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Reducing computing times in optimizing energy system models – challenges and opportunities

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Agenda

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1. Introduction: challenges & motivation
2. Energy system model (ESM) REMix
3. Types of speed up methods for ESM
4. Results (speed up, quality of results)
   a) Best practice GAMS modeling
   b) Spatial clustering
   c) Technological simplifications
   d) Rolling horizon dispatch
5. Conclusion & outlook

Challenges & motivation

Challenges I: complex energy systems

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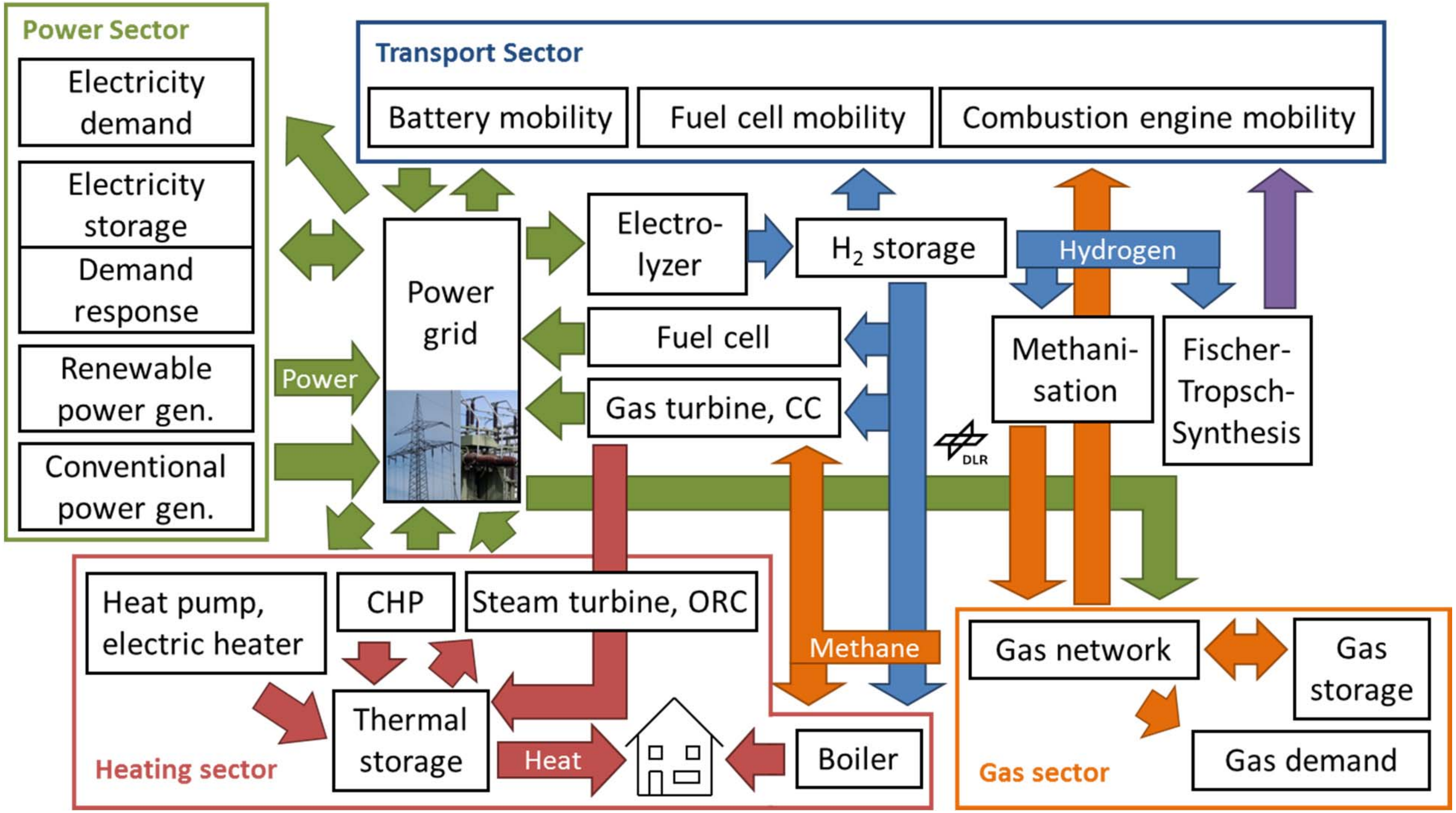
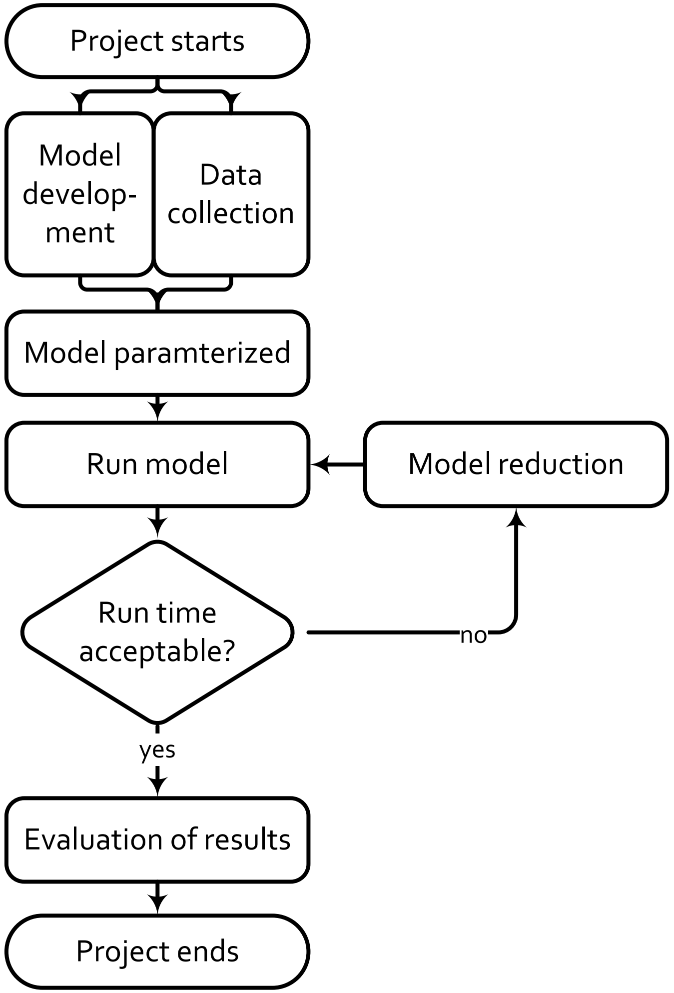
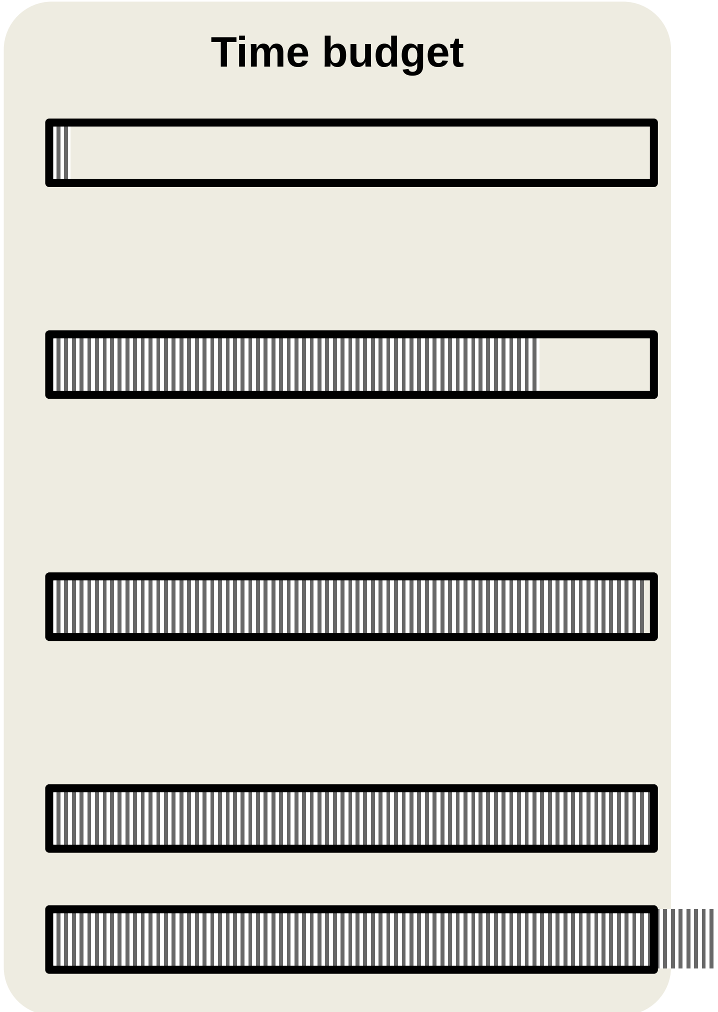


