Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

BEAM-ME

Getting linear energy system models ready for High Performance Computing

Manuel Wetzel[1], Karl-Kien Cao[1], Frederik Fiand[2], Hans Christian Gils[1]

OR2017 Berlin, 07.09.2017

[1]German Aerospace Center (DLR)

[2]GAMS Software GmbH

A PROJECT BY

GAMS

berlin

HLRS

JÜLICH FORSCHUNGSZENTRUM

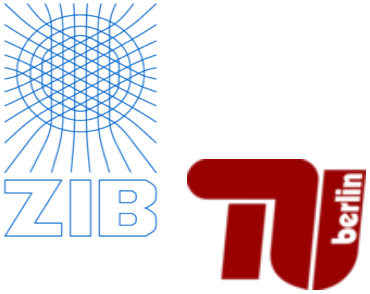
DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

ZIB

Interdisciplinary Project Partners

BEAM-ME

- German Aerospace Center (DLR),
  Department for System Analysis and Technology Assessment



- Zuse Institute Berlin (ZIB),
  Department for Mathematical Optimization and Scientific Information
- Technical University Berlin,
  Institute for Mathematics

- GAMS Software GmbH

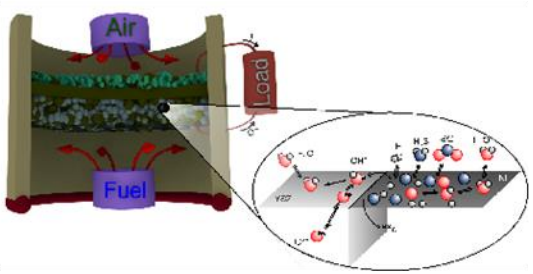
- Forschungszentrum Juelich (FZJ),
  Juelich Supercomputing Centre (JSC)
- High Performance Computing Center Stuttgart (HLRS)

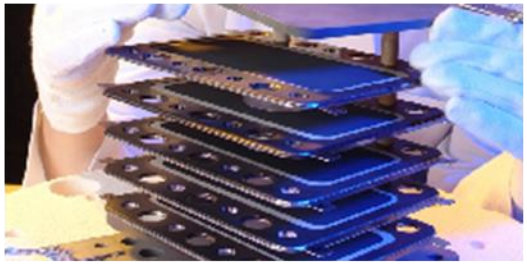
It is not all about rocket science in DLR…

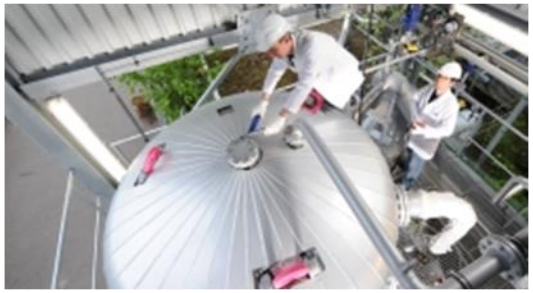
BEAM-ME

DLR

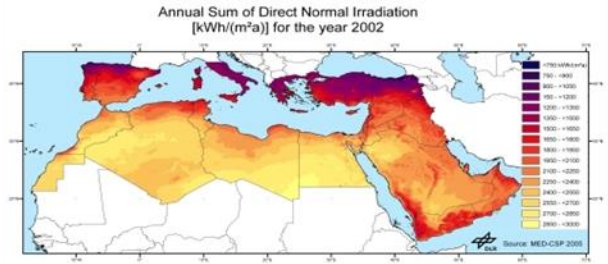
Institute of Engineering Thermodynamics

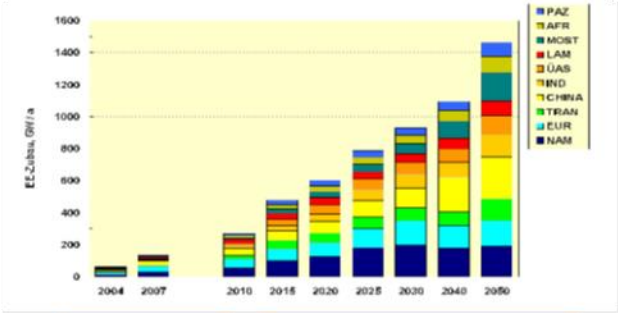


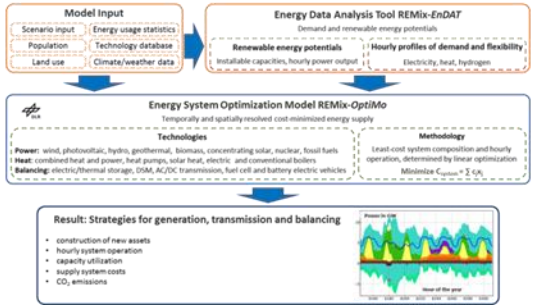




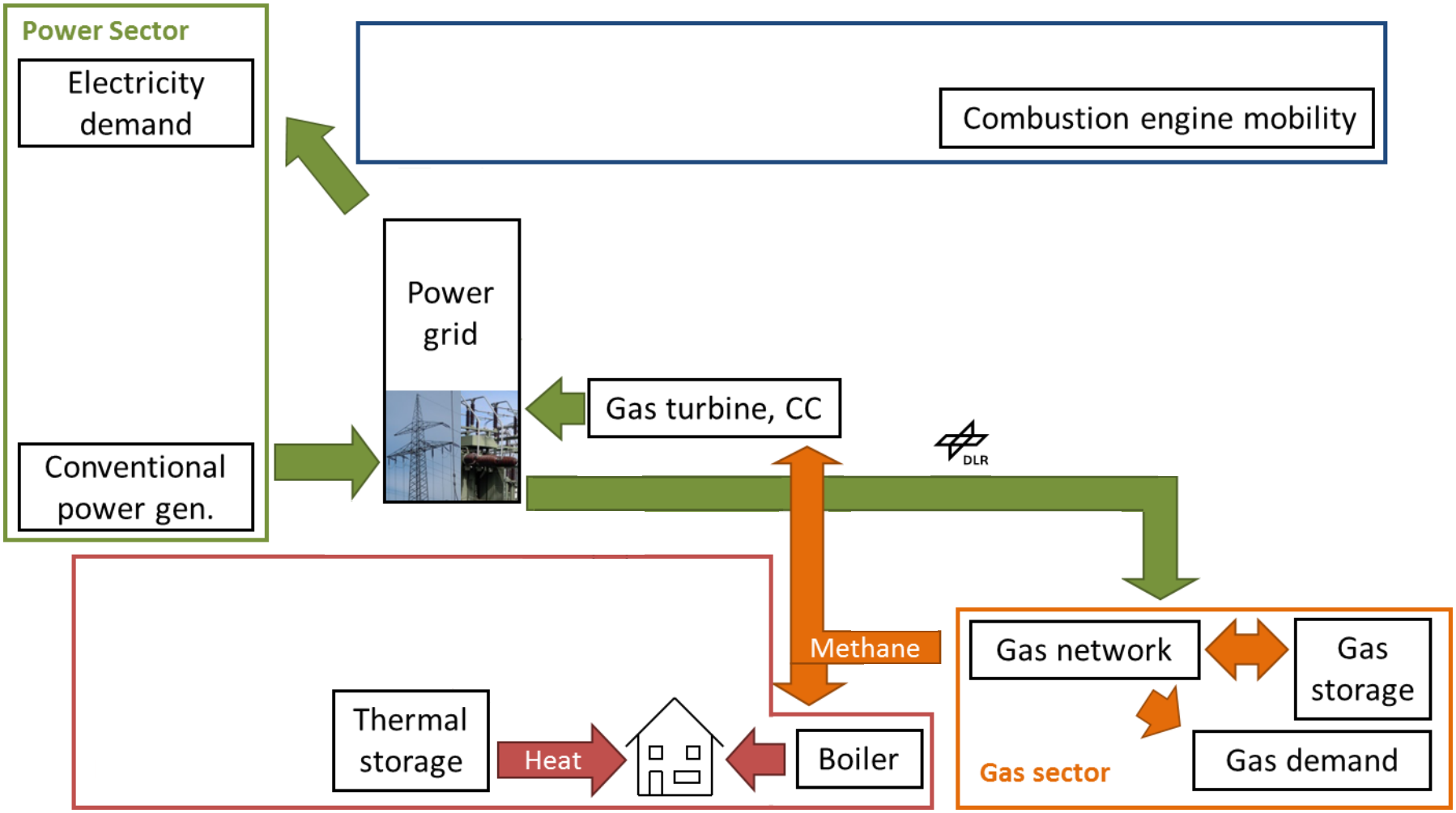
Systems Analysis and Technology Assessment





