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Chair of Energy Economics

INSIGHTS FROM DISTRIBUTED COMPUTING OF THE NODAL PRICING MODEL ELMOD AND CONCEPTUAL SPEED-UP TECHNIQUES

FORSCHUNGSNETZWERKTREFFEN 2019
SESSION 2G

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ELMOD is prepared to be solved with PIPS and applying a rolling horizon approach

ELMOD

SOLVING STRATEGIES

1. PIPS

Enhanced solver performance using distributed computing resources at JSC

- Annotation of ELMOD instances for distributed solution
- Preparation of GAMS/PIPS work flow to solve model instance on Jülich super computers
- Started test runs with different task configuration

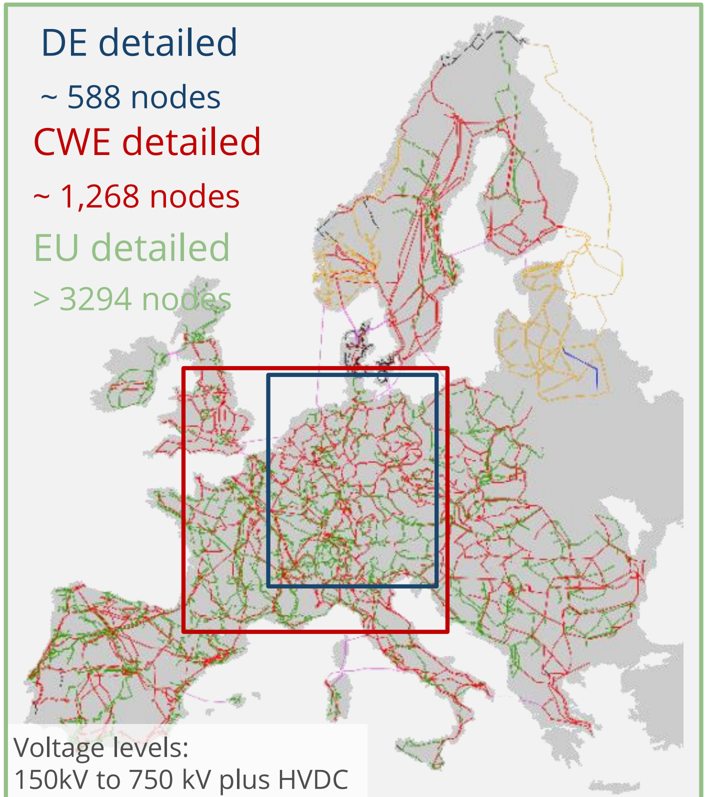
2. MANUAL SPEED-UP

Alternative model formulation using a rolling planning horizon

- Reformulation of ELMOD allowing to apply a free adjustable rolling horizon approach
- Solution of ELMOD instances with different configurations

ELMOD is a nodal pricing market model for the entire European Union

Dynamic adjustment of model scope



Exemplary model applications

AVERS: Security of Supply in South-Germany

AVERS ANALYSE VERSORGUNGSSICHERHEIT SÜDDEUTSCHLAND

- Analysis of different market zone configurations
- Clustering of market zones based on nodal price information
- Implications for security of supply and necessary congestion management measures

LKD-EU: Uncertainties in generation and transmission

lkDEU langfristige Planung und kurzfristige Optimierung des **Elektrizitätssystems in Deutschland** im europäischen Kontext

- Congestion management under uncertainty in RES generation
- Stochastic approaches for the unit commitment problem
- Intersectoral strategies for dealing with uncertainty

