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PSI

Evangelos Panos :: Energy Economics Group :: Laboratory for Energy Systems Analysis

Acceleration strategies for speeding up the solution time of the TIMES energy systems model generator

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Overview

1 Introduction

2 Conceptual speed up methods

3 Technical speed up methods

4 Conclusions

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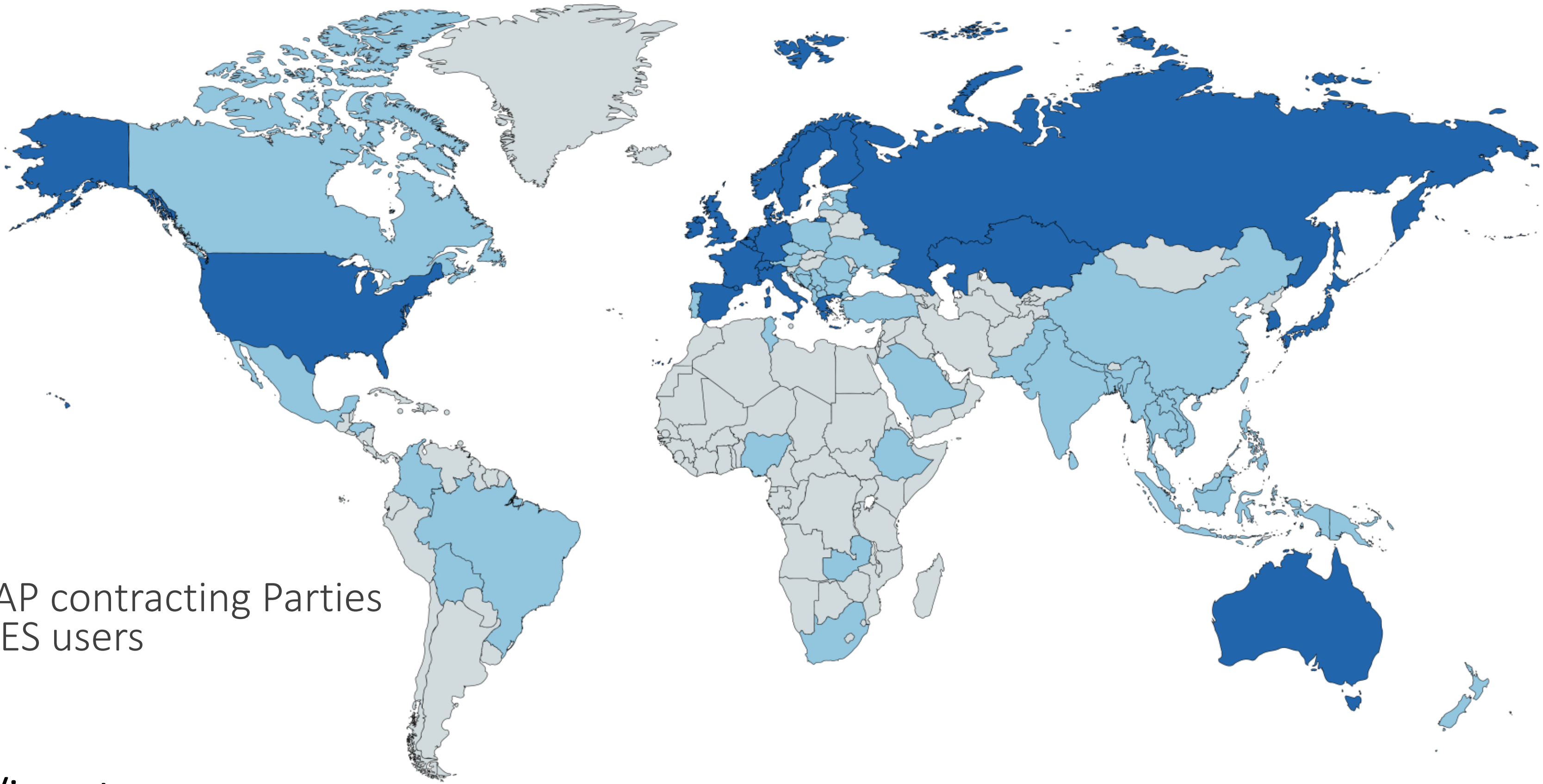
1 Introduction