Time steps (8760) x Mile stone years (7) x Regions (28) x Technologies (20) ≈ 35 Mio. variables

Challenges II





Challenges III

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How can we decrease calculation times while retaining a good quality of the results?

How much speed up can we achieve?

What is a good quality?

The energy system model REMix

REMix* energy system model

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Input

Climate and weather data, techno-economic technology parameter, scenario data

REMix Energy System Model

DLR

Energy Data Analysis Tool *REMix-EnDAT*

Calculation of RE technology potentials, as well as hourly profiles of power demand and RE power generation

Energy System Optimisation Model *REMix-OptiMo*

Least-cost composition and hourly operation of the power system, determined by linear optimisation

Minimize $C_{system} = \sum c_j x_j$

Output

Hourly system operation, system costs, CO_2 emissions, construction of new assets

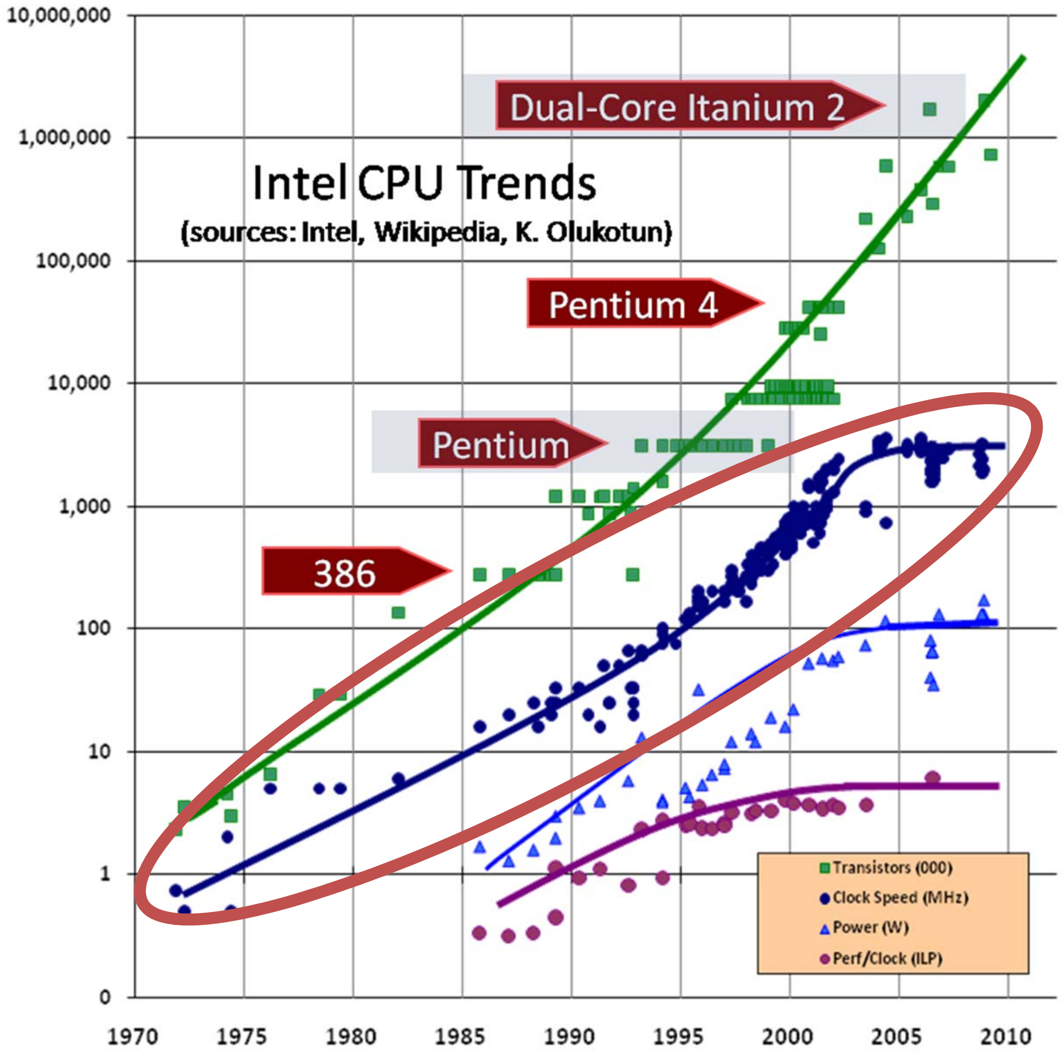
- Deterministic linear optimisation model realised in GAMS
- Assessment of investment and hourly system dispatch during one year

* H. C. Gils et al., “Integrated modelling of variable renewable energy-based power supply in Europe,” *Energy*, vol. 123, pp. 173–188, 2017