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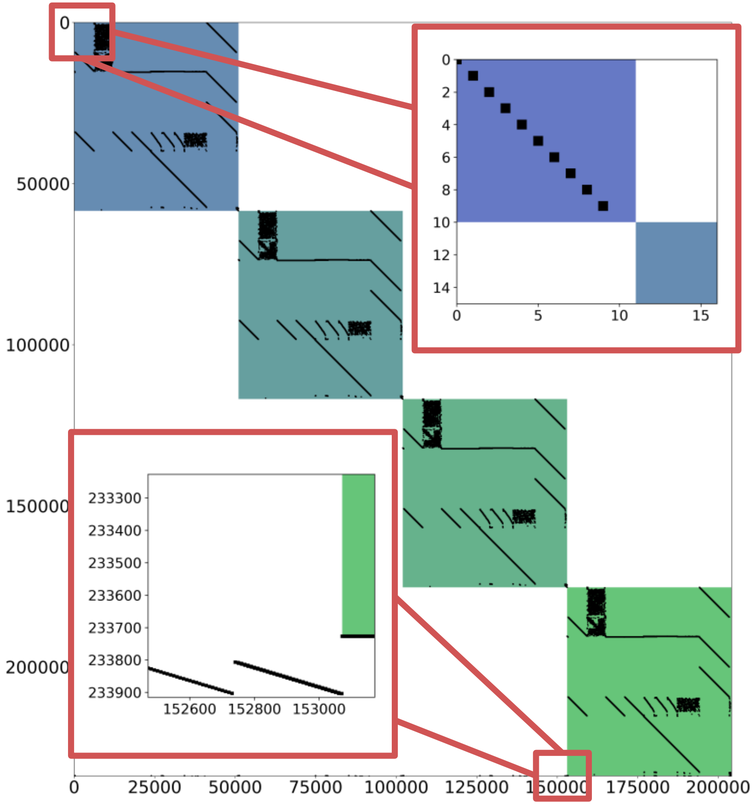
Annotation applied using time as dimension: Illustration on an exemplary model instance 4_10

Plot of Jacobian matrix



Own compilation

- **4** blocks with **10** hours each
- Parallel processes (Stage 2-5):
  - Var./Eq.: generation, stored energy, line flows, curtailment, voltage angles, dump demand/generation
- Stage 1:
  - Var.: sum gen. reservoir, total costs
  - Eq.: restrictions on reservoir generation
- Stage 6:
  - Weak-linking eq.: Ramping up, ramping down, PSP storage level
  - Strong-linking eq.: total costs, sum generation reservoir