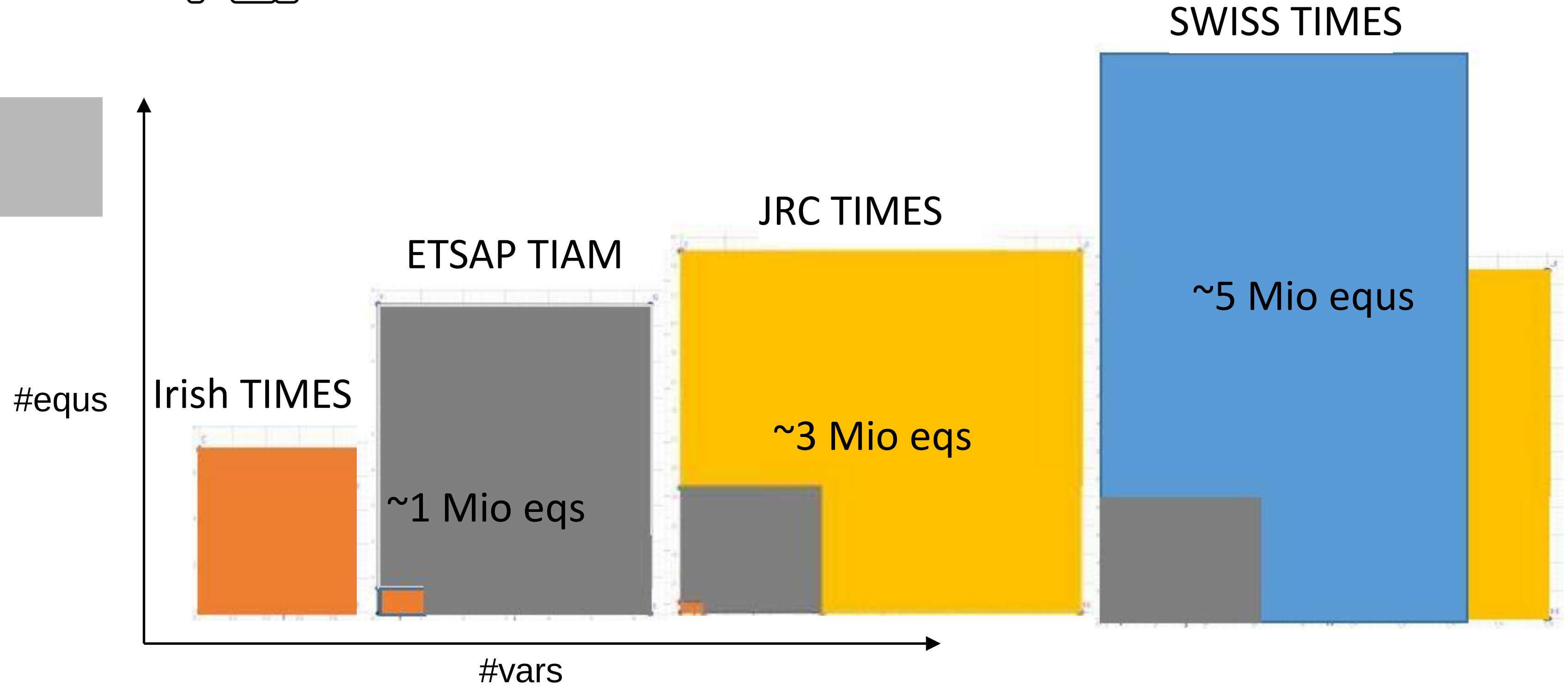
The TIMES Modelling Framework
and the PSI's EUSTEM model
used in the BEAM-ME MEXT project

IEA-ETSAP TIMES Modelling framework



https://iea-etsap.org

Typical matrix sizes of TIMES-based models

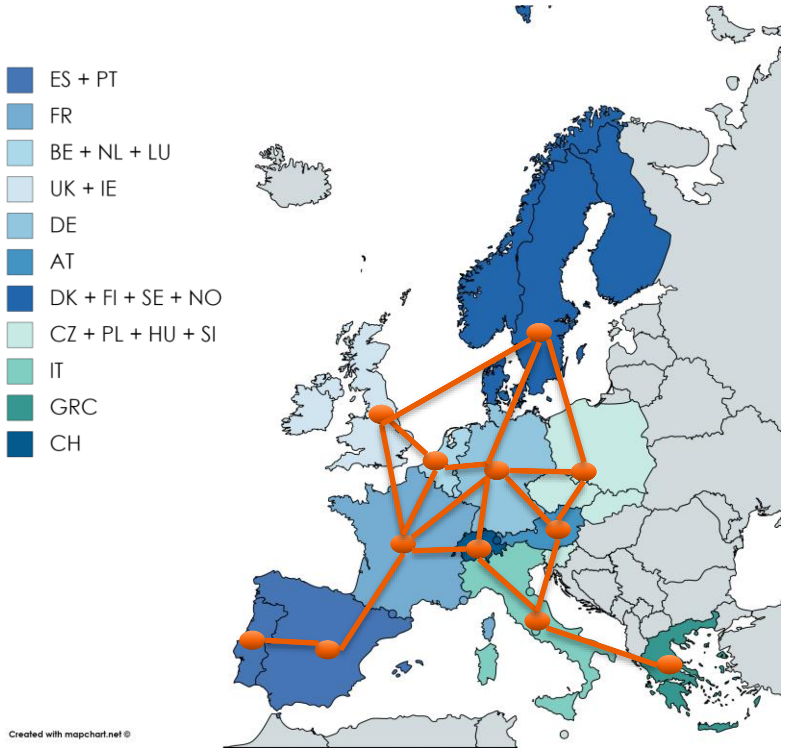


- The TIMES model generation includes an advanced reduction algorithm, exploiting the structure of the model to eliminate in advance invalid instances of equations and variables
- More than 75% reduction is achieved resulting in smaller, denser and almost square model matrices

PSI's EUSTEM Model - Overview

- Bottom-up electricity sector model of the EU
- Periods: 2015 – 2065 (flexible)
- Regions: from 11 to 22 (flexible)
- Timeslices: from 288 to 8760 (flexible)