Acceleration strategies for linear programs

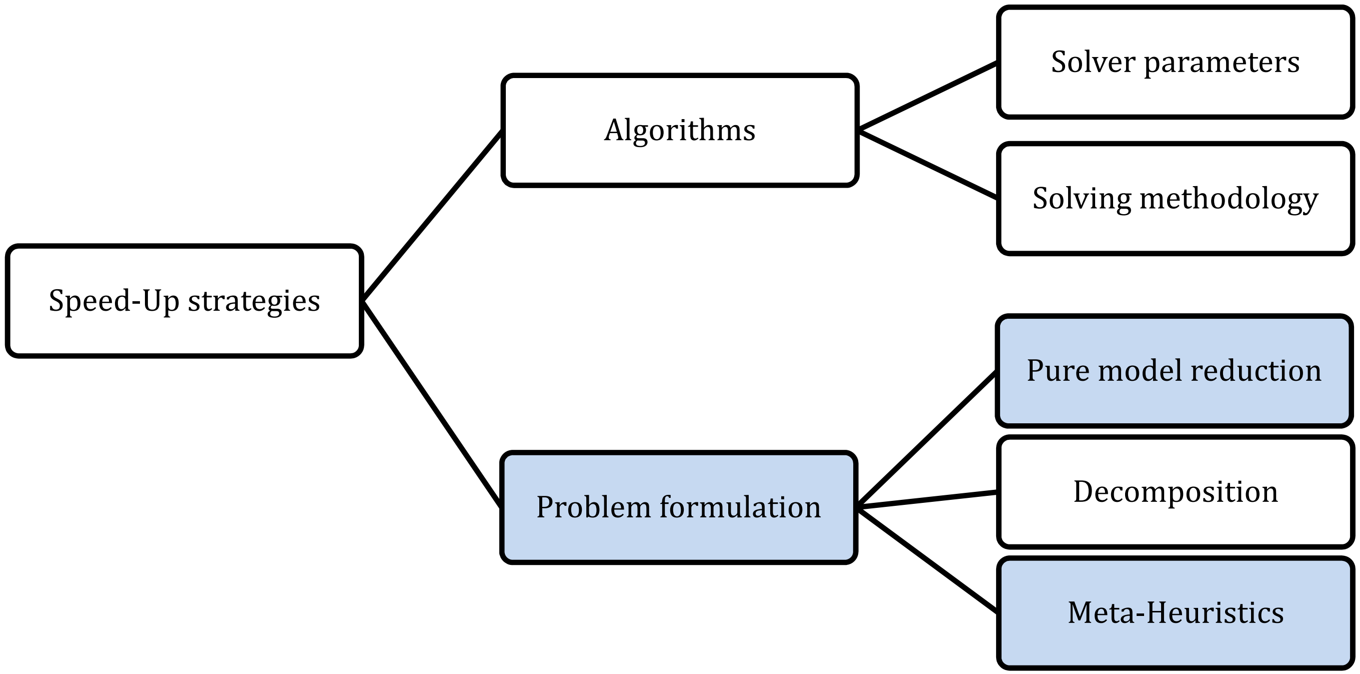
Approach I (the probably most popular one)

„The free lunch is over“

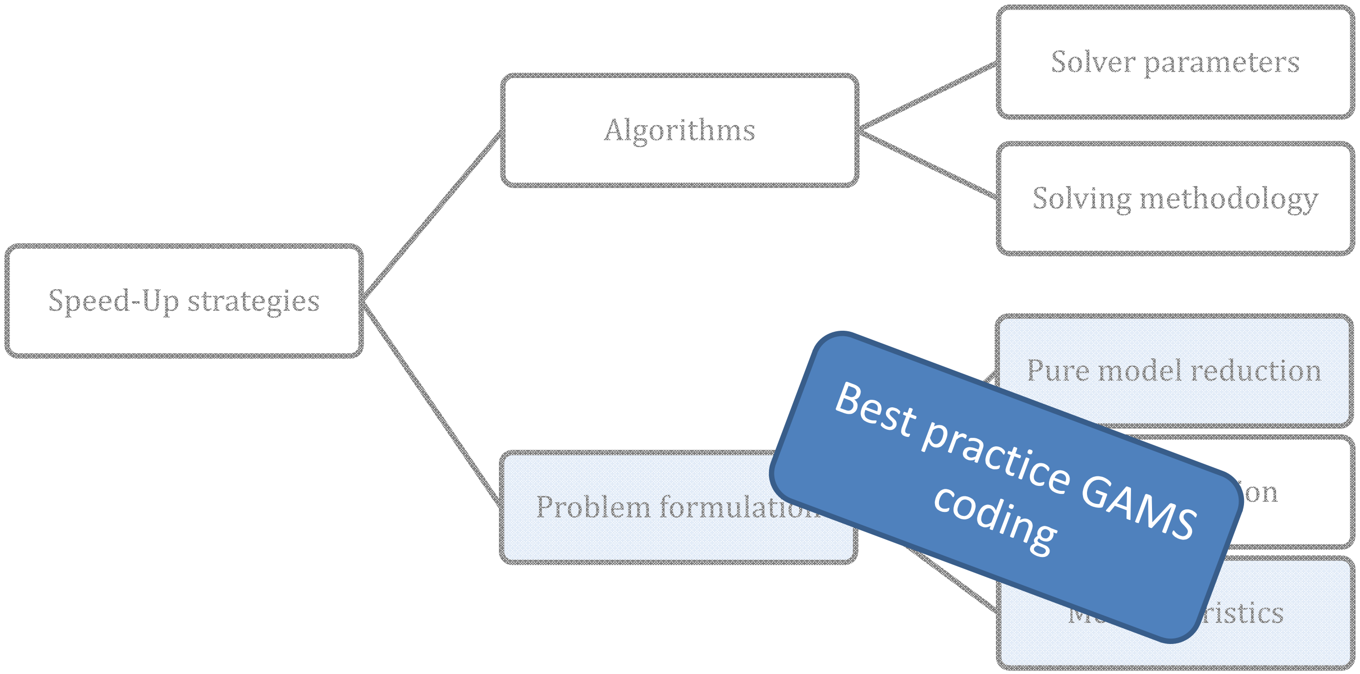


Herb Sutter (2005):
The Free Lunch Is Over. A Fundamental Turn Toward Concurrency in Software, Dr. Dobb's Journal, 30(3), March 2005, http://www.gotw.ca/publications/concurrency-ddj.htm