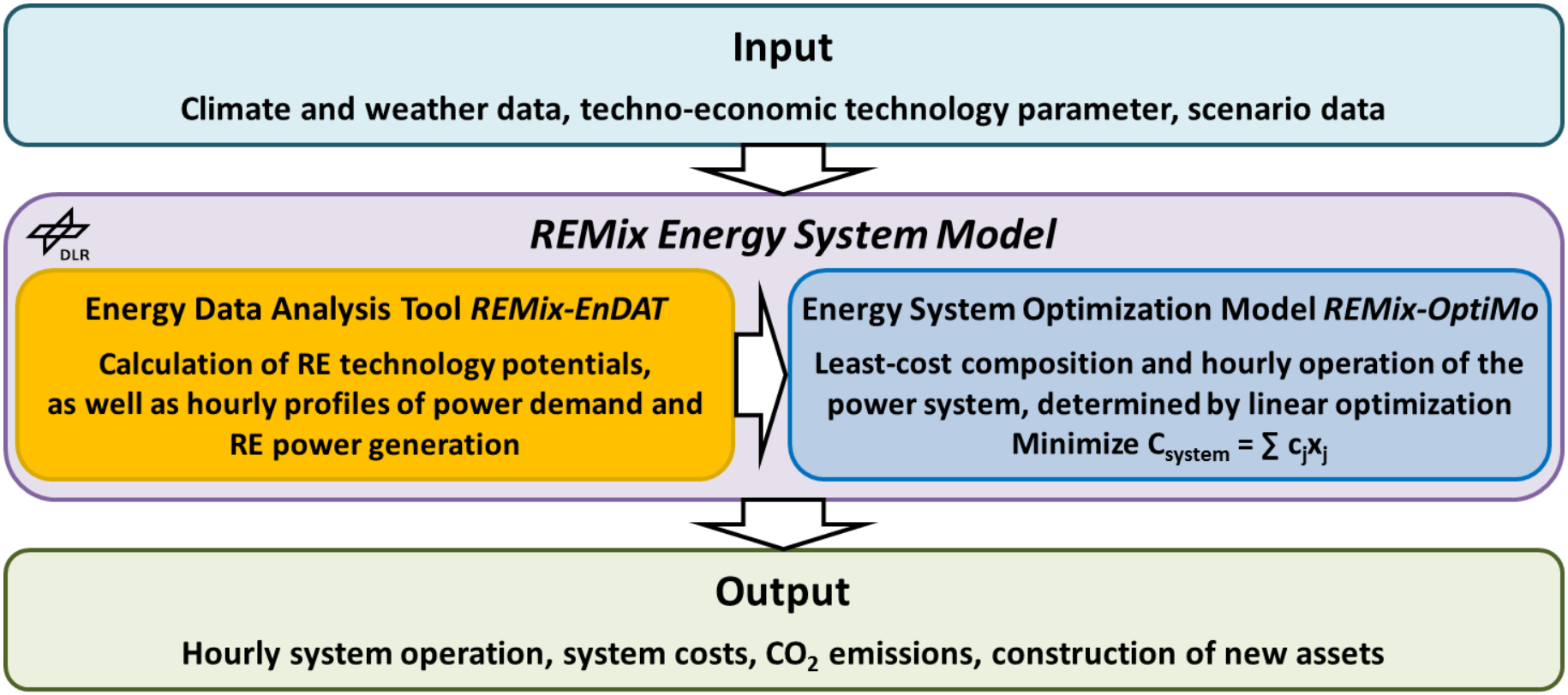


Energy Sector Integration



Ongoing transformation **drastically increases complexity** of the energy system

DLR Energy System Model REMix



Idea and scope of BEAM-ME

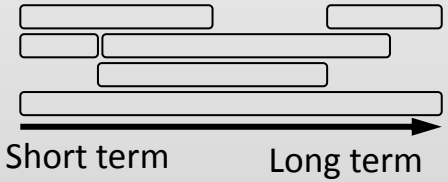
Reduction of solution times urgently needed to enable the reflection of energy system complexity in state-of-the-art models

- Evaluation of different approaches to reduce model solution times
  - Increased modelling efficiency
  - Higher computing power
- Implementation of selected approaches into REMix
- Assessment of the transferability to other models
- Definition of best-practice strategies

