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Start-Up and Shut-Down Capabilities in a Unit Commitment Model for Generation Expansion Planning with Fully Flexible Temporal Resolution

TU Delft

1. Background

Generation Expansion Planning (GEP) →
Computational techniques for finding investment plans into the energy generation, minimizing system costs while meeting projected energy demand

Flexibility of energy systems →
The electrical grid's ability to respond to varying conditions such as the varying output of renewable energy sources

Unit Commitment Problem (UC) →
Finding optimal schedule of enabled generators to meet demand while satisfying a set of operational constraints

Start-up & Shut-down Capabilities (SU/SD) →
Limits of the rate at which generators can change their power output at the time of their start-up or shut-down

Temporal Resolution →
Time in model is discretised, and variables are defined at specific time blocks. The length of these blocks defines the resolution

→ **GEP + UC**
GEP can be combined with UC to better model flexibility of energy systems [1]

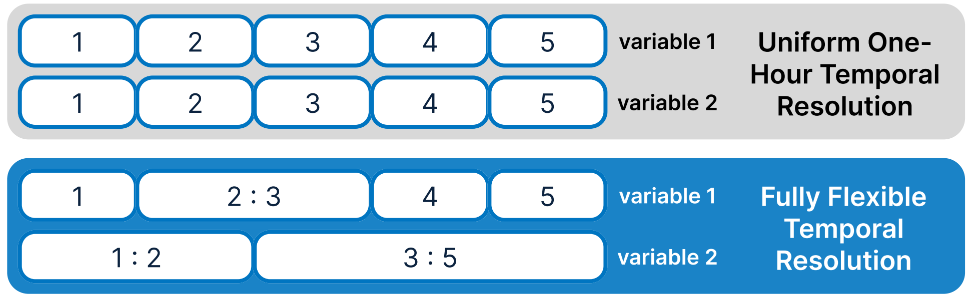
→ **Uniform One-Hour Temporal Resolution**
Models in literature commonly use uniform one-hour temporal resolution [2], where each variable is defined in hourly time blocks

→ **Fully Flexible Temporal Resolution**
Variables can be defined at different, possibly non-uniform, resolutions that are not multiples of resolutions of other variables

Tulipa Energy Model [3]→
Energy Optimisation Model allowing GEP with UC for flexible temporal resolutions, currently missing advanced UC constraints such as Start-Up and Shut-down capabilities (SU/SD)

Temporal Resolution

Time blocks at which variables are defined



2. Research Question

"How does the inclusion of constraints that limit the ***start-up and shut-down capabilities*** *of generators affect the* ***optimal solutions*** *and the* ***computation time*** *of the Tulipa Energy Model for varied* ***temporal resolutions****?"*

computation time | investment decisions | optimal total cost | commitment schedule

3. Method & Experimental Setup

→ A large case study based on EU with UK, Switzerland and Norway, with Thermal generators, Renewables and Batteries.

→ Collect run & creation time, investment solutions, total system cost and commitment variables

→ Vary temporal resolution and constraint configuration:

Temporal Resolution
- Uniform in {1, 2, 4} (hr)
- Geographically Decreasing

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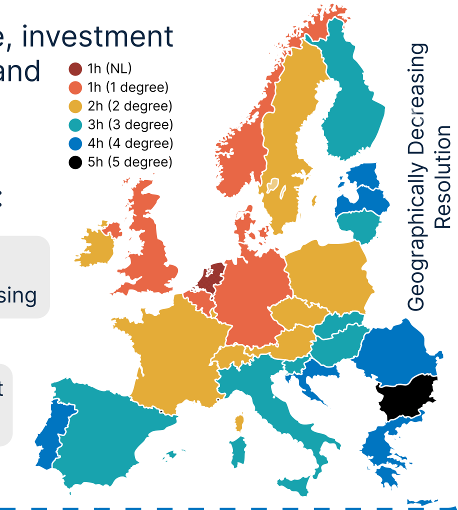
Constraints
- Basic Unit Commitment
- SU/SD Capabilities



5. Conclusions

→ **Minimal differences** in **investments** and **costs** when SU/SD capabilities are introduced

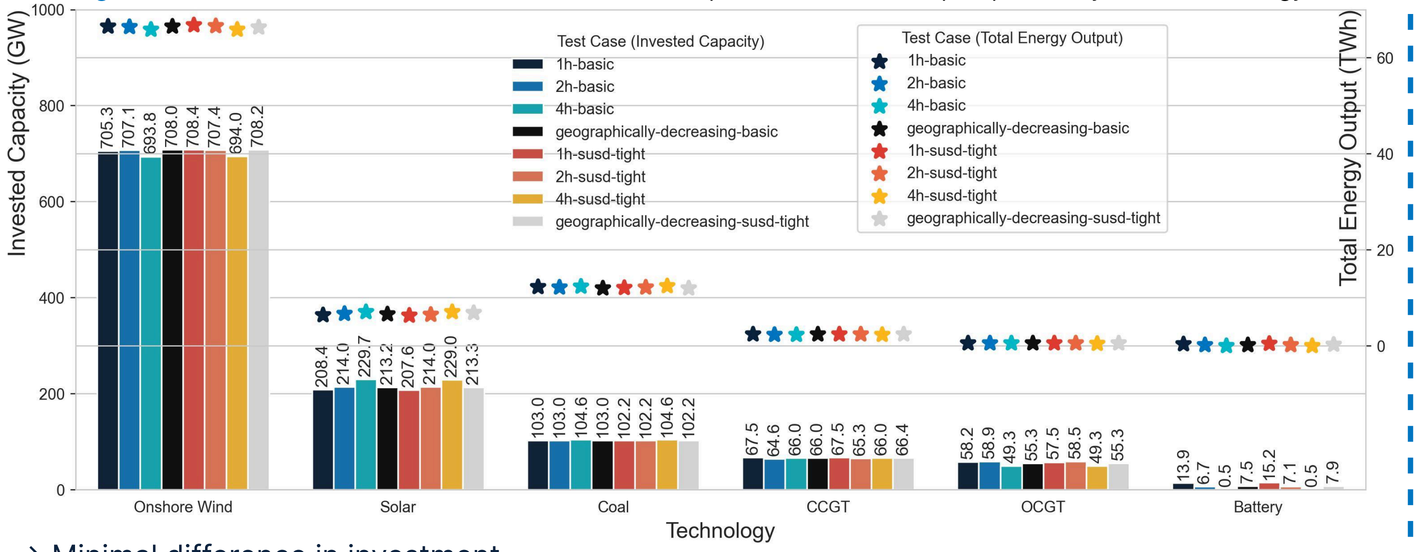
→ Noticeable **increase in run time** with SU/SD capabilities