Approach II: Software related speed-up strategies



„Low Hanging Fruits“

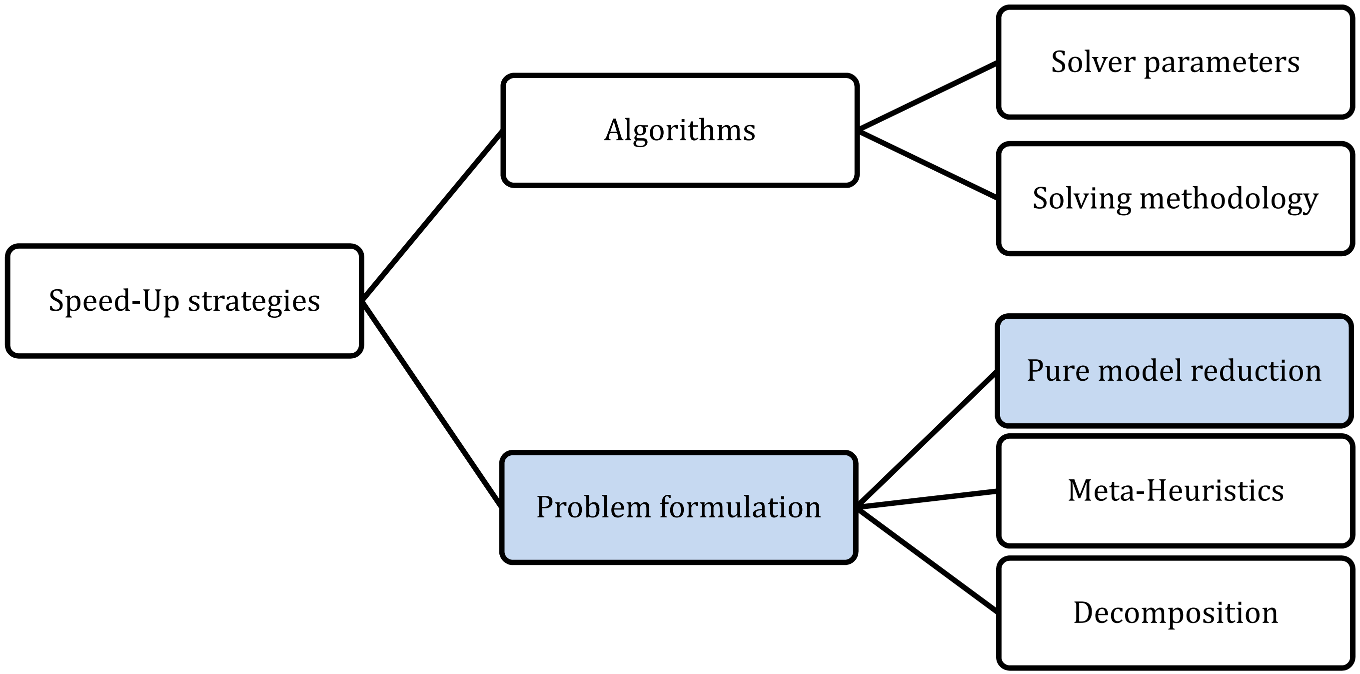


Source code improvement

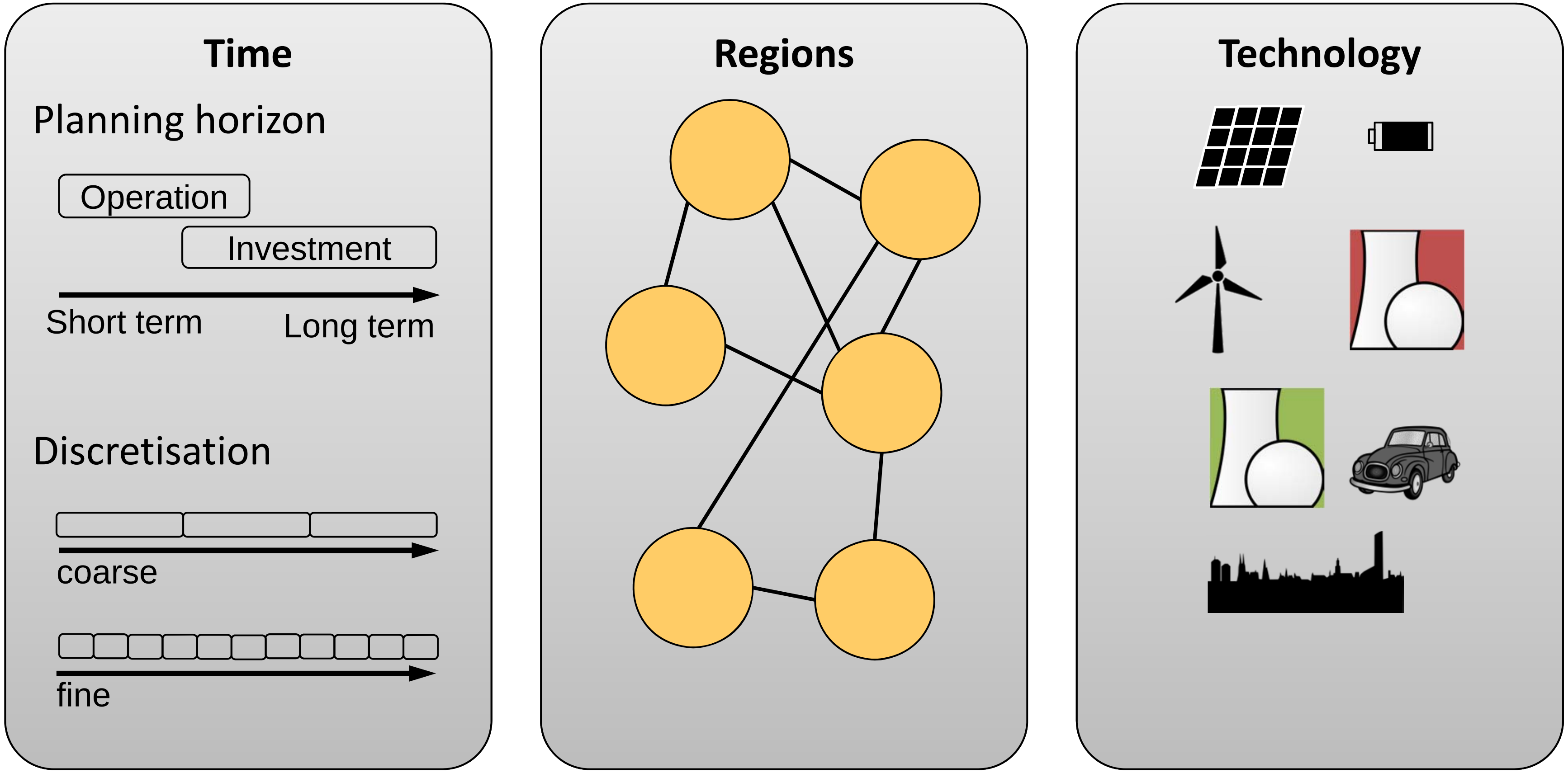
- Selection of measures (also useful for decrease memory need):
  - Input data should not differ much in its order of magnitude
  - Index order influences computing time
    - Useful, but not necessarily faster
    - Assignment statements with a different set order can be faster
    - It can be better 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

Conceptual strategies

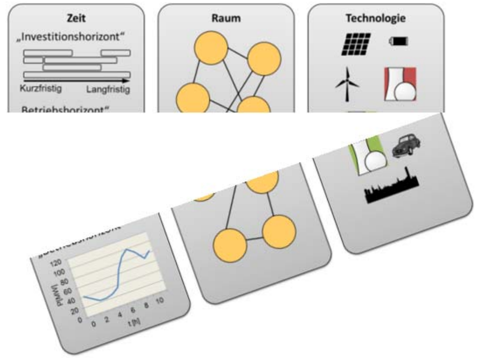


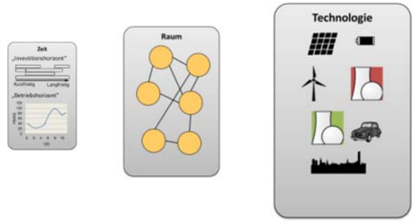
Typical model dimensions



Types of model reductions in ESM

- Pure model reduction
  - Cutting
    - Shortening time horizons
    - Focusing geogr. regions
    - Neglecting technologies
  - Coarsening resolutions
    - Bigger time steps
    - Spatial aggregation
    - Defining technology classes
    - Simplification of technology properties





Pure model reduction

What we know…

- Everybody does it (and hopes it‘s sufficient)
- We often do not know the **error** (and the speed up) caused by throwing away information

Implementation cost	Speed-up capability
	

What we already learnt…

- Changing model resolution is preferable to cutting , but harder to implement

What we estimate…

- Methods aiming at reducing the „biggest dimension“ might be the most effective ones

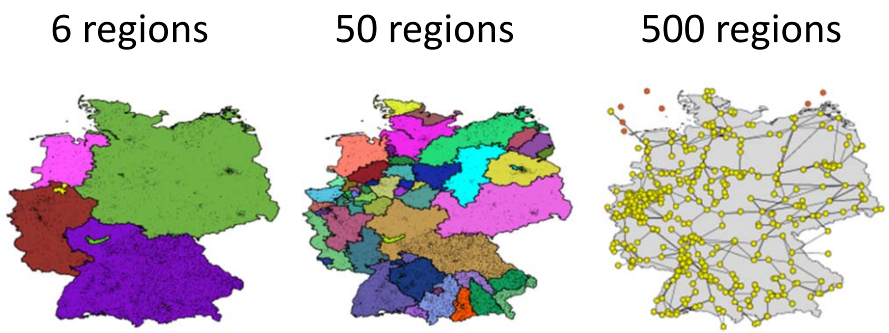
What we want….

