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Copernicus Institute of Sustainable Development

This publication is part of the project NextGenOpt (with project number ESI.2019.008, which is (partly) financed by the Dutch Research Council (NWO).

The results are obtained using Tulipa Energy Model developed by TNO [1].

Fully Flexible Temporal Resolution for Energy System Optimization

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Summary

We propose a concept of fully flexible temporal resolutions for energy system optimization, where energy flows and balances can have resolutions that are independent from each other, and capable of varying dynamically across the temporal horizon.

Benefits

1. Users do not face the limit of choosing one resolution for the whole system.
2. Resolutions bespoke to each decision variable series, not limited to energy carrier, technology, sector or geographic zone.
3. Reduce computational cost without losing much accuracy. For instance, having a geographical focus within an inter-connected large system.

Mathematical formulation

Let us consider an electrolyzer that uses electricity to produce hydrogen. The optimization problem can be written as

$$\min_t E e_t$$

s.t.

$$h_t = \eta e_t \quad \forall t \in [1,2,3,4,5,6]$$
$$\sum_t h_t = D,$$

where e_t is the electricity input, h_t the hydrogen production, E the linear cost parameter, η the fixed conversion efficiency and D the total hydrogen demand.

Say we want longer temporal periods L for the variables and the conversion constraint, S is accumulated period length

$$L_i^h \in [4,2], \quad S_i^h \in [4,6], \quad i \in [1,2]$$
$$L_j^c \in [3,2,1], \quad S_j^c \in [3,5,6], \quad j \in [1,2,3]$$
$$L_k^e \in [2,2,2], \quad S_k^e \in [2,4,6], \quad k \in [1,2,3]$$

We can convert the optimization problem into

$$\min_k E e'_k$$

s.t.

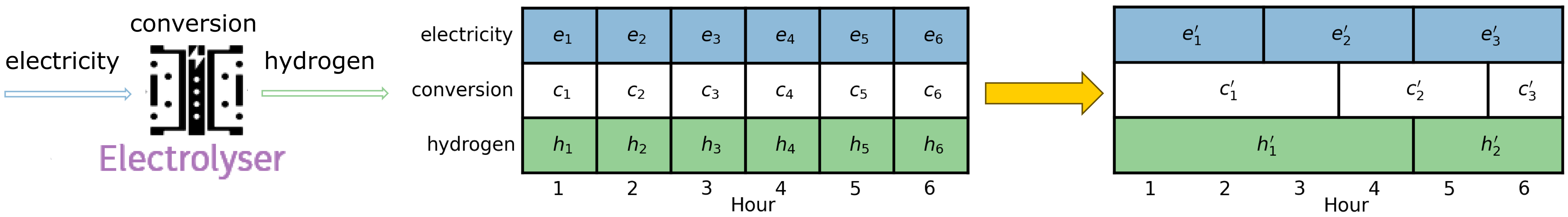
$$\sum_i M_{i,j}/L_i^h h'_i = \eta \sum_k N_{k,j}/L_k^e e'_k \quad \forall j$$
$$\sum_i h'_i = D,$$

where $M_{i,j}$ and $N_{i,j}$ are the mapping matrices between index pairs i,j and k,j, respectively. They can be calculated as

$$M_{i,j} = \begin{cases} S_j^c, & if\ S_j^c < S_i^h and\ i = 1 \\ S_j^c - S_{i-1}^h, & if\ S_j^c < S_i^h and\ i > 1 \\ S_i^h, & if\ S_j^c \geq S_i^h\ and\ j = 1 \\ S_i^h - S_{j-1}^c, & if\ S_j^c \geq S_i^h and\ j > 1 \end{cases}$$

This can be applied similarly to $N_{k,j}$. What the calculation above does is essentially counting for how many hours each energy flow variable participate in each conversion constraint.