Three different grid configurations prepared

Grid representation and model statistics of test instances

DE instance

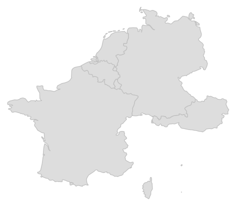
Grid representation

DE:	detailed
neighbor:	aggreg. nodes

Model statistics

# nz:	142.94 x $1e^6$
# eq:	51.11 x $1e^6$
# v:	44.59 x $1e^6$
Size JC:	4.52 GB

CWE instance



Grid representation

CWE:	detailed
neighbor:	aggreg. nodes

Model statistics

# nz:	272.19 x $1e^6$
# eq:	98.65 x $1e^6$
# v:	85.65 x $1e^6$
Size JC:	8.73 GB

EU instance

Grid representation

EU:	detailed (almost)
neighbor:	aggreg. nodes

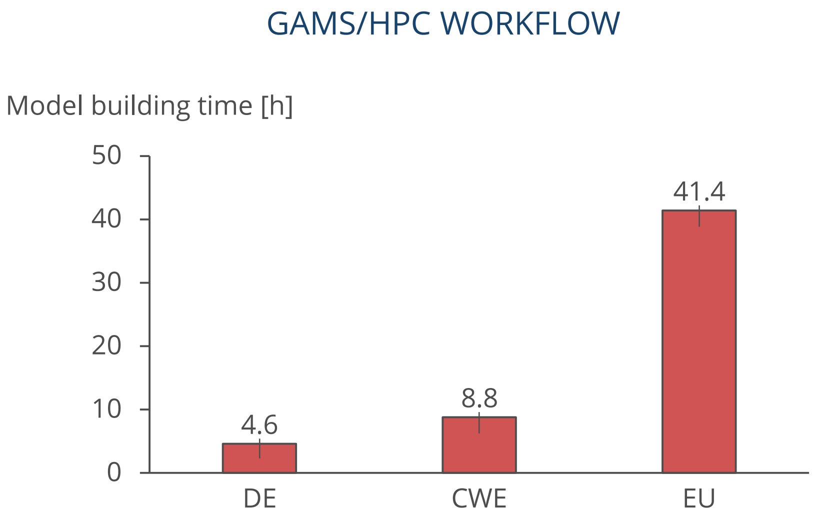
Model statistics

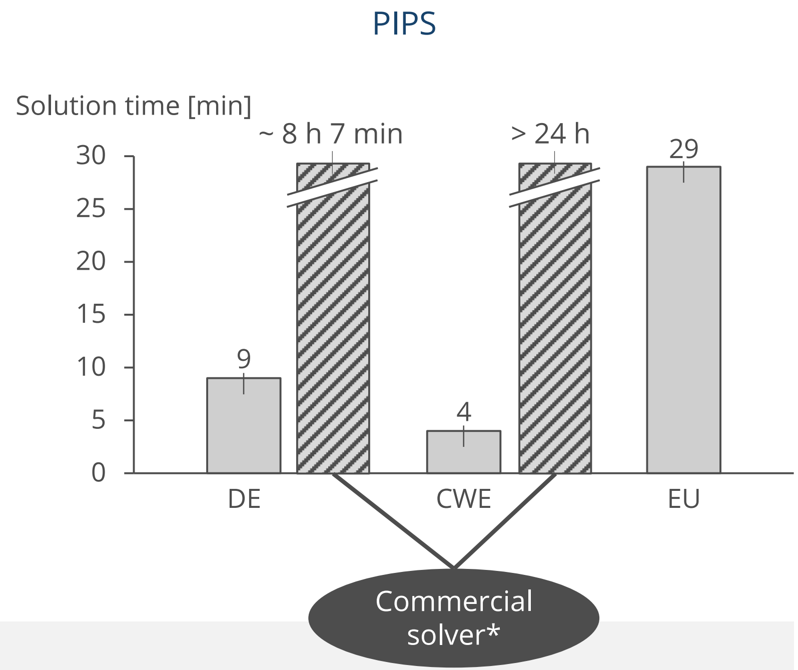
# nz:	712.45 x $1e^6$
# eq:	254.30 x $1e^6$
# v:	224.67 x $1e^6$
Size JC:	22.43 GB

Statistics taken from 8760 hour model scope configuration

Going large: Model building time turns out to be the bottle neck whilst PIPS reduces solution time tremendously

Model building time [hours] and solution time [min] consumed by PIPS for different grid configurations





1. Tremendous reduction of solution time by PIPS.
2. Time consumption for model building reaches limits. Noteworthy, that is partly in responsibility of the modeler and can be affected by the way of model formulation. We are working on it together with GAMS.

*Among others, CPLEX Barrier using up to 8 threads was tested and provided best results.

Insights from HPC runs with PIPS

1. MODEL PREPERATION

Time consumption for Jacobian creation and handling of extremely large file sizes challenging.

2. PIPS

Tremendous time reduction for model solution. Promising insight for large scale applications of nodal pricing models.

3. END USER

Annotation and workflow implementation take some efforts, but end user suitability proved. Several test runs currently ongoing…

[Thanks to Daniel, Thomas and Fred for the excellent and immediate support when needed!]

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ELMOD

SOLVING STRATEGIES

PIPS **1.**

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MANUAL SPEED-UP **2.**

Alternative model formulation using a rolling planning horizon

- Reformulation of ELMOD allowing to apply a free adjustable rolling horizon approach
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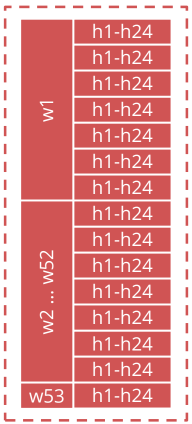
ELMOD can be solved using a simultaneous solve and rolling horizon approach using dynamic configurations

Simplified illustration of rolling planning strategy

SIMULTANEOUS

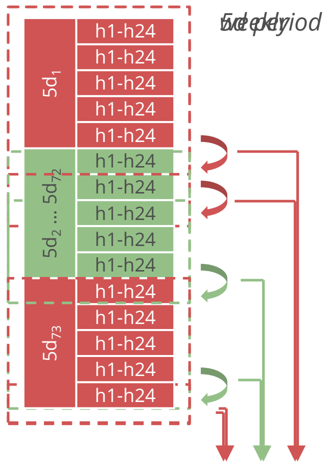


gather solution

Very large model instance

Extremely time consuming

ROLLING PLANNING



gather solution

- Separation into smaller instances
- Slow: 53 x built and solve in a row

PIPS ?! ->

IMPLEMENTED HEURISTIC FOR ROLLING PLANNING

1. First instance is solved for one planning horizon plus 24 hours overlap to the next period

   This ensures a natural short term storage behavior.

2. Retrieve and store model results from the current planning horizon

   Make sure the objective value sums up only over the period's time steps without the overlap when saving the results!

3. Set start values for the next horizon using the level values of the last time step in the prior period

How does horizon length impact power plant dispatch?