- Endogenous capacity expansion
- Endogenous dispatching constraints (LP or MIP)
- Grid transmission constraints between regions
- Rich in power plant types and storages
- P2X options



https://www.psi.ch/en/eem/projects/european-swiss-times-electricity-model

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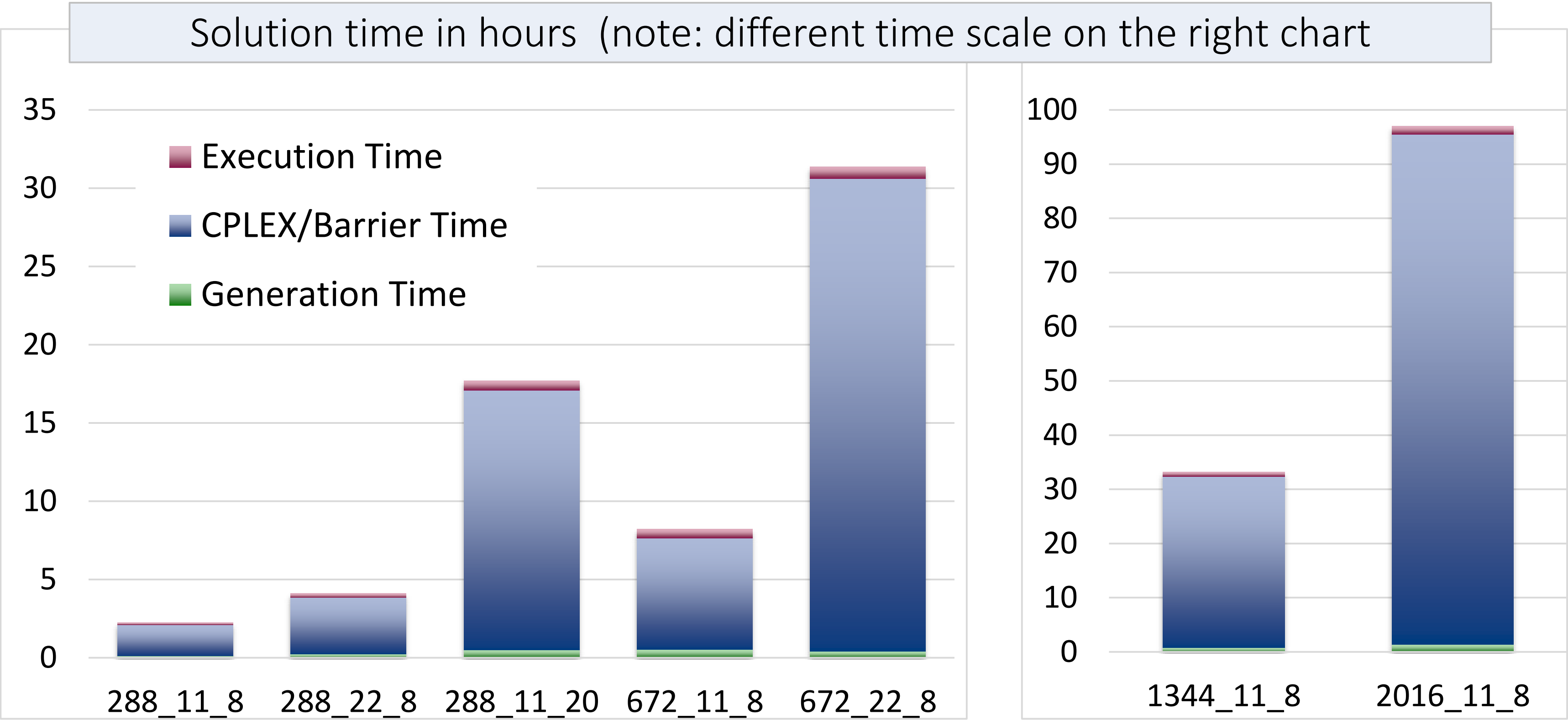
EUSTEM Model Instances in BEAM-ME MEXT

Instance (XXX_YY_ZZ) XXX=timeslices YY=regions ZZ=periods	Initial model matrix passed to the solver			Memory to generate the instance(GB)	% of equations and variables eliminated by CPLEX presolve
	Variables (millions)	Equations (millions)	Non-Zeros (millions)		
288_11_8	8.3	12.3	118.8	10.2	31%
288_22_8	15.5	22.6	218.3	18.9	31%
288_11_20	55.2	36.8	551.5	46.5	28%
672_11_8	19.4	28.6	446.4	38.9	29%
672_22_8	53.7	36.7	839.1	73.1	29%
1344_11_8	57.1	38.7	892.3	77.6	34%
2016_11_8	85.7	58.1	1,340.6	116.7	29%
4032_11_8	116.1	171.3	**-1,616.5 (GAMS overflow)**	233.1	
8076_11_8	Needs >384 GB RAM, but it will create overflow in number of non zeros				

EUSTEM on a single node* (JUWELS HPC centre)



* 2 X 24 cores @ 2.7 GHz, 12 x 16 GB RAM @ 2666 MHz , CPLEX/Barrier options optimized for EUSTEM structure

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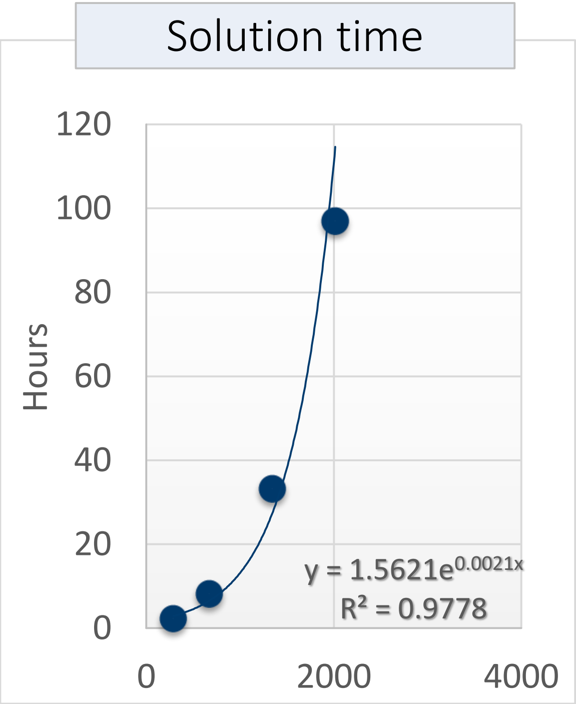
BEAM-ME