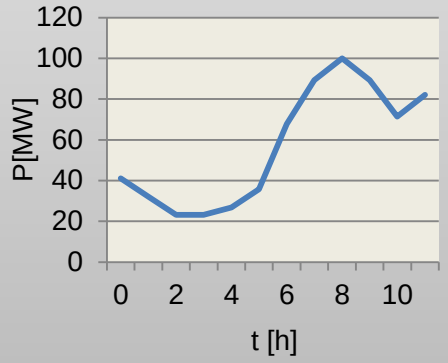
Typical energy system model dimensions

Time

Investment horizon

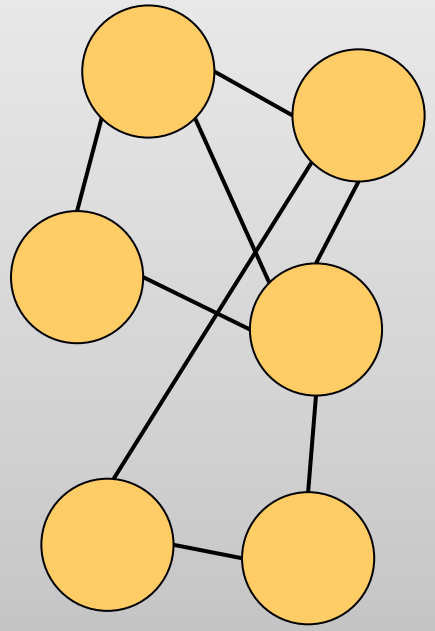


Operation horizon



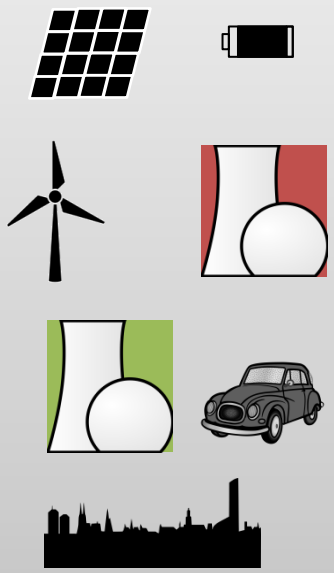
8760 time steps

Space



60 regions

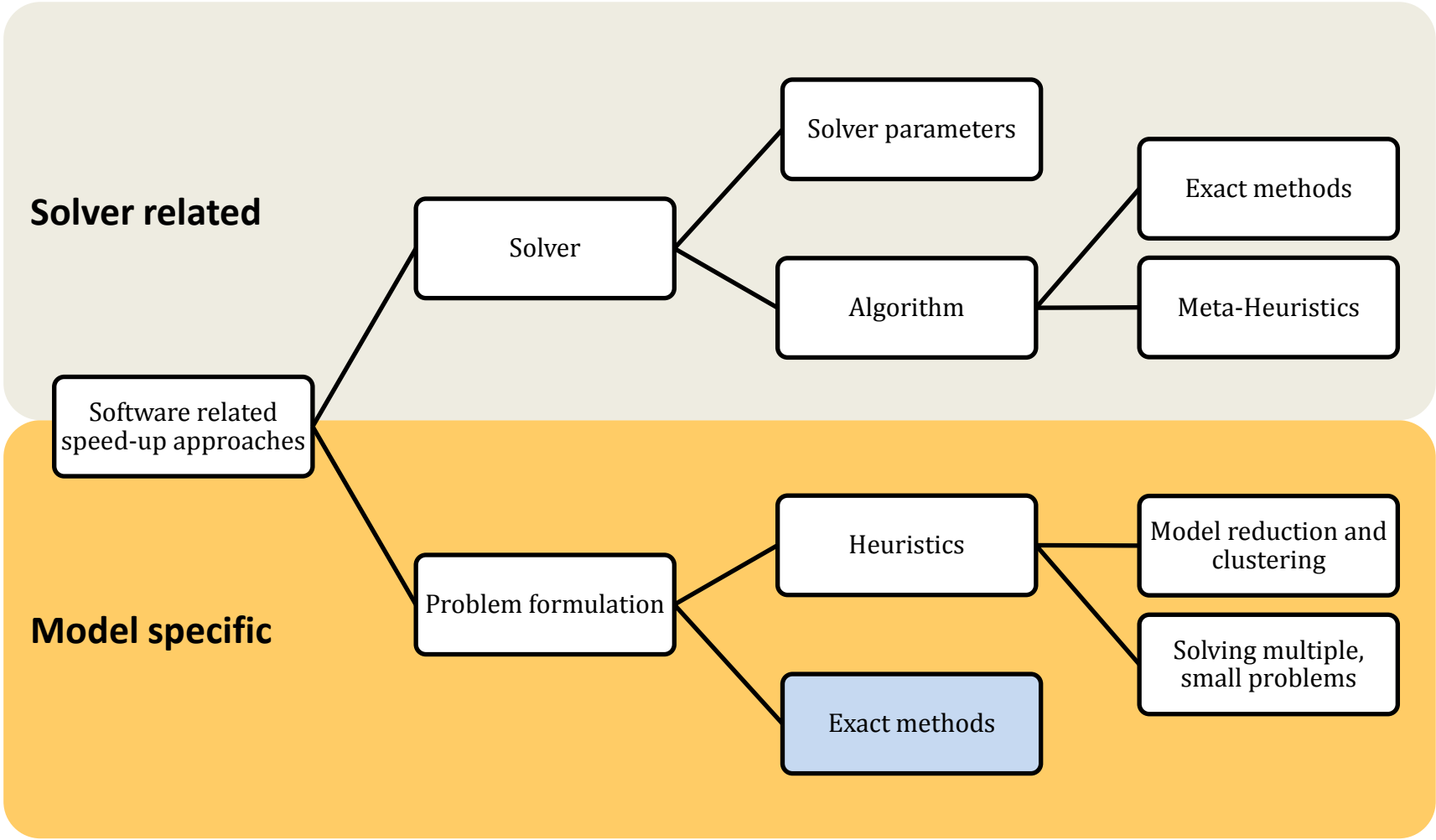
Technology



20+ technologies

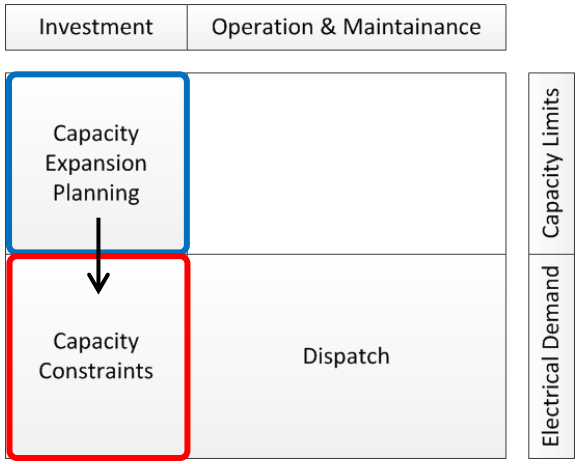
Interlinking between dimensions leads to decomposition options