- A systematic (and representative) benchmark of the speed-capability
- Error estimation

Spatial aggregation I

Idea and implementation

- Reference model: 500 regions
- Aggregation of regions using spectral clustering
- Criterion: grid bottleneck between regions, i.e. small delta of marginal costs
- Comparison of system costs, power generation, grid utilisation and calculation times



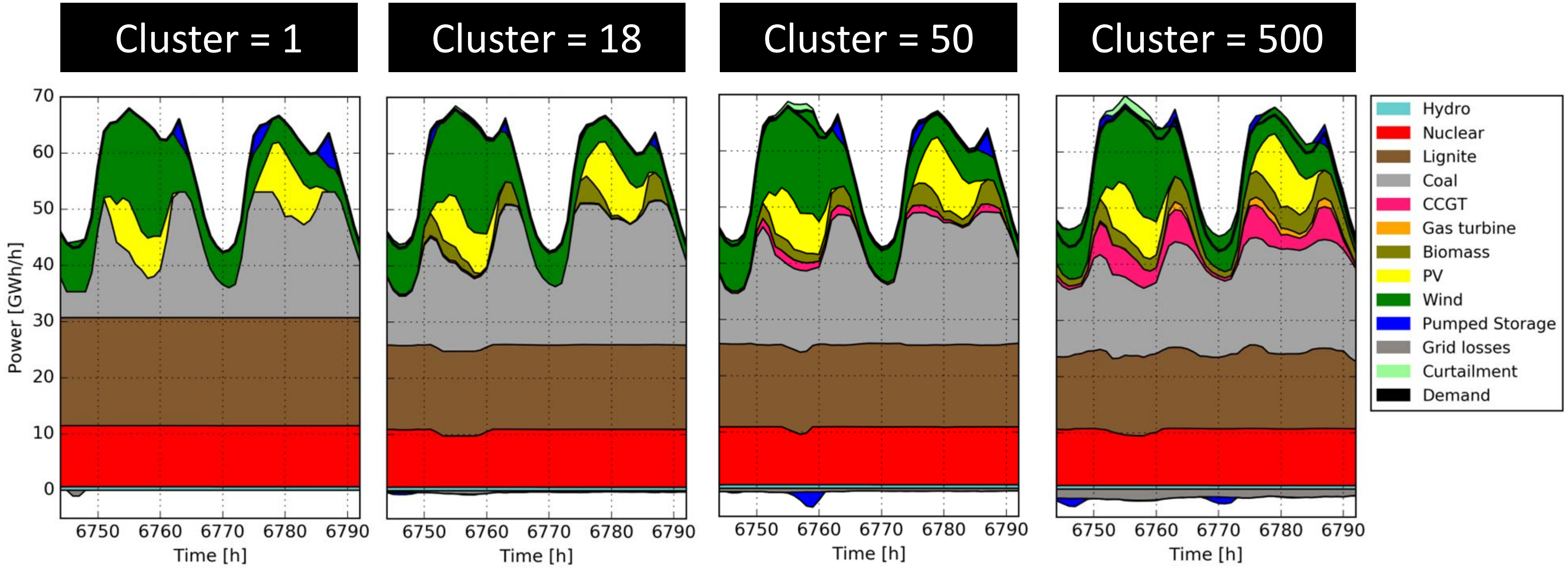
Results

- Hypothesis: computing times increase with approx. **linearly** (further evaluation needed)
- However, significant effects on model accuracy

Number of clusters	1	6	18	30	50	75	100	500
Cplex time [s]	1	4	28	41	150	167	171	3784
System costs [M€]	751	758	839	843	854	869	926	968
Lignite power generation [TWh]	13.12	13.14	10.69	10.44	10.36	10.29	9.23	8.88
Hard coal power generation [TWh]	7.44	7.51	9.85	9.66	9.97	10.11	10.39	9.86

References: Metzdorf, J.: “Development and implementation of a spatial clustering approach using a transmission grid energy system model”, University Stuttgart, 2016