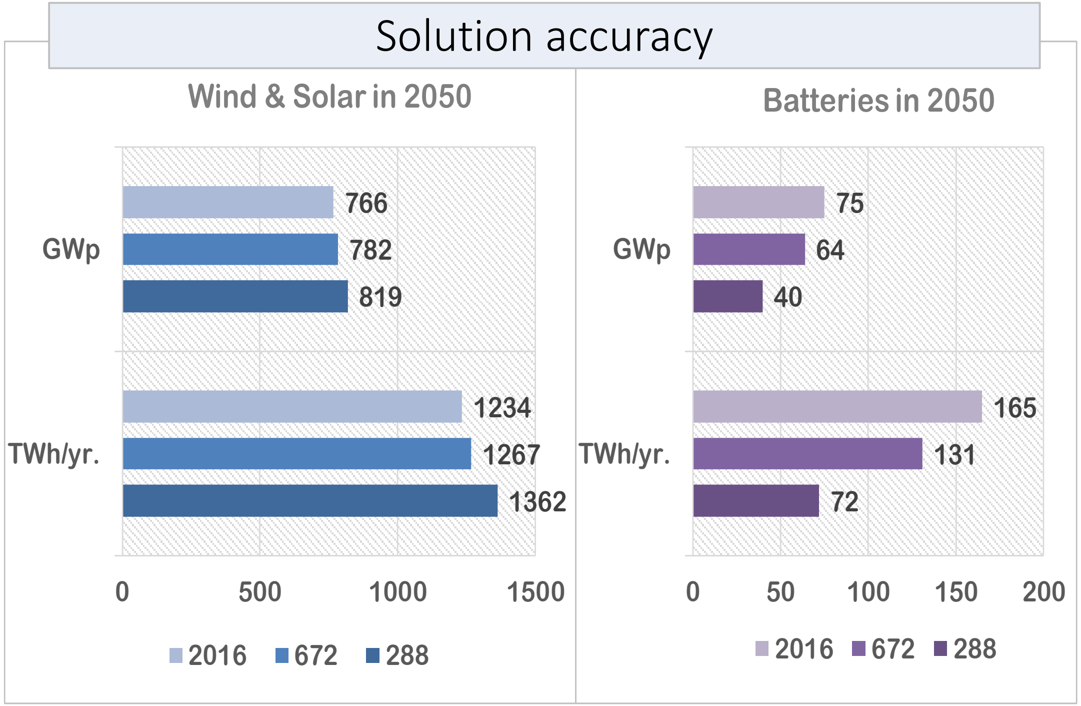
2 Conceptual speed up methods

Conceptual speed-up methods		Applicable to EUSTEM ?
1.	Scenario runs with smaller number of time slices	YES
2.	Model reduction based on representative day	YES
3.	Myopic approach: Rolling investment	YES
4.	Spatial aggregation	YES
5.	Rolling horizon heuristics	Not applicable
6.	Benders decomposition	Not applicable (needs MIP)

1. Timeslices

- (Diss)agregation is based on averaging to typical days (e.g. working day, Saturday or Sunday)
- Increasing the resolution it only avoids the averaging of VRES patterns to some extent