Categorization of speed-up approaches

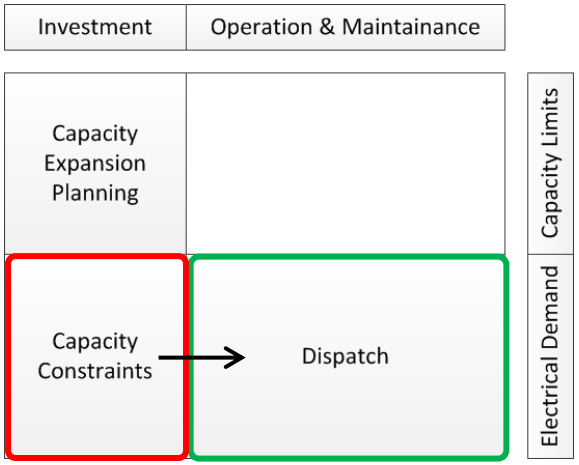


Benders Decomposition

Optimization of power plant capacities
based on expected future costs



Optimization of power plant dispatch
based on given power plant capacities



$$\min c \cdot x \quad A \cdot x \leq b \qquad + \qquad \theta$$

Future costs of subproblems

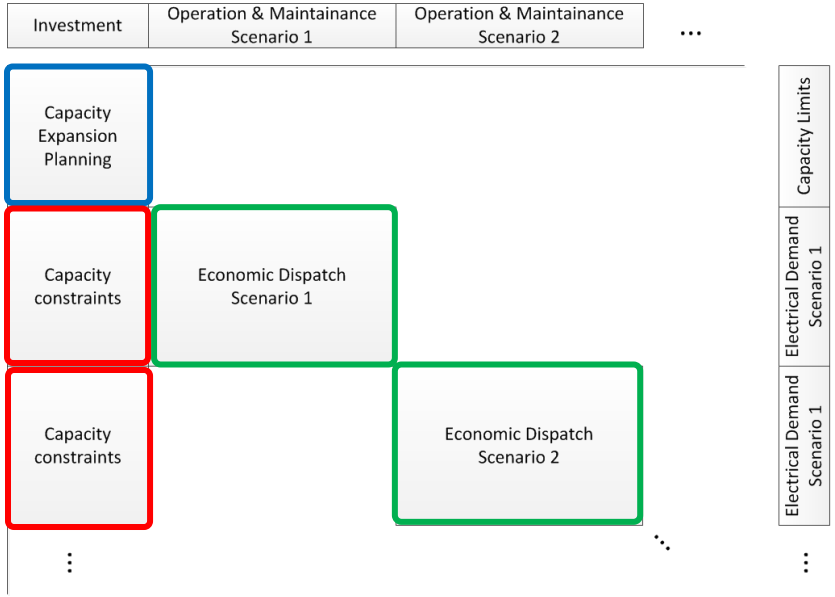
$$\min c \cdot x \quad A \cdot x \leq b$$

Actual costs of subproblems

Information about actual costs of the subproblems
improves new estimation of future costs (optimality cuts)

Stochastic Optimization

Stochastical Optimization leads to large LP structures (**deterministic equivalent**)

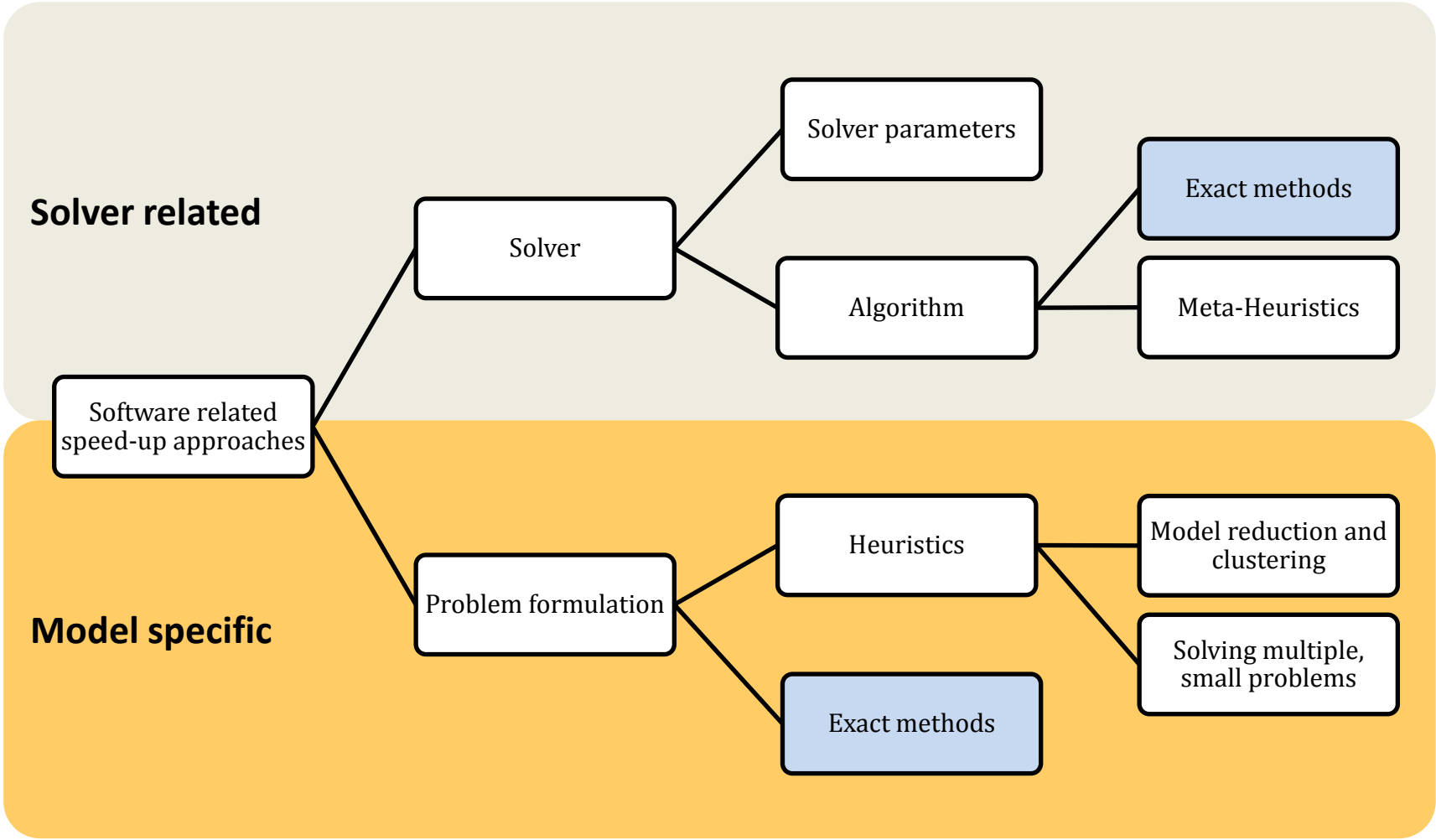


$$
\begin{aligned}
&\min \quad c^T x \\
&\text{s.t.} \quad T_0 x_0 \\
&\qquad T_1 x_0 + W_1 x_1 \\
&\qquad T_2 x_0 + \qquad W_2 x_2 \\
&\qquad \vdots \qquad\qquad\qquad \ddots \\
&\qquad T_N x_0 + \qquad\qquad\qquad W_N x_N
\end{aligned}
$$