8760h monolithic solve compared against weekly and daily rolling planning of the DE instance

	RUN	JOB NAME	PERIODS	HORIZON
MONO-LITHIC	#1	M_1_8760	1	8760 h
ROLLING HORIZON	#2	RH_53_168	53	168 h
ROLLING HORIZON	#3	RH_365_24	365	24 h

CONFIGURATION SUMMARY

MONOLITHIC:

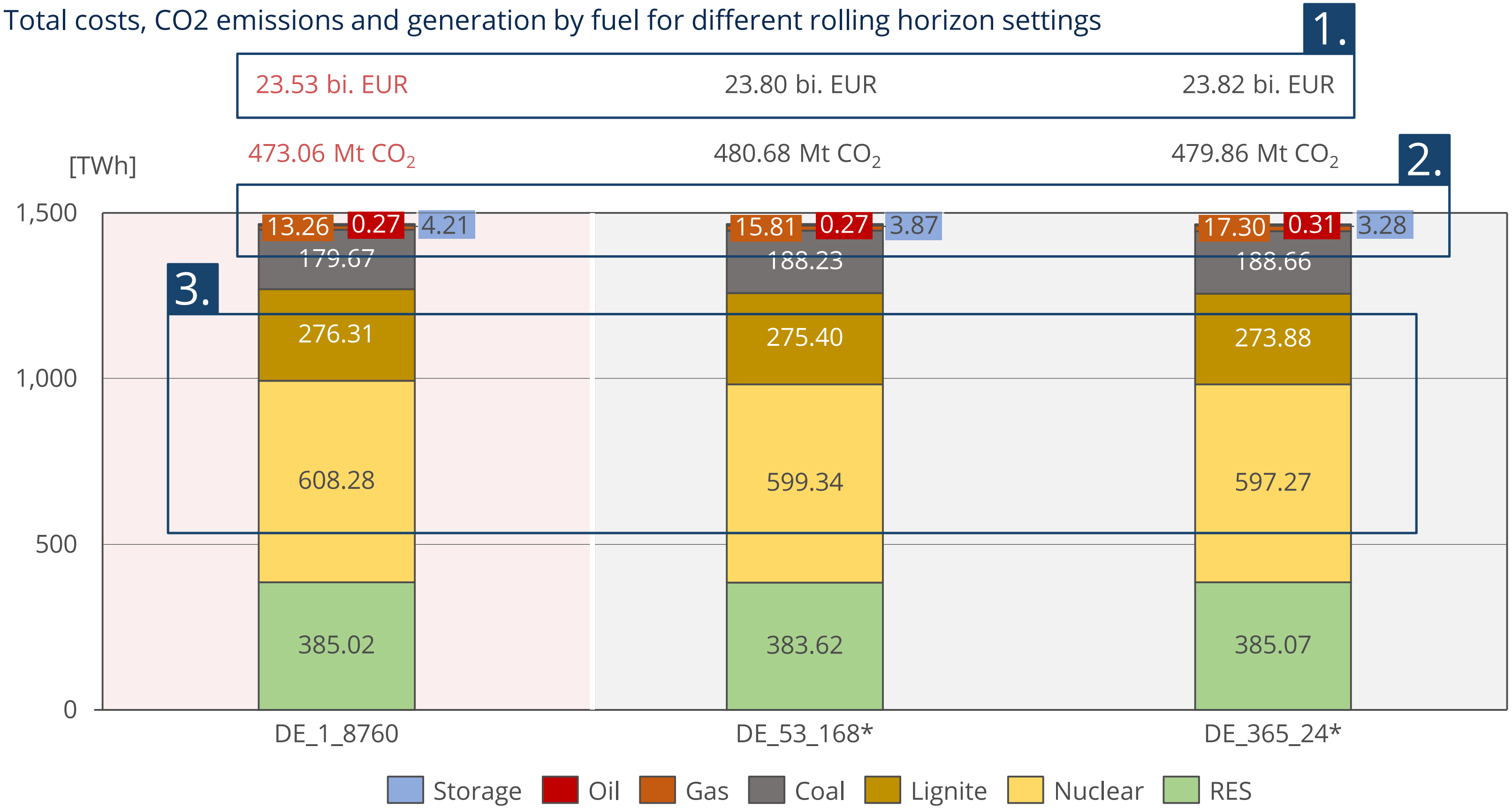
- TOTAL TIME SCOPE: 8760 hours at once
- REGIONAL SCOPE:
  DE detailed, aggregated neighbors

ROLLING HORIZON:

- TOTAL TIME SCOPE: 8760 hours
- REGIONAL SCOPE:
  DE detailed, aggregated neighbors
- HORIZON LENGTH:
  53, 365 periods with 168h, 24h length

Rolling horizon leads to higher overall costs and the dispatch of more flexible technologies

Total costs, CO2 emissions and generation by fuel for different rolling horizon settings



24 h overlap at rolling horizon runs.