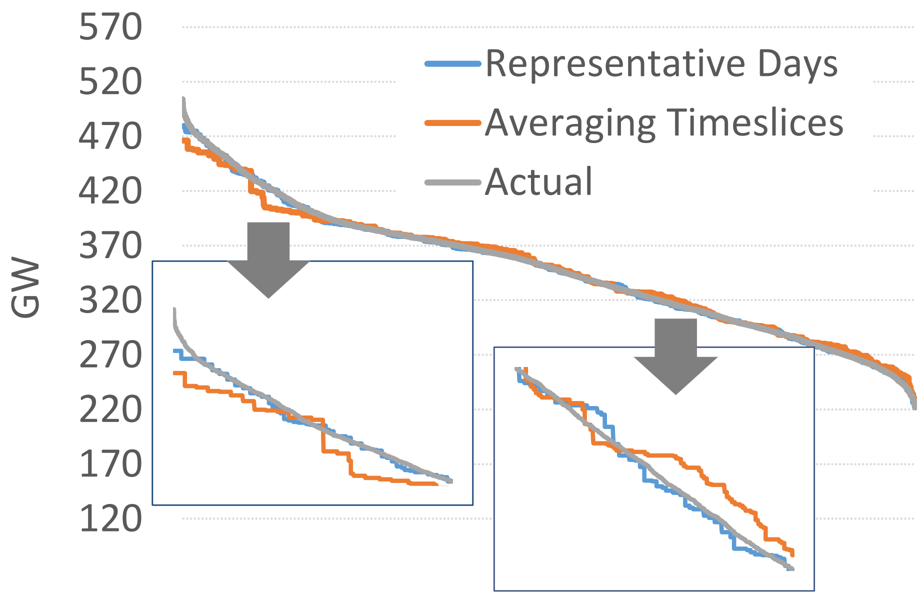


Horizontal axis: number of timeslices

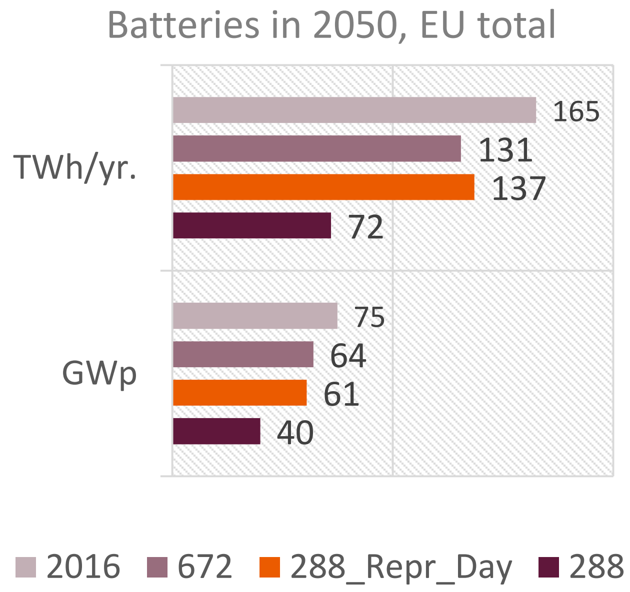
2. Representative days

- Selection algorithm: MILP minimizing the difference between the actual and approximated curve(s)
- Sensitive to the number and type of curves and the number of regions

Approximation of EU load curve with 288 timeslices



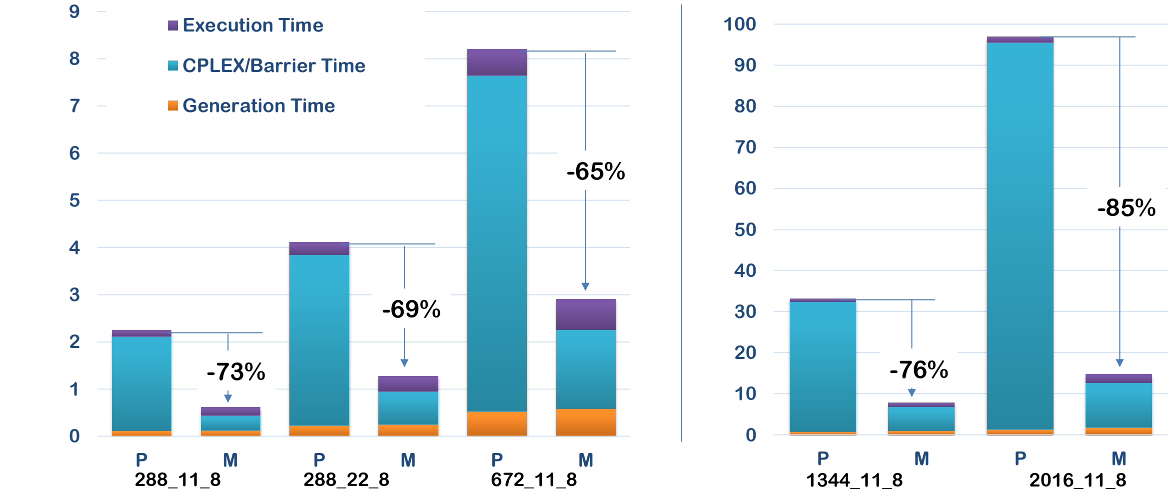
Solution accuracy



3. Myopic approach: Rolling Investment

- The model horizon is solved in a series of successive (and overlapping to some extent) steps
- Sensitive to the length of the steps, alters the decision mechanism of the model
- Overinvestment and higher costs if not calibrated to the perfect foresight → time consuming

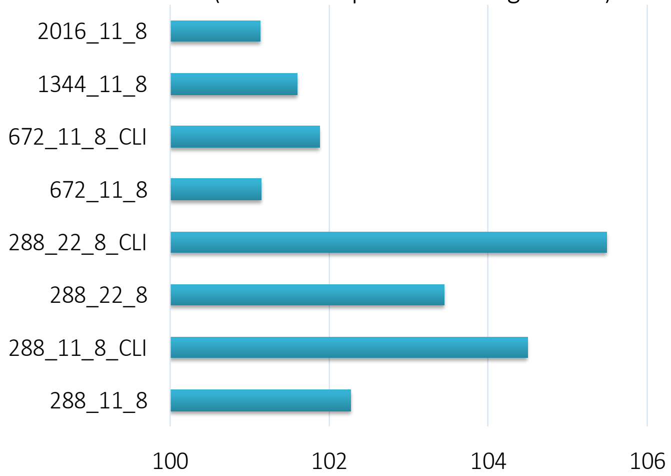
Solution times compared to perfect foresight