- Capacity expansion decisions influence the stochastic dispatch scenarios
  → Linking variables connecting the investment and dispatch decisions

- Different dispatch scenarios are not linked to each other only via the master problem
  → No linking constraints

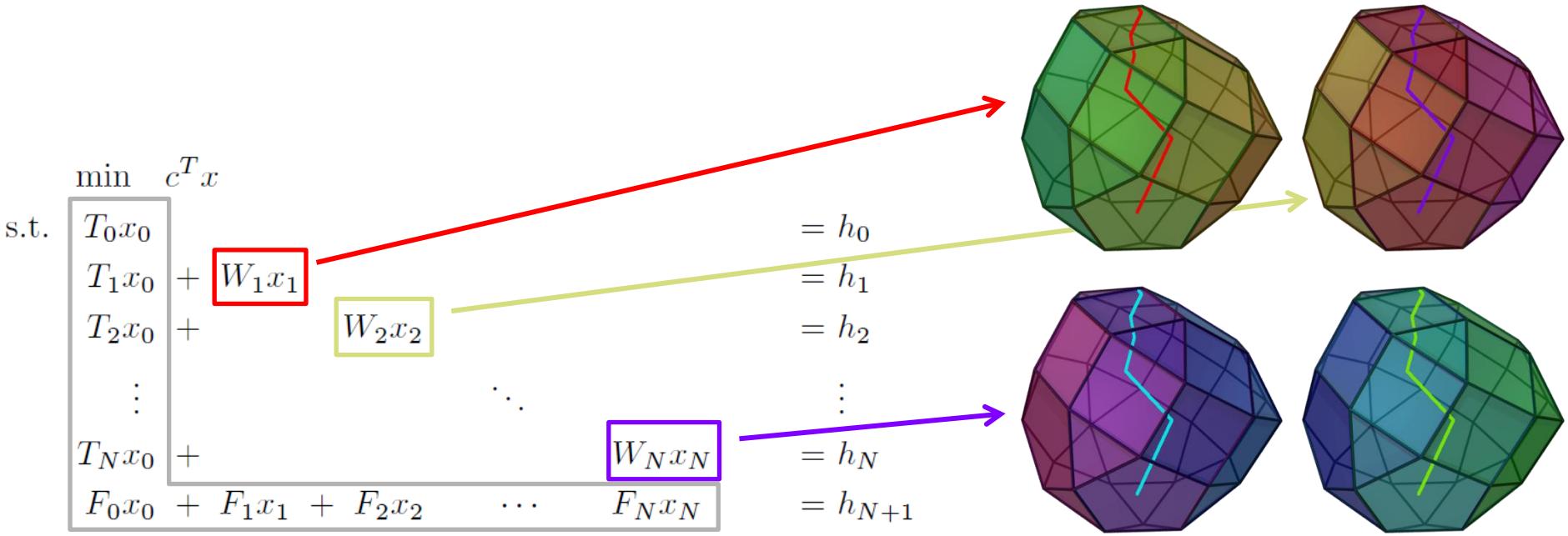
Categorization of speed-up approaches



Introducing PIPS-IPM

Parallel Interior Point Solver – Interior Point Method (PIPS-IPM)

- Petra et al. 2014: *"Real-Time Stochastic Optimization of Complex Energy Systems on High-Performance Computers"*
- Wind feed-in planning in electrical power systems under uncertainty



➡ **TB-02-4:** D. Rehfeldt *„Optimizing large-scale linear energy problems with block diagonal structure by using parallel interior-point methods"*

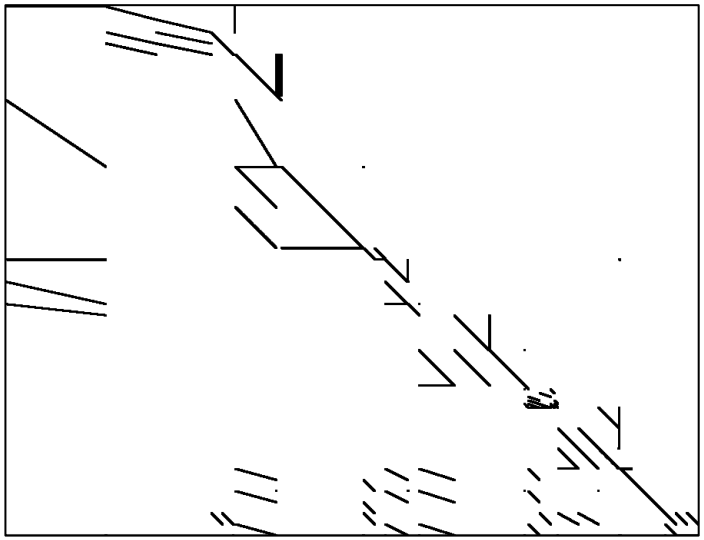
Development in the BEAM-ME Project

- Annotation of REMix model to communicate block structure
  - Application of the *stage* functionality to **assign variables and constraints to blocks** (DLR/GAMS)

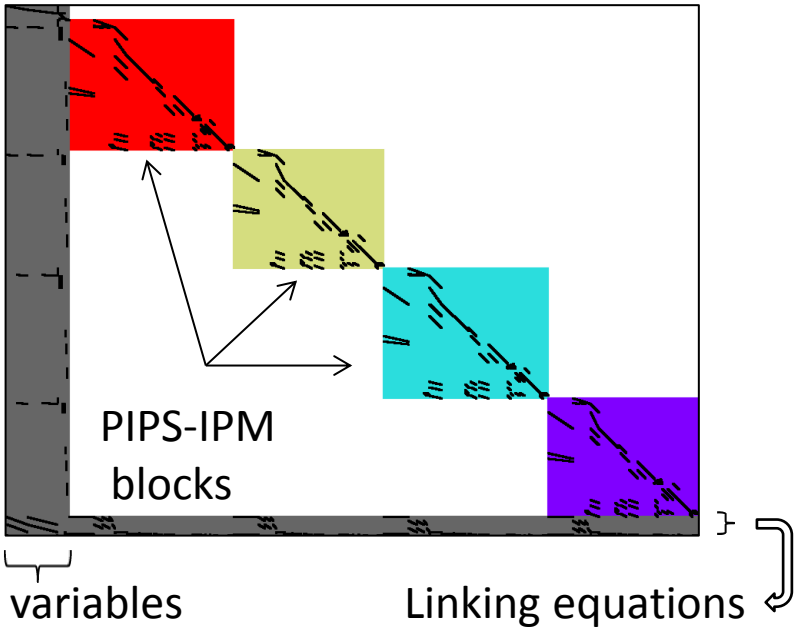
- Enhancement of PIPS-IPM
  - Extension to handle LPs with both **linking variables and constraints** (ZIB/TU Berlin)
  - Development of a link between **GAMS and PIPS-IPM** (GAMS)
  - Consideration of **requirements of high performance computers** (ZIB/GAMS/HLRS/JSC)