An illustrative example of the fully flexible temporal resolution



Case study: Focus on the Netherlands in the north-west EU power system

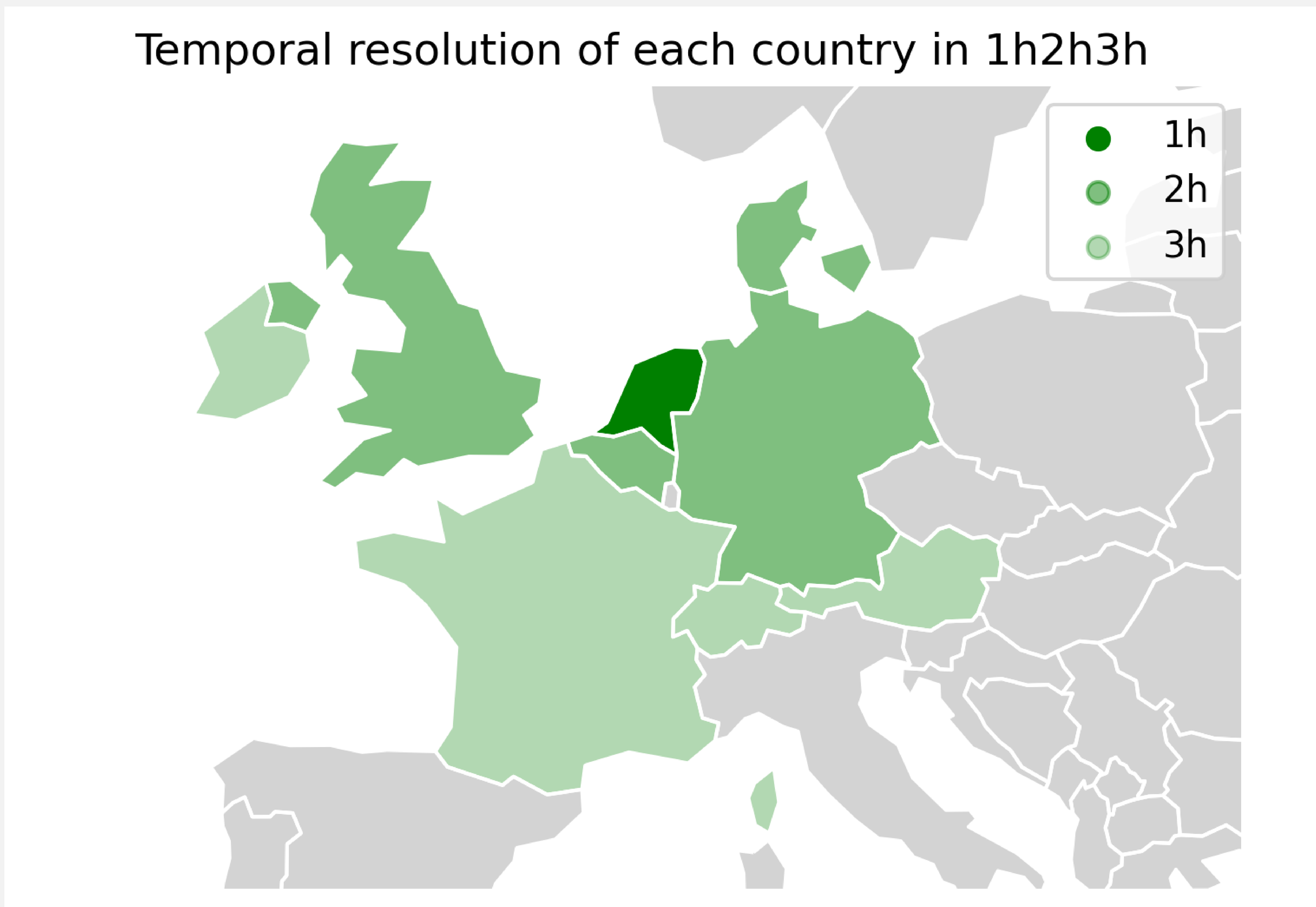
Specifications:
- One geographical node for each country
- Complete fleet of energy technologies according to TYNDP 2030 scenarios.
- Optimal operation of one year (8760 hours) [all_1h]
- Netherlands is the area of interest.