P=Perfect foresight run , M= myopic run

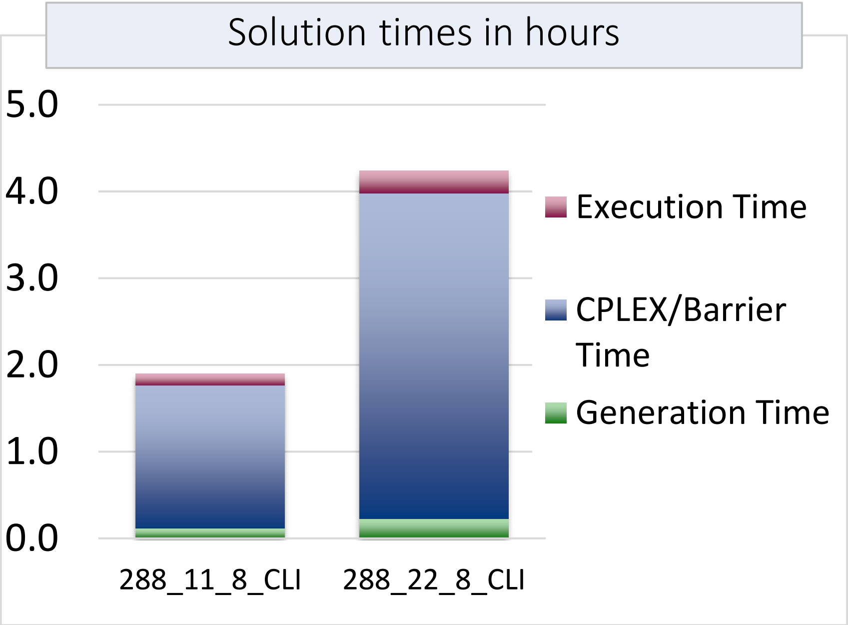
Solution accuracy

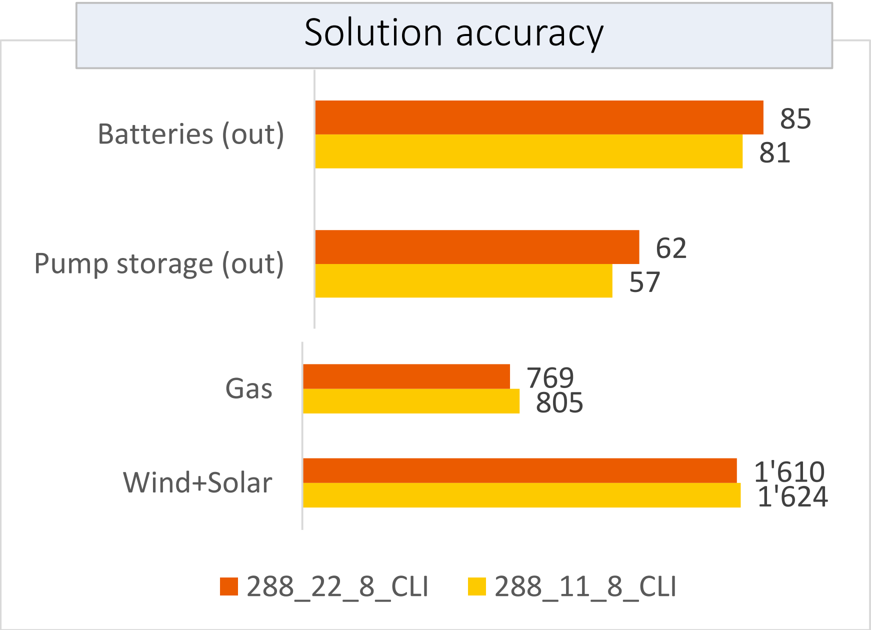
Cumulative investment 2015-2050
(Indexed to perfect foresight=100)



4. Spatial aggregation

- (Diss)agregation is based on averaging countries to regions
- Aggregation tends to underestimate congestion, overestimate access to resources
- There a sweet-spot in the trade-off between solution accuracy and solution time (shown below)





CLI = climate scenario

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3 Technical speed up with the PIPS - IPM solver

$$
\begin{array}{llllllll}
\min & c^T x & & & & & & \\
\text{s.t.} & T_0 x_0 & & & & & & = h_0 \\
 & T_1 x_0 & + & W_1 x_1 & & & & = h_1 \\
 & T_2 x_0 & + & & W_2 x_2 & & & = h_2 \\
 & \vdots & & & & \ddots & & \vdots \\
 & T_N x_0 & + & & & & W_N x_N & = h_N \\
 & F_0 x_0 & + & F_1 x_1 & + \; F_2 x_2 & \cdots & F_N x_N & = h_{N+1}
\end{array}
$$