Spatial aggregation II

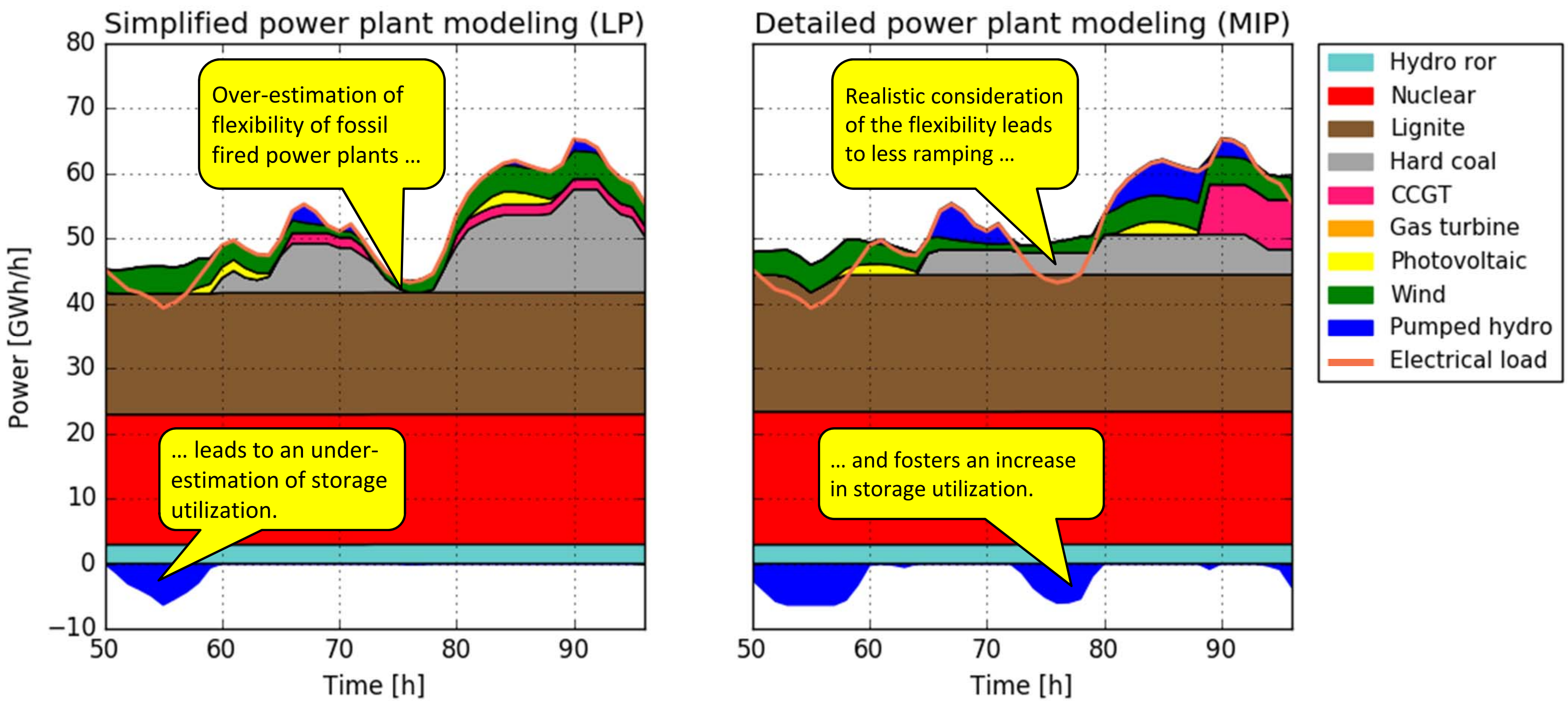


- Cluster = 1 equals large copperplate, no grid congestion, a lot of flexibility to cover the electrical load
  - Total amount of electricity in the copperplate scenario the lowest, since no grid losses of grid lines (i.e. most grid losses in 500 clusters)
- Technology ratios
  - Decreasing utilization of base load power plants (lignite, nuclear), low operational costs (fuel costs)
  - Increasing utilization of peak load plants (CCGT, GT) and storage

Technology simplifications I

Influence of power plant modeling approach*

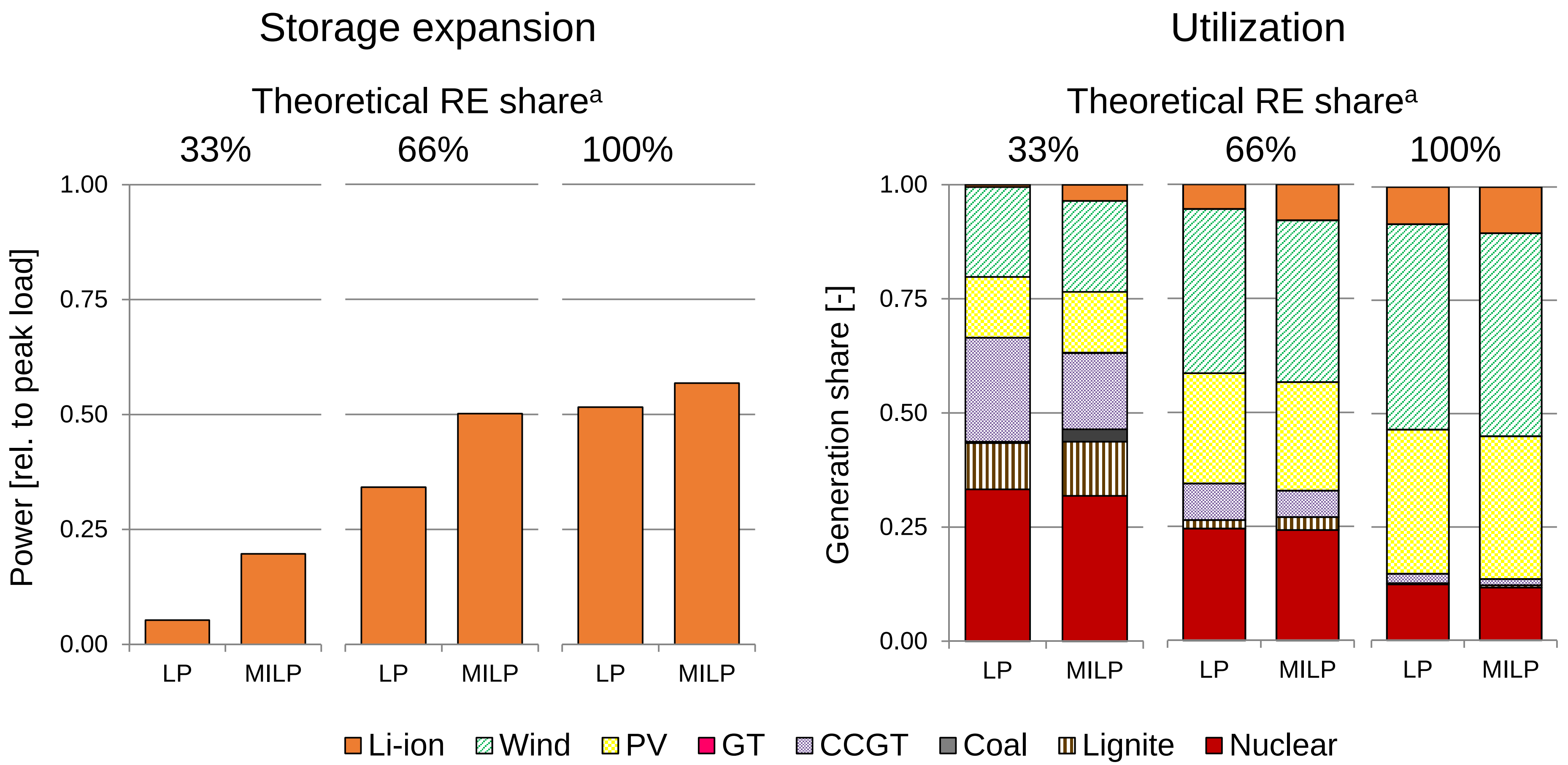
LP versus MIP



* F. Cebulla and T. Fichter, "Merit order or unit-commitment: How does thermal power plant modeling affect storage demand in energy system models?," *Renewable Energy*, vol. 105, pp. 117–132, 2017