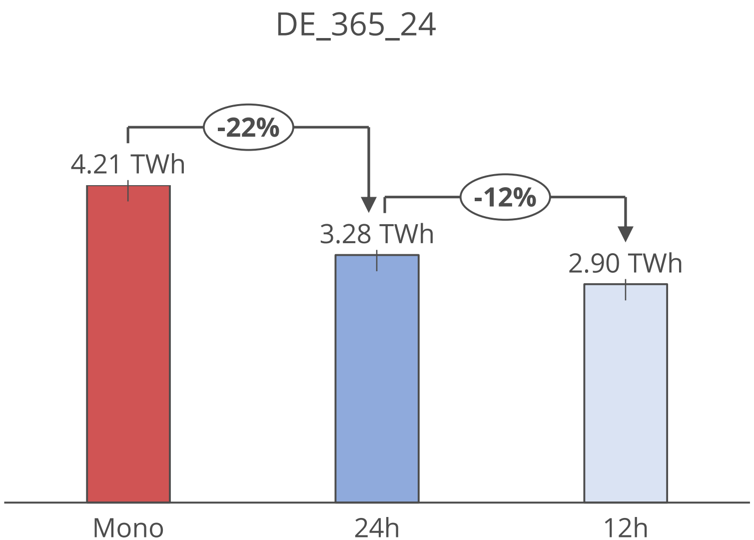
How does overlap period affect storage operation?

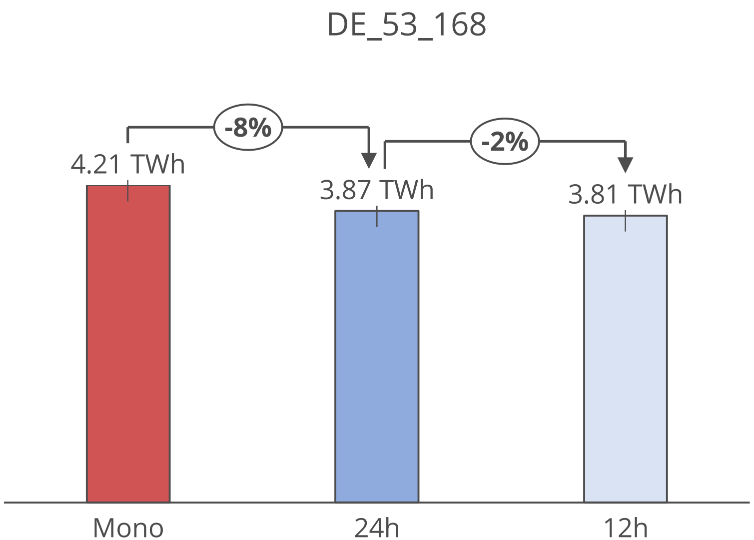
24h compared against 12h overlap period for DE instance

	RUN	JOB NAME	PERIODS	HORIZON	OVERLAP
ROLLING HORIZON	#1	DE_365_24	365	24 h	24 h
	#2	DE_365_24	365	24 h	12 h
ROLLING HORIZON	#3	DE_53_168	53	168 h	24 h
	#4	DE_53_168	53	168h	12 h

12h overlap period reduces storage operation significantly in daily rolling horizon runs

Storage utilisation for daily and weekly rolling horizon of DE instance





1. Reduction of overlap period to 12 hours significantly impacts storage operation.
2. Due to the higher number of adjacent planning horizons, limited foresight take effect strongest at the 365_24 instance.
3. Lower number of planning horizons reduces the deviations related to limited foresight.

How does total model time scope impact model execution time?