→ Commitment Schedule of thermal generators changes, **units kept on for more total hours** when SU/SD used

→ **SU/SD capabilities can be omitted** from **flexible systems** with Batteries to reduce run time **if focus is** on **costs & investments**, and not on operation of the model

4. Results

Fig. 1: Total Investments in GW (bar chart) and Total Output in TWh (star-shaped points) by asset technology



→ Minimal difference in investment decisions between the Basic and SU/SD configurations (**Fig. 1** - bar chart)

→ Varying resolution causes larger differences in investments than inclusion/ exclusion of SU/SD (**Fig. 1** - bar chart)

→ Share of energy production remains effectively unchanged with/without SU/SD (**Fig. 1** - star points)

→ Noticeable run time increase as SU/SD included, highest at 1h res. (**Fig. 2**)

→ Small cost increase when SU/SD capabilities added at 1h resolution (**Table 1**)

→ Cost differences from inclusion/exclusion of SU/SD are significantly lower than from varying the temporal resolution (**Table 1**)

→ Units operate for longer hours in the 1h and geographically-decreasing resolutions (**Table 2**)

Fig. 2: Mean **Run** and **Creation** Time per temporal resolution and constraint configuration

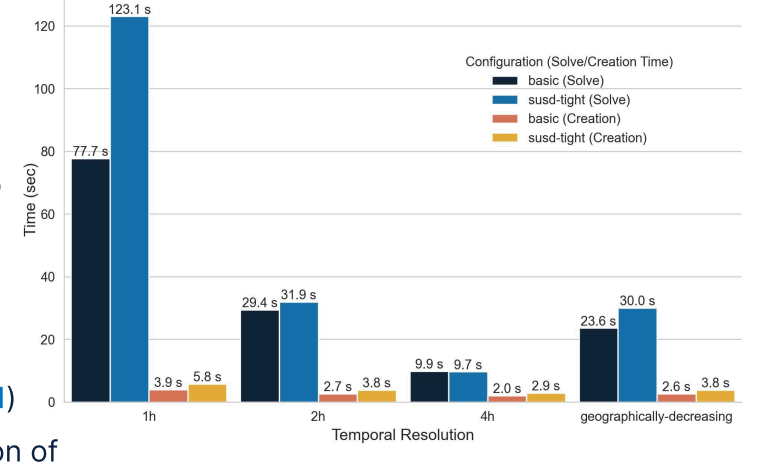


Table 1: NL and EU+3 Total Cost (Billions of Euro) & Change

Type	Configuration	1h		2h		4h		Geo-Decreasing	
EU+3	Basic UC	63.030	-	62.823	-0.3287%	62.278	-1.192%	62.708	-0.5105%
	SU/SD + Tight	63.053	+0.0366%	62.823	-0.3282%	62.277	-1.194%	62.714	-0.5015%
NL Only	Basic UC	2.2226	-	2.2117	-0.4913%	2.2046	-0.8125%	2.2227	+0.0034%
	SU/SD + Tight	2.2231	+0.0189%	2.2117	-0.4913%	2.2046	-0.8125%	2.2235	+0.0376%

Table 2: Number of Unit-Hours Online & Change per resolution, case and thermal generator type

Configuration	Case	CCGT		Coal		OCGT	
1h	Basic	7892	-	18306	-	2287	-
	SUSD Tight	8320	+5.42%	18443	+0.75%	2623	+14.69%
2h	Basic	7640	-3.19%	18092	-1.17%	2762	+20.77%
	SUSD Tight	7760	-1.67%	18252	-0.29%	2762	+20.77%
4h	Basic	7632	-3.29%	18648	+1.87%	2344	+2.49%
	SUSD Tight	7580	-3.95%	18692	+2.11%	2328	+1.79%
Geographically Decreasing	Basic	7604	-3.65%	18301	-0.03%	2355	+2.97%
	SUSD Tight	8016	+1.57%	18507	+1.10%	2429	+6.21%

References

[1] Bryan S. Palmintier and Mort D. Webster. Impact of Operational Flexibility on Electricity Generation Planning With Renewable and Carbon Targets. IEEE Transactions on Sustainable Energy, 7(2):672–684, April 2016. Publisher: Institute of Electrical and Electronics Engineers (IEEE).

[2] Luis Montero, Antonio Bello, and Javier Reneses. A Review on the Unit Commitment Problem: Approaches, Techniques, and Resolution Methods. Energies, 15(4):1296, February 2022

[3] Abel Soares Siqueira, Diego A. Tejada-Arango, Germán Morales-España, Grigory Neustroev, Juha Kiviluoma, Lauren Clisby, Maaike Elgersma, Ni Wang, Suvayu Ali, and Zhi Gao. Tulipa Energy Model, April 2025.