Independent block of equs and vars

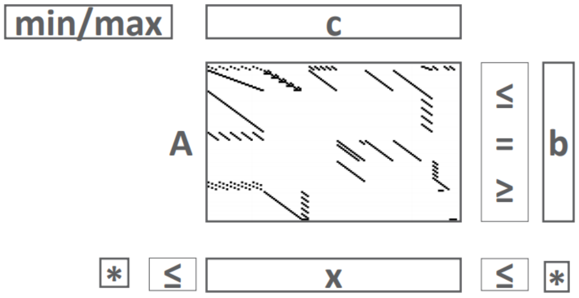
Linking variables

Linking constraint

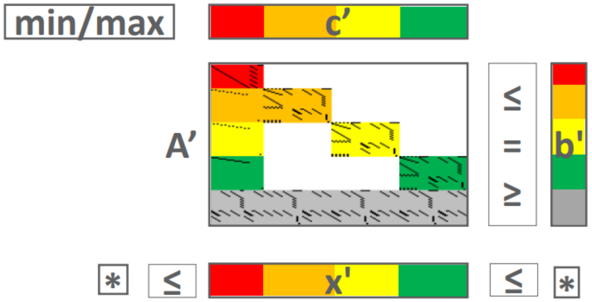
Model Annotation

1. Principle of the Annotation

Original problem with "random" matrix structure



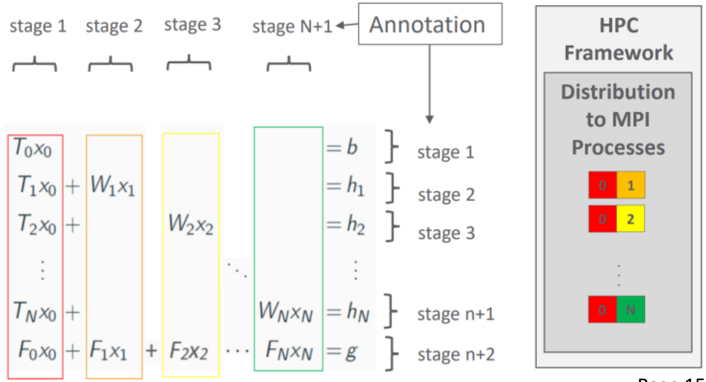
Permutation reveals block structure



2. Implementing Annotation in GAMS

```
[...]
* Master variables and equation
FLOW.stage(t,net(rr1,rr2))        = 1;
LINK_ADD_CAP.stage(net(rr1,rr2)) = 1;
[...]
* Block variables and equations
POWER.stage(t,rp(rr,p))       = ord(rr)+1;
EMISSION_SPLIT.stage(rr,e)  = ord(rr)+1;
[...]
eq_power_balance.stage(t,rr)     = ord(rr)+1;
eq_emission_region.stage(rr,e)  = ord(rr)+1;
eq_emission_cost.stage(rr,e)    = ord(rr)+1;
[...]
* Linking Equation
eq_emission_cap.stage(e)  = card(rr)+2;
```

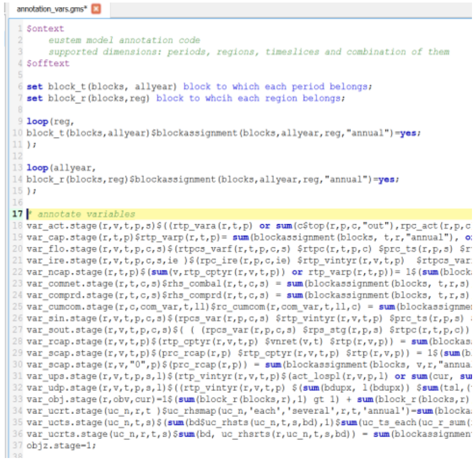
Matrix structure required by PIPS API



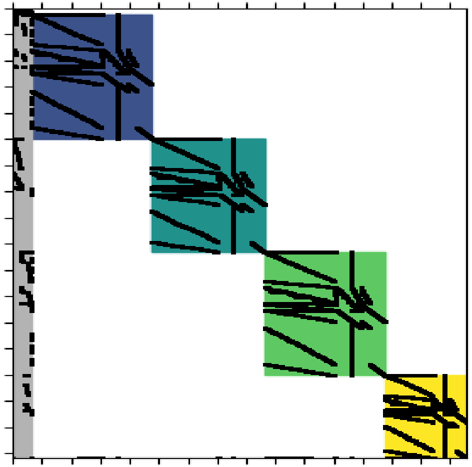
Source: Fiand, F., 2018.GAMS & High Performance Computing. Operations Research 2018, Brussels

Procedure to solve EUSTEM with PIPS on HPC

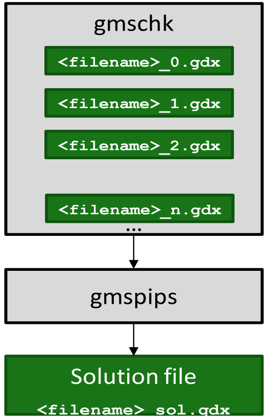
1. Annotate model via .stage attribute in GAMS



2. Check if annotation is correct and meets PIPS limits and adjust



3. Upload the annotated Jacobian to HPC, split it into its blocks and call PIPS



Tools needed to perform the tasks

GAMS version 25 or higher

Python tool & checkanno.gms developed in the BEAM-ME project

SCP/FTP client
gamschk tool
PIPS solver installed on HPC

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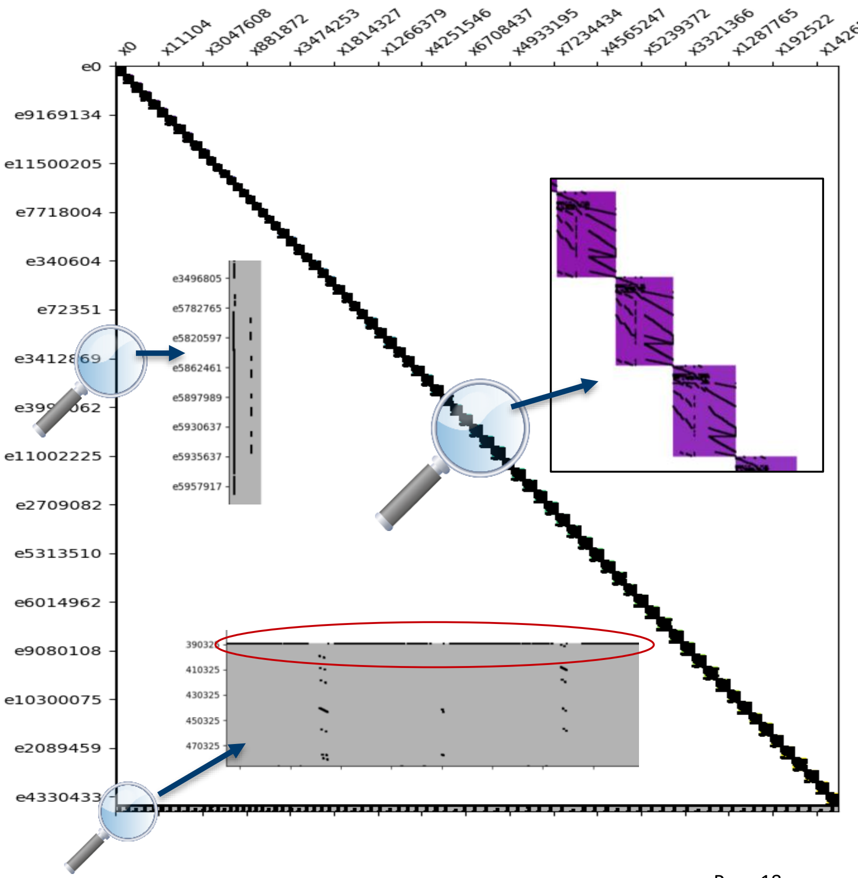
Solving EUSTEM with PIPS - Instances