GAMS Annotation for PIPS-IPM

Matrix of **non-zero entries** of REMix LP



Permuted matrix revealing **block structure**

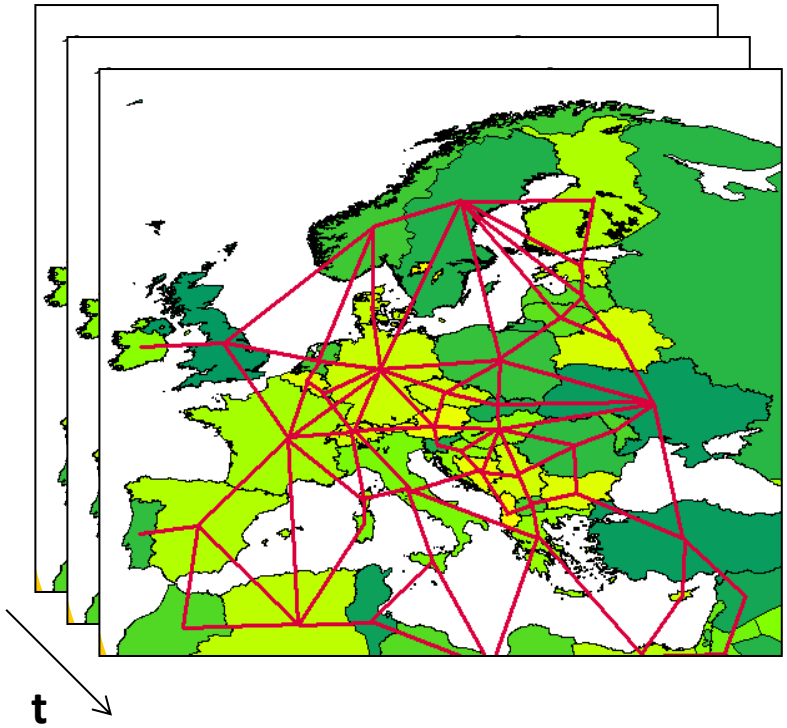


Annotation can be implemented directly in GAMS
Modellers provide knowledge about problem and decompositions

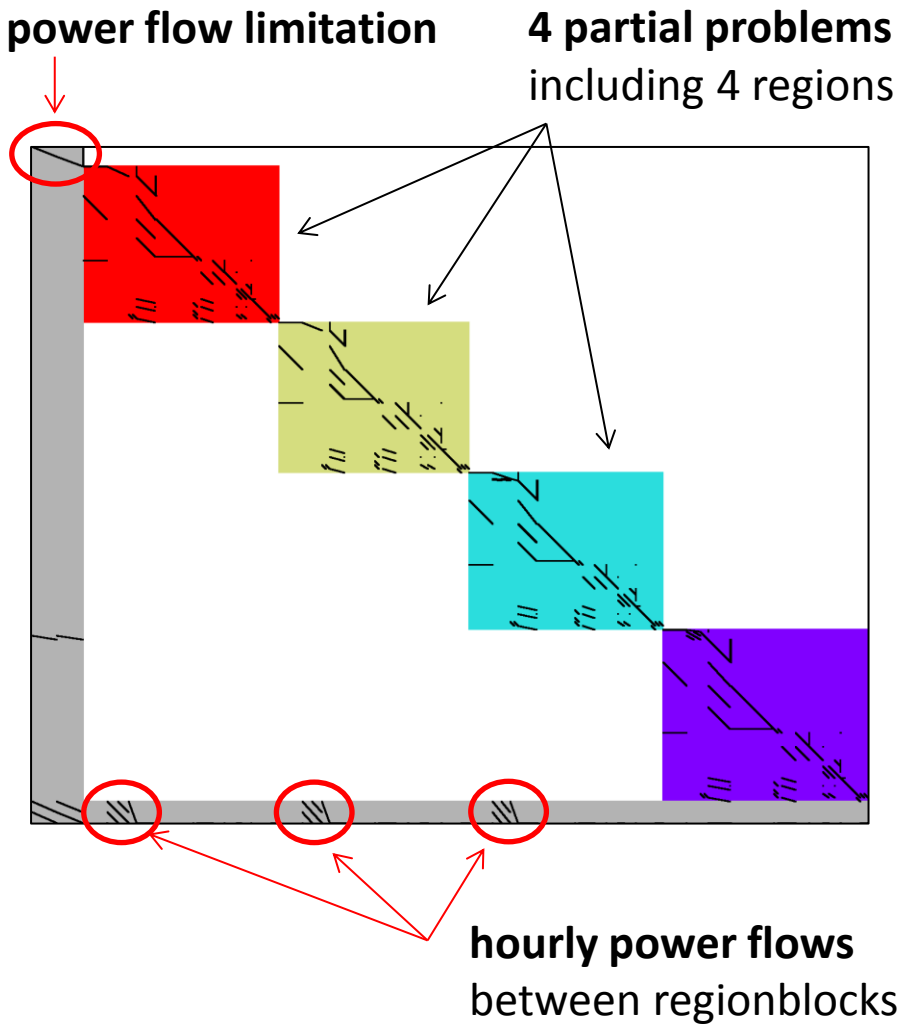
➡ **TB-02-3:** F. Fiand *„High Performance Computing with GAMS “*

Decomposition by region I

Linking by region: electricity transports, fuel transports, global constraints (CO_2)