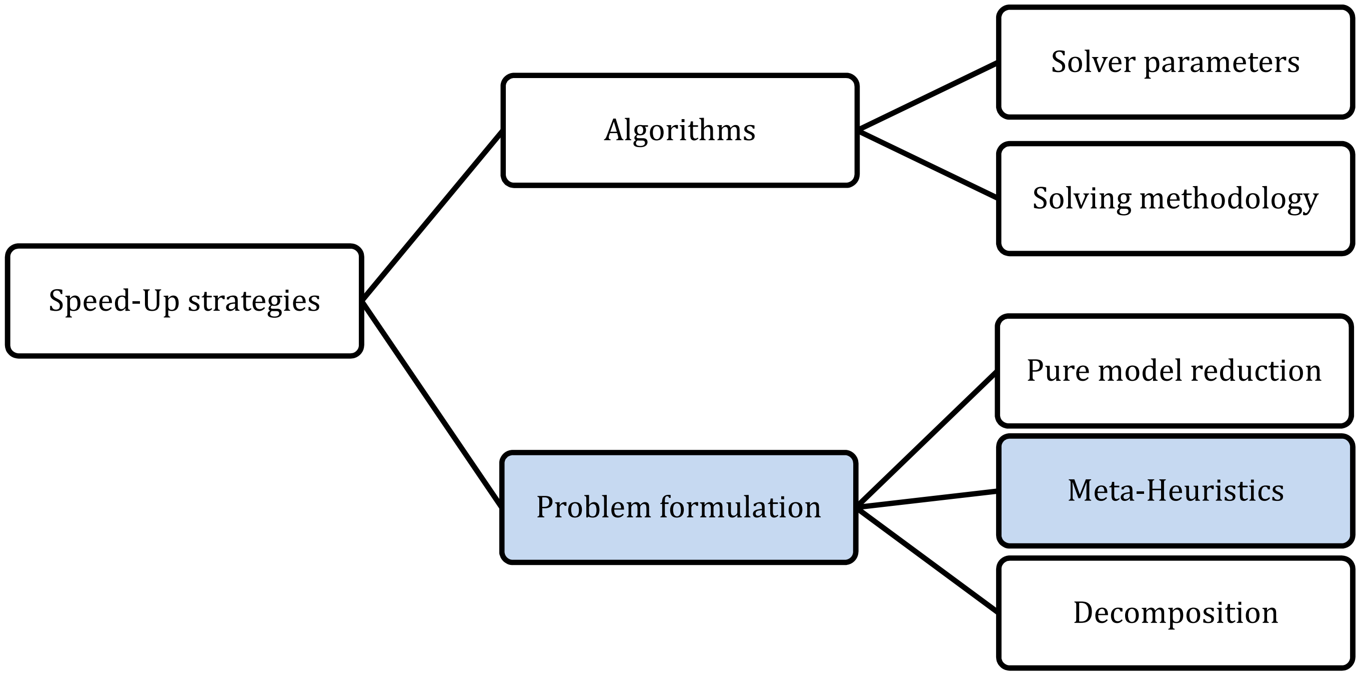
Influence of power plant modeling approach*

LP versus MILP

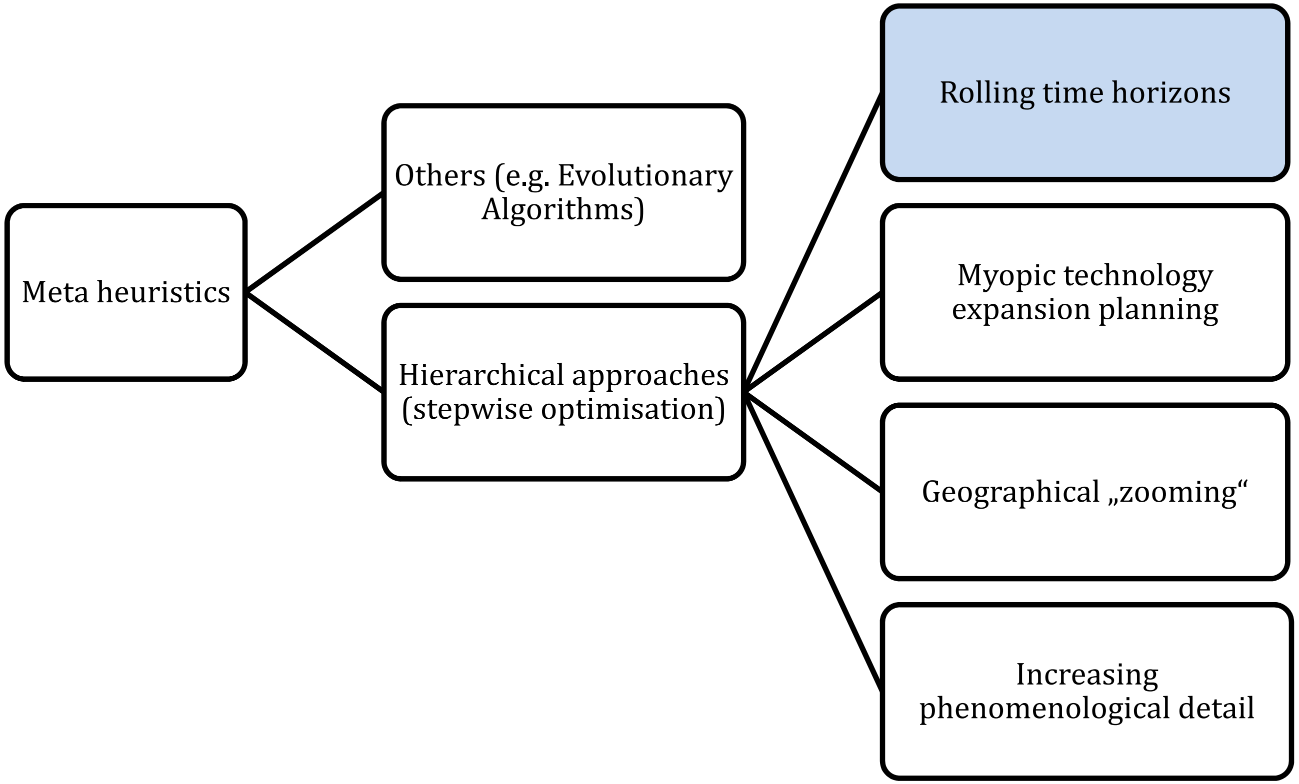


[a] Before curtailments, storage- and transmission losses

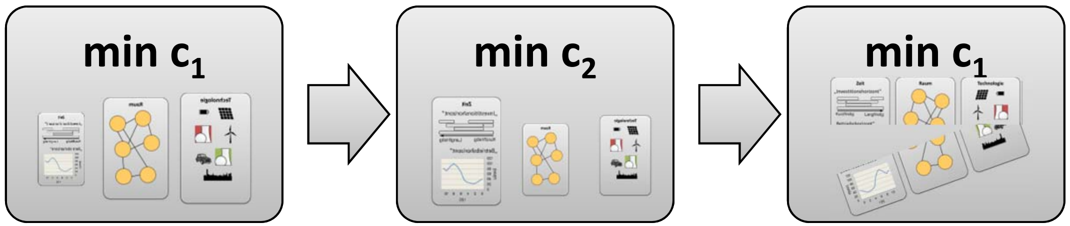
Conceptual strategies



Meta heuristics



Hierarchical approaches



Heuristics: Rolling horizon dispatch

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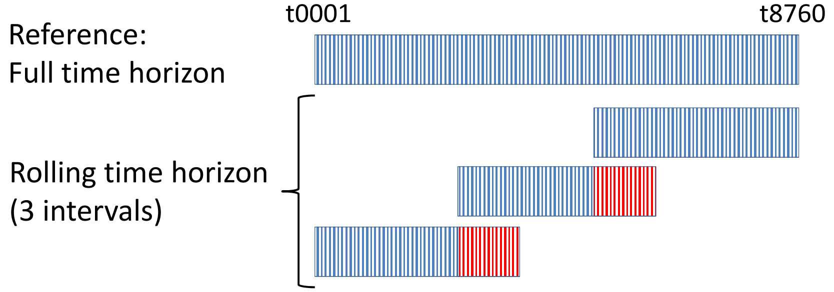
Idea and implementation

- Splitting of the optimisation time horizon into several *intervals*, using different *overlaps*
- Test influence of *intervals* and *overlaps* w.r.t. computing time and solutions accuracy (e.g. deviation in system costs, CO_2 emissions)
- time steps to be fixed after solving an interval