Monolithic solve and different rolling horizon configurations compared for ¼, ½, ¾ and total year model scope

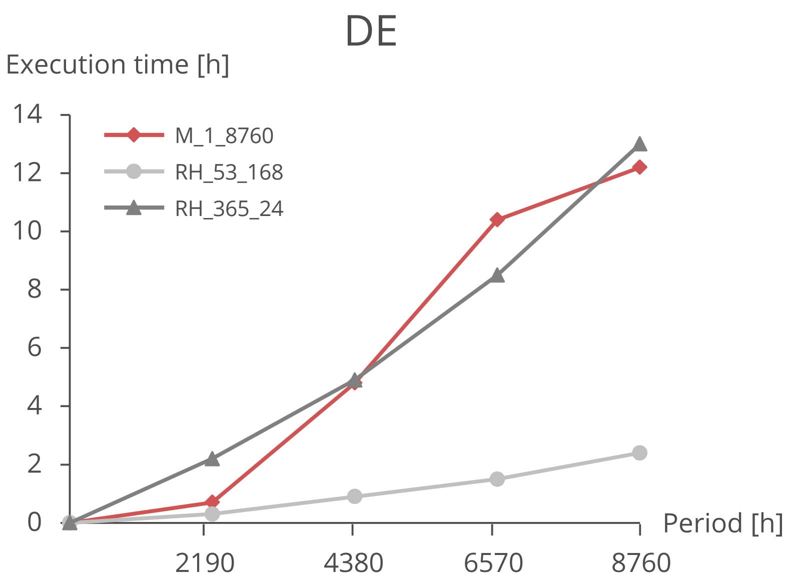
	RUN	JOB NAME	PERIODS	HORIZON
MO. LITHIC	#1	DE_X_1	2190, 4380, 6570, 8760	entire period
ROLLING HORIZON	#2	DE_X_24	91, 182, 273, 365	24 h
	#3	DE_X_168	13, 26, 39, 53	168h

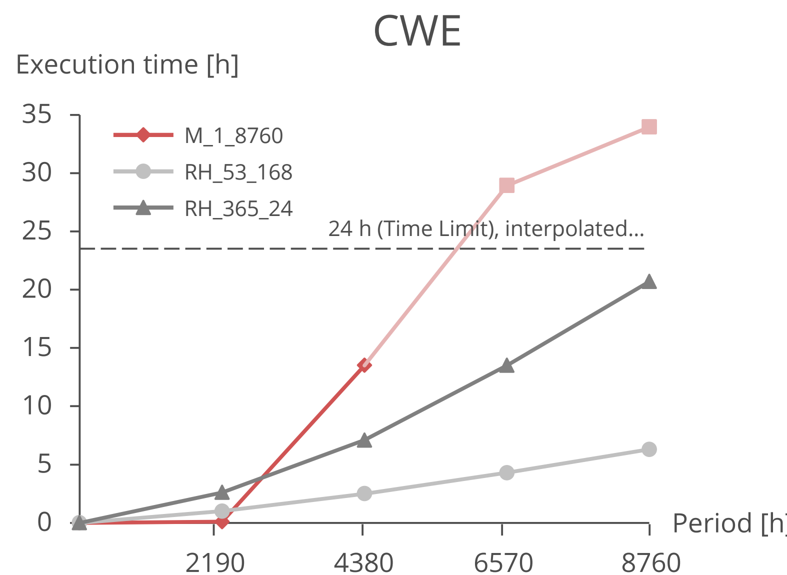
	RUN	JOB NAME	PERIODS	HORIZON
MO. LITHIC	#4	CWE_X_1	2190, 4380, 6570, 8760	entire period
ROLLING HORIZON	#5	CWE_X_24	91, 182, 273, 365	24 h
	#6	CWE_X_168	13, 26, 39, 53	168h

24 h overlap at rolling horizon runs.

53_168 instances perform best in both grid configurations

GAMS execution time of DE and CWE instance for different model time scopes





1. 365_24 run performs similar to monolithic solve but comes with reduced solution precision.

1. Monolithic solve breaks time limit.
2. Significant improvement by 53_168 instance.

Instances solved on JUWELS applying Barrier using 4 threads.

Insights from conceptual speed-up techniques

1. HORIZON LENGTH

Rolling horizon leads to higher overall costs and the dispatch of more flexible technologies.

2. HORIZON OVERLAP

Strong deviations in storage operation when using only 12 h overlap. Deviations remain at a reasonable level at 24 h overlap compared to monolithic solve.

3. MODEL TIME SCOPE

Significant performance improvement at weekly horizon runs. CWE instance have not been solved in reasonable time (<24 hours) monolithically.

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