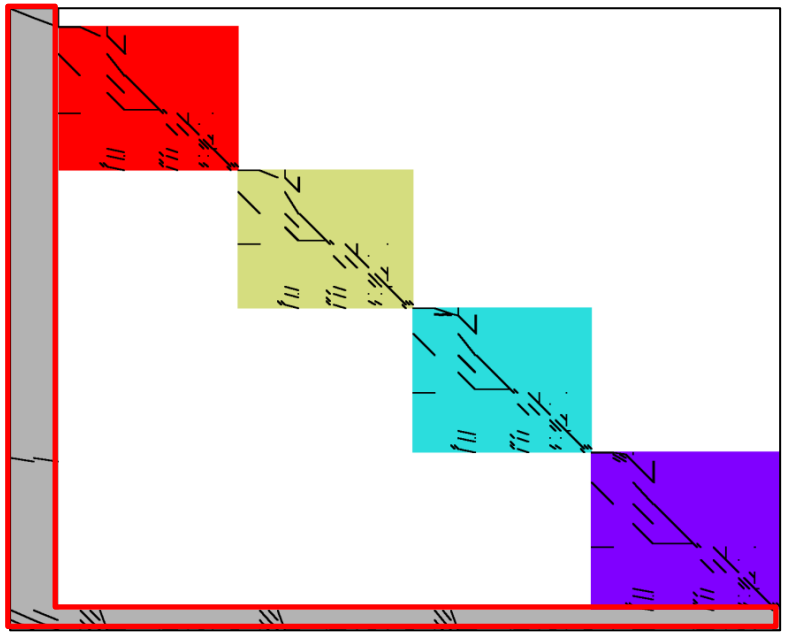


Temporal dimension of transport decisions leads to the largest number of linking variables

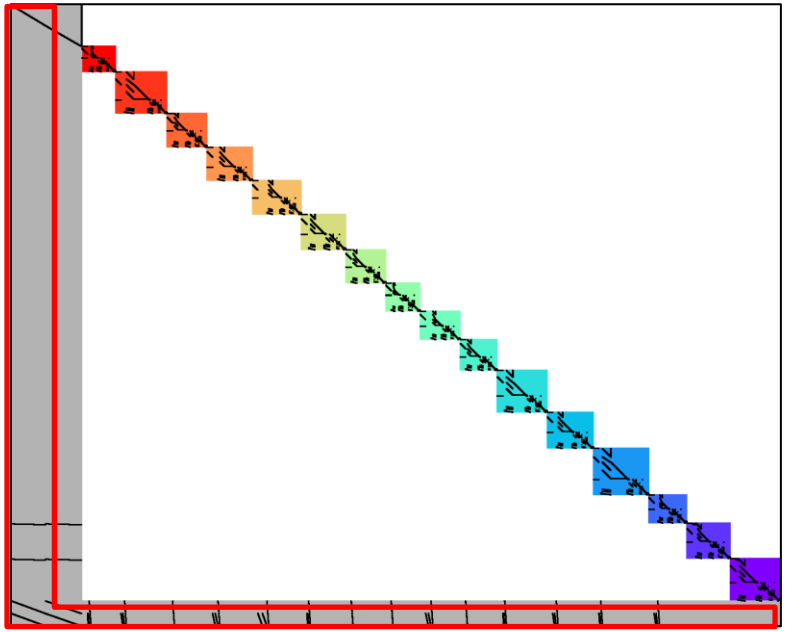


Decomposition by region II

4 partial problems
including 4 regions



16 partial problems
including 1 region

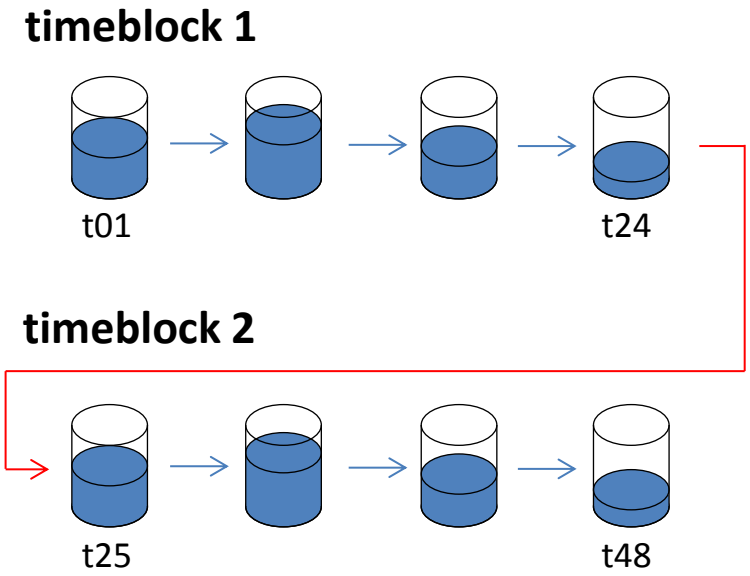


low increase in linking variables and constraints
due to **sparsely connected regions**

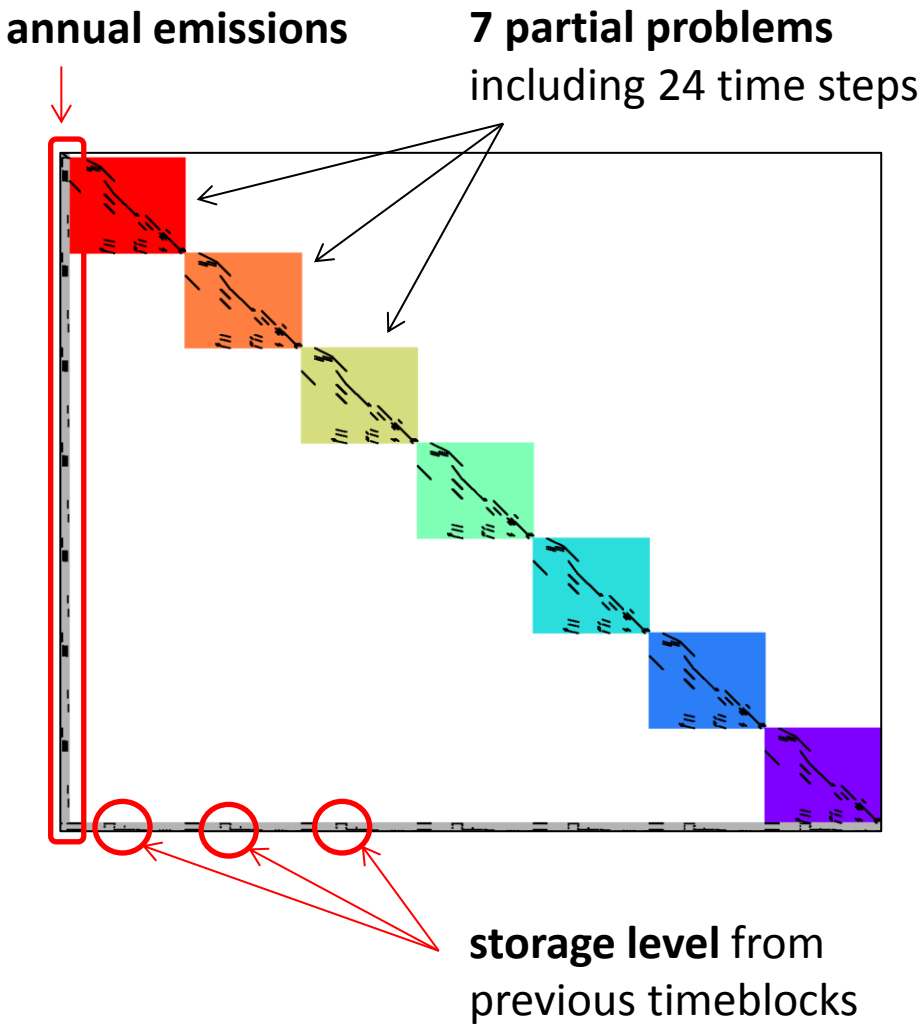
Target: Find **maximum number** of regionblocks of **similar size** which are **sparely linked** to other regionblocks