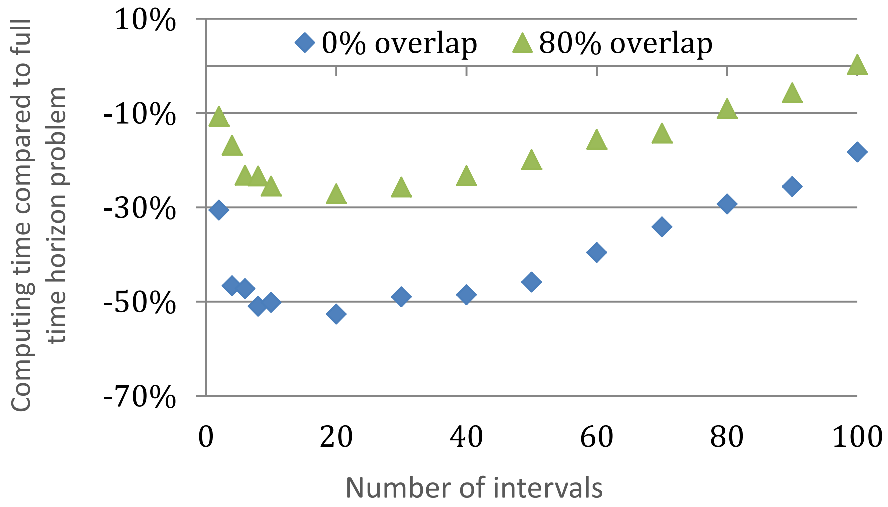


Time steps to be fixed (solved) after solving each partial model

Overlap time steps to avoid full-discharge of storage units

Results (medium-size ESMs)

- Reduction of computing times up to 53%



- Deviation of objective value usually <1%

Overlap-size [%]	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

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

Rolling horizon dispatch

Challenge: Treatment of time integral constraints

- Storage balance: $$\mathbf{P}_{stor,charge}(\tau_{stor}, y, n, t) - \mathbf{P}_{stor,discharge}(\tau_{stor}, y, n, t) - \mathbf{P}_{loss}(\tau_{stor}, y, n, t) = \frac{\left(\mathbf{S}(\tau_{stor}, y, n, t) - \mathbf{S}(\tau_{stor}, y, n, t_{-1})\right)}{t_{slen}}$$
$$\forall \tau_{stor} \in TEC_{stor}, \forall y \in Y, \forall n \in N, \forall t \in T$$

- Resource limit $$\sum_{\tau_{gen},t} \mathbf{P}_{fuel}(\tau_{gen}, y, n, t, f) \leq R(y, n, f)$$
$$\forall \tau_{gen} \in TEC_{apl}, \forall y \in Y, \forall n \in N, \forall f \in F$$

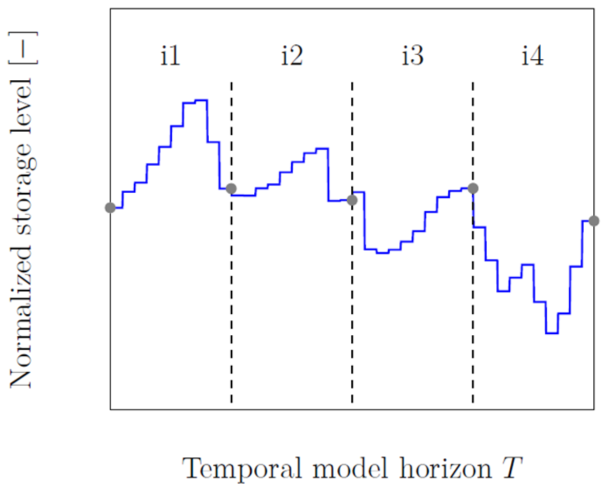
- Emission limit $$\mathbf{G}(\tau_{gen}, y, n, f, e) = 1000 \cdot t_{ilen} \cdot \eta_{fe}(f, e) \cdot \sum_{t} \mathbf{P}_{fuel}(\tau_{gen}, y, n, t, f)$$
$$\forall \tau_{gen} \in TEC_{gen}, \forall y \in Y, \forall n \in N, \forall f \in F, \forall e \in E$$

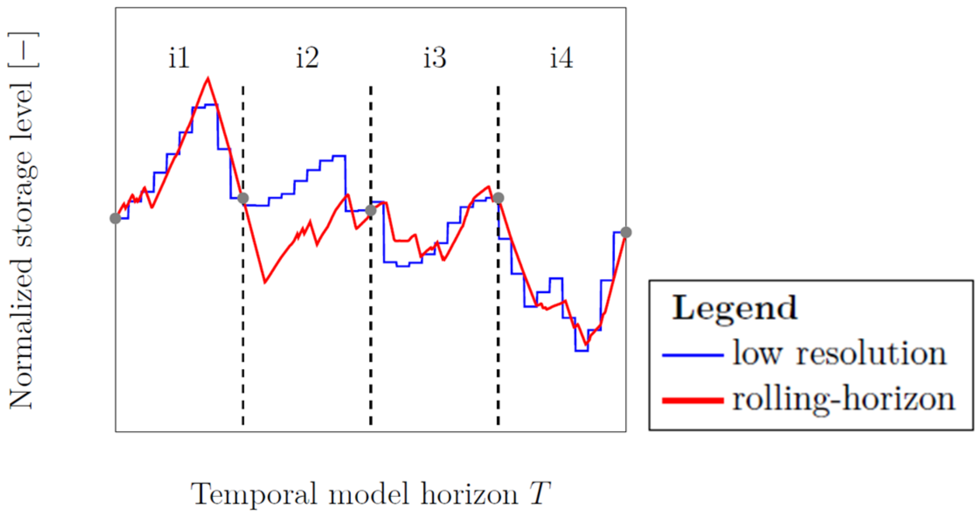
Heuristics

Heuristics to improve modeling of time integral constraints

e.g. saisonal storage, CO_2-caps, biomass potential

Solve with low temp. resolution → Use sampling points for storage level → Rolling-Horizon /w high temp. res.





Meta heuristics

What we know...

- There is a whole bunch of them
- ESM often apply rolling time horizon approaches
- No guarantee for getting the global optimum

What we already learnt...

- Require additional knowledge about the system
- Trade-off between speed and loss of accuracy

Implementation cost	Speed-up capability
👉	👉

What we estimate...

- Meta heuristics will still occur in ESM for other reasons (e.g. better approximation of reality)

What we want....

- Keep them in mind, but we would like to get exact solutions.

Summary and Conclusions

- Waiting for the next generation of processors is no reasonable option
- Best-practice usage of GAMS already helps a lot

  → take "low hanging fruits"
- Detailed evaluation of the impact of model aggregation has high value

  → do systematic benchmark of speed-capability and error estimation
- Evaluation of required technological detail important (e.g. MIP vs. LP in power plant dispatch)

  → What detail is required? How do results change?

Next steps

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- Systematic evaluation of conceptual speed-up strategies
  - Quantification of advantages
  - Evaluation of scaling behaviour
- Implementation of different decomposition techniques in REMix
  - Performance tests
  - Comparison with other ESM using LP
- Further evaluation of the requirements of using HPC
- Preparation of REMix for the application of HPC

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