Instance (XXX_YY_ZZ) XXX=timeslices YY=regions ZZ=periods	Variables (millions)	Equations (millions)	Non-Zeros (millions)	Annotated (YES= pass PIPS solver limits)	Solved by PIPS-IPM
288_11_8	8.3	12.3	118.8	YES	YES
288_22_8	15.5	22.6	218.3	YES	YES
288_11_20	55.2	36.8	551.5	YES	In progress
672_11_8	19.4	28.6	446.4	YES	NO, needs the new PIPS extension
672_22_8	53.7	36.7	839.1	NO	
1344_11_8	57.1	38.7	892.3	NO	
2016_11_8	85.7	58.1	1,340.6	NO	

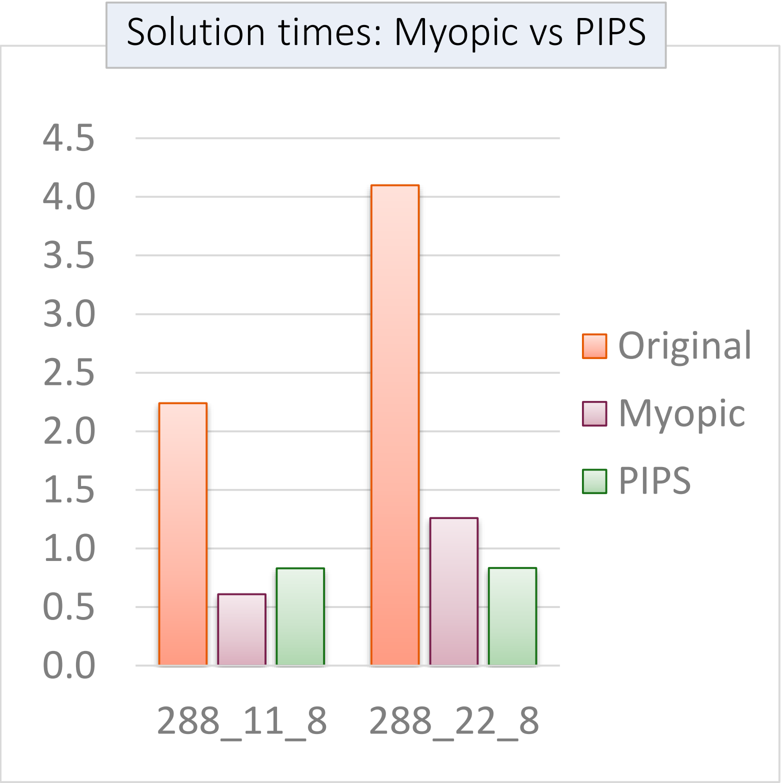
EUSTEM on PIPS – Annotation insights

- Linking variables
  - Slack variables of cross-regional constraints (inequality constraints in TIMES are represented as equalities)
- «Global» linking variables
  - Capacity investments & retirements
- Linking constraints
  - Transmission grid constraints
  - Other cross-regional constraints
- «Global» linking constraints
  - Cumulative constraints (e.g. stockpiling)
  - Cumulative targets
  - Cross-regional constraints (dense)



EUSTEM on PIPS – Insights from solution times

- The salient features of TIMES (capacity expansion, dispatch, transmission constraints, energy system approach) impose challenges in meeting PIPS requirements
- The annotation needs to keep balance between number of blocks, size of blocks and number of global linking constraints and variables
- Different annotation strategies need to be explored, which also exploit model structure
- High degree of parallelization needs to be achieved, otherwise the communication overhead is significant (i.e. >100 blocks/nodes)
- Smaller model instances do not benefit much from the PIPS, and the time spent in annotation is an overhead in this case



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Conclusions

Aggregating timeslices results in exponential reduction in solution times
but it can leads to overestimation of VRES and underestimation of flexibile capacities

Representative days approximate well the load duration curves with a few timeslices
but the selection algorithm is sensitive to the number of curves and regions

Spatial model aggregation also reduces exponentially the solution time
but congestion issues and limits in access to rersources are underestimated

The rolling investment horizon reduces solution time from 65% to 85%
but it is sensitive to steps' length, leads to delay technology uptake and high costs

Solving the model with PIPS-IPM needs a high degree of parallelization
but the expected reduction in the solution time is worth the effort of annotation

Wir schaffen Wissen – heute für morgen

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