Decomposition by time I

Linking by time: storages, demand side management, annual constraints

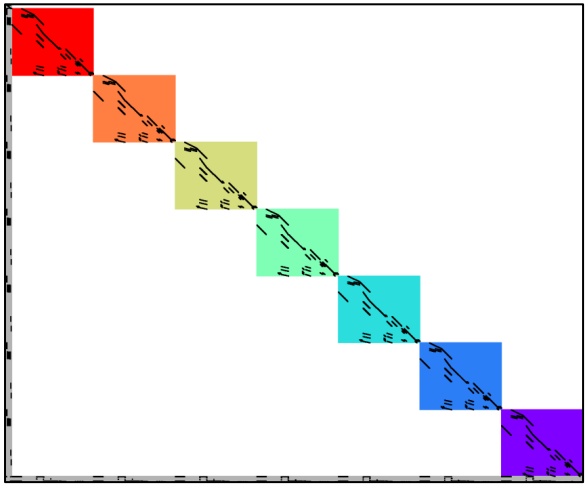


Linking of storage levels to their previous time step leads to linking constraints between timeblocks



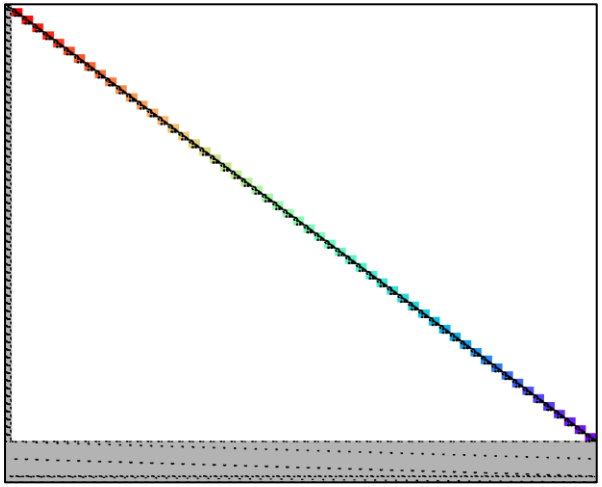
Decomposition by time II

7 partial problems
including 24 time steps



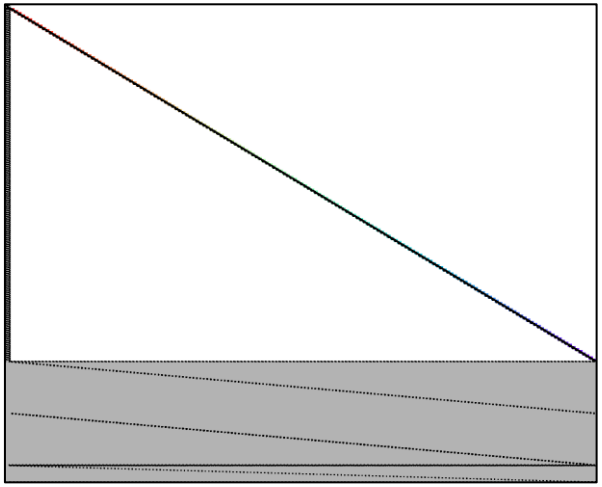
1 out of 24 storage constraints linking

56 partial problems
including 3 time steps



3 out of 8 storage constraints linking

168 partial problems
including 1 time step



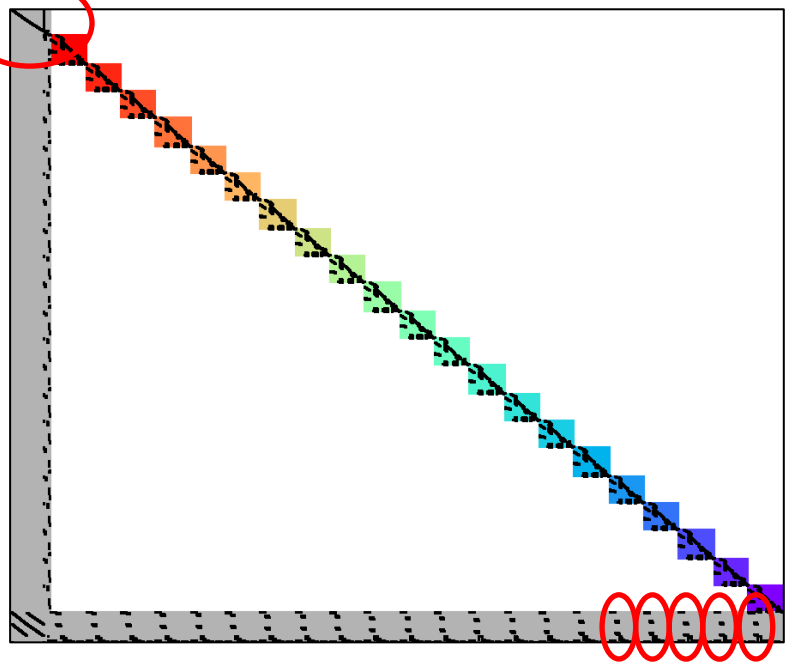
Every storage constraint linking

Target: Find good **trade-off** between **number of time blocks** and **number of linking constraints**

Evaluation of Annotations

Decomposition by **time and region** can be applied at the same time

power flow limitation from spatial decomposition



Linking to previous time step from temporal decomposition

All previously shown annotation plots describe exactly the **same ESM problem**
→ **Systematic evaluation** of promising annotations required

➡ TB-02-4: T. Breuer *„High Performance Computing for Energy System Modelling“*

Conclusions and Outlook

- Application of high performance computing requires substantial preparation

  → identification of block structures, linking variables, linking constraints

- Systematic evaluations necessary to determine best decomposition strategies

- Strategies promising for REMix will be tested in other models as well

- Results to be summarized in a best-practice guide for energy system modelling

Contact:
Manuel.Wetzel@dlr.de
DLR – German Aerospace Center
Institute of Engineering Thermodynamics
Systems Analysis and Technology Assessment
Pfaffenwaldring 38-40
70569 Stuttgart
Germany

www.beam-me-projekt.de

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

BEAM-ME

A PROJECT BY

GAMS

berlin

H L R S

JÜLICH
FORSCHUNGSZENTRUM

DLR Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center

ZIB