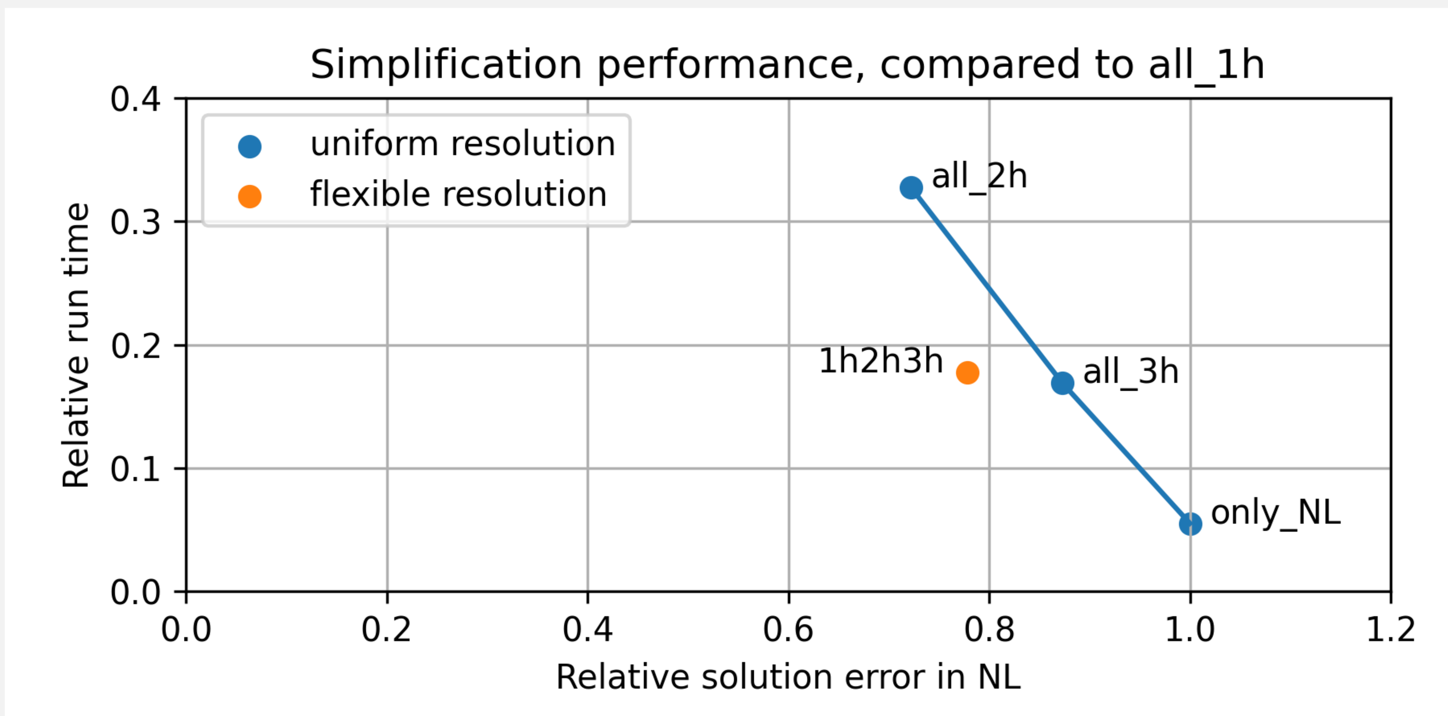
Simplifications with uniform resolution:
- The north-west EU in bi-hourly and tri-hourly resolution [all_2h, all_3h]
- Only NL is considered, in hourly resolution [only_NL]

Simplification enabled by the fully flexible resolution:
- NL in 1h; UK, BE, DE, DK in 2h; IL, FR, CH, AT in 3h. [1h2h3h]

Results

- For uniform resolution, run time decreases at the expense of accuracy.
- 1h2h3h is relatively more accurate at computational cost similar to all_3h
- Note that the resolution is on the mathematical formulation, not the data. Therefore, the model creation time also decreases.





Conclusion

- Introducing fully flexible temporal resolutions of flexibility in the temporal resolutions of energy flows and balances.
- Temporal resolutions are not necessarily multiples of each other and can vary across the temporal horizon.
- Illustration with an example of an electrolyzer.
- Demonstrated an improvement in computational efficiency and accuracy.

[1] Tejada-Arango, D. A., Morales-España, G., Clisby, L., Wang, N., Siqueira, A. S., Subayu, A., ... & Gao, Z. (2023). Tulipa Energy Model: Mathematical Formulation. *arXiv preprint arXiv:2309.07711*.

Any further questions or ideas? Contact us! z.gao1@uu.nl m.gazzani@uu.nl