START-UP AND SHUT-DOWN COSTS IN GEP MODELS WITH A FULLY FLEXIBLE TEMPORAL RESOLUTION

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1. Background

Generation Expansion Planning models:

- find optimal investment plans for expanding energy systems
- to reduce computation time, they often sacrifice accuracy, by:
 - ignoring start-up and shut-down costs of thermal generators
 - lowering the temporal resolution (using larger timesteps)

Fully flexible temporal resolution (Fig 1):

- allows less relevant information (for example, more distant countries) to be modelled with a lower resolution
- this can decrease computation time, while maintaining accuracy [1]

Tulipa energy model:

- GEP model with fully flexible temporal resolutions
- without start-up and shut-down costs

[1] Zhi Gao et al. Fully Flexible Temporal Resolution for Energy System Optimization. en. Nov. 2025. doi: 10.2139/ssrn.5214263.

2. Research Question

How does the addition of generator startup and shut-down costs affect a GEP model with a fully flexible temporal resolution in terms of computation time, objective function value, and investment plan, compared to uniform temporal resolutions?



Figure 1: Example of a fully flexible temporal resolution, where countries further from the Netherlands are modelled with less temporal detail

Figure 2: Trade-off between model runtime and error for the Dutch energy system compared to an hourly resolution with start-up and shut-down costs

-	No SU/SD	Uniform hourly		Computation	Comput
	constraints	resolution	Cheap	time	• Addi
	Full SU/SD	Uniform resolutions	SU/SD	Objective	dow
	constraints	(2-5 hours)	Expensive	function	• Com
	Compact SU/SD	Geographically	SU/SD	Optimal	perf
	constraints	decreasing resolution		investment plan	cons

3. Experimental Setup

Supervisor: <u>Maaike Elgersma</u>

4. Results

				Uniform Hourly Resolution				[%
No SU/SD costs Compact constraints			Battery	33.9	33.9	33.9	33.9	- 30 - 30 - 30 - 30 - 30 - 30 - 30 - 30
Full constraints Pareto front without geographical				14.9	15.2	16.3	16.8	- 10 - 10
Pareto front with geographical			CCGT	0.0	0.0	0.0	0.0	10 hand
	International reso	biution	OCGT	0.0	0.0	0.0	0.0	20 20 30
	2 h		cheap;compact cheap;full expensive;compact expensive;full					Perc
■ 3h		Geogiraphically Decreasing Resolution					[%]	
	■ 4h		Battery	140.0	817.8	140.0	794.8	apacity 000 -
	Geogra	phical	Battery storage	15.2	6.8	24.2	27.2	- 400 - 200 - 200 - 200
			CCGT	0.0	0.0	0.0	-14.3	200 gui
			OCGT	0.0	-20.0	0.0	0.0	entage 009
0 75	100 125	150		cheap;compact	cheap;full	expensive;compact	expensive;full	Pero 000

Figure 3: Percentage difference in invested capacity in the Netherlands caused by adding start-up and shut-down costs, for a uniform hourly resolution (top) and the geographically decreasing resolution (bottom)

5. Conclusions

ation time:

- ing start-up and shutn costs increases
- putation time
- pact constraints
- orm better than full straints

Objective function:

- Compact constraints exceed the Pareto front between runtime time and accuracy in the Netherlands
- Geographical resolution has the highest variance in cost

Investment plan:

- More batteries are purchased
- Sensitive to constraint set used