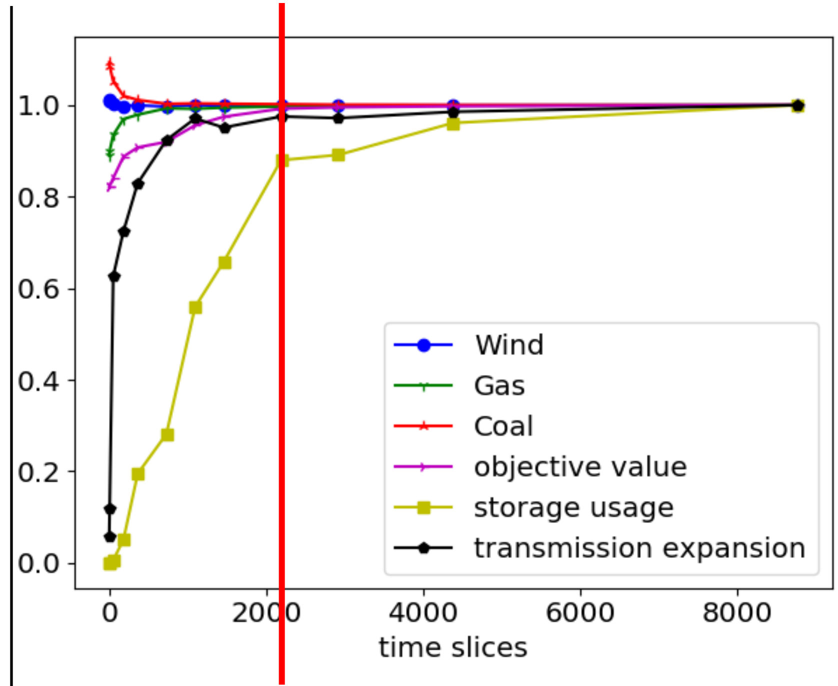
2 a) Accuracy error mainly < 10 % (grids: ≈20%)

Temporal downsampling

Performance



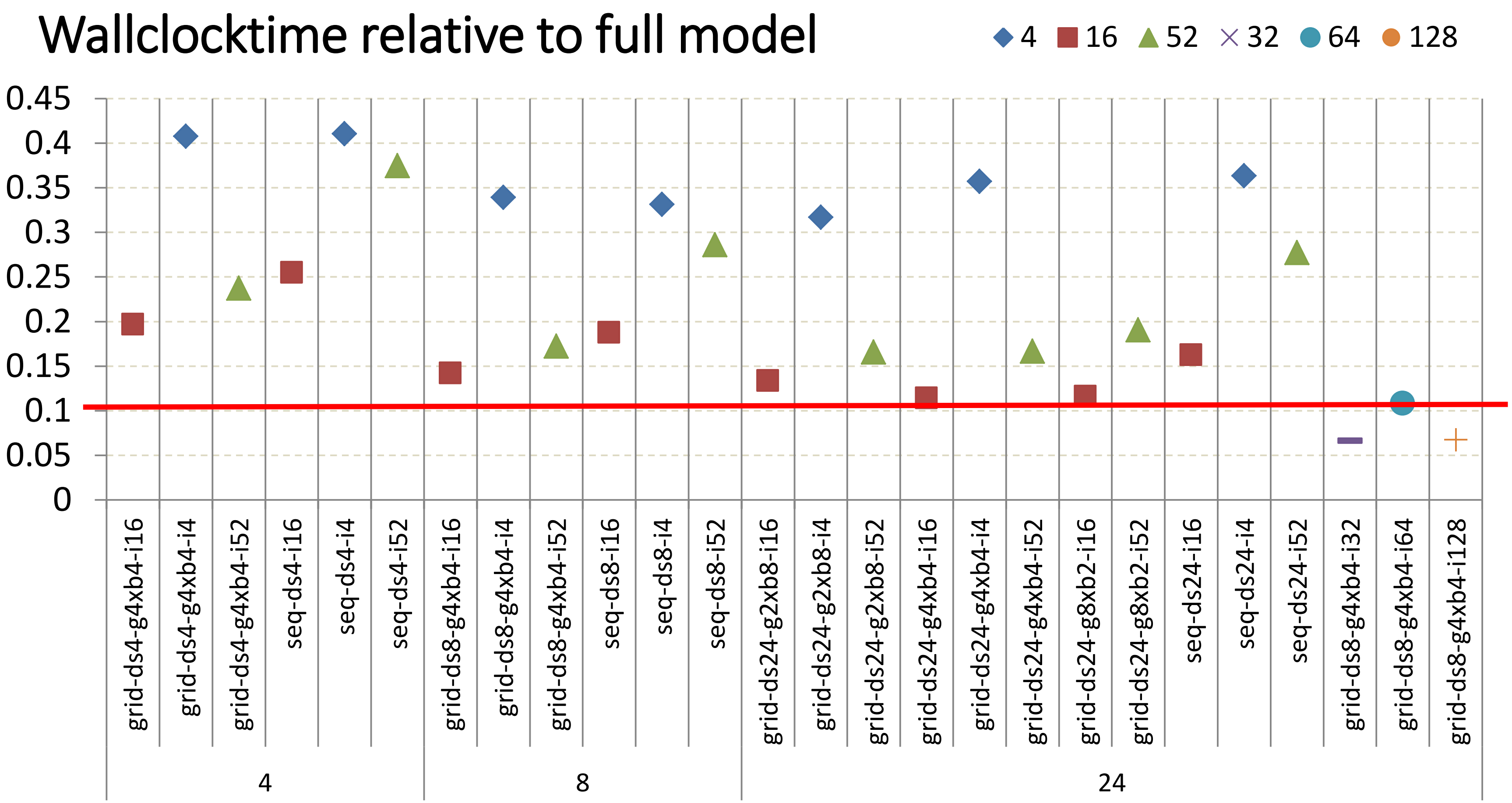
Accuracy



1 b) Speed-up factor: ≈5

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

Temporal zooming



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

Conclusions

Research Question

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

Short answer

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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