Three Pillars of Hourly Matching: A Tour From Model Land to Real World

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The Three Pillars

- A concept of **hourly matching** got into the spotlight with debates on clean hydrogen regulation
- Also a foundation for voluntary 24/7 carbon-free electricity (CFE) procurement
- Set of rules and regulations, aka **the Three Pillars** address aspects of temporal alignment, geographical scope, and additionality of clean energy supply
- Today, let's:
  – discuss the Three Pillars in the real world and in the mathematical models
  – try to bridge the gap between the two

ChatGPT4 hallucination, 2024

I Pillar: Temporal matching

Discussion: Implementing stricter regulations requires assessing the impact on hydrogen production costs.

Hourly electricity matching is the only reliable way to reduce emissions from green hydrogen: study

Annual correlation of additional renewable power can push green H2 carbon intensity above that of blue hydrogen made with abated fossil gas, say German researchers

Proposed stringent EU rules on green hydrogen 'would put the brakes on development'

New plans on 'additionality' and strict hour-by-hour coupling of wind and solar output to electrolysers would increase the price of renewable H2, says RWE

Publication 13 October 2022 • 04:45

Sustainaweekly - Not-so-green hydrogen perhaps a necessary evil

Sustainability Energy transition

'Far from perfect' | Strict rules in new delegated act will 'make green H2 projects more expensive': Hydrogen Europe

Announcement is nevertheless welcomed by industry as it will enable companies to 'finalise investment decisions and business models'

Hydrogeninsight (February 2023), Abnamro (October 2022), rechargenews (May 2022), Hydrogeninsight (February 2023)

Temporal matching: definition

Hourly matching is modelled with a constraint, which matches electricity demand for electrolysis process with generation of renewable resources on an hourly basis.

$$\sum_{r \in R} g_{r,t} + \sum_{s \in S} \left(\bar{g}_{s,t} - \underline{g}_{s,t} \right) - ex_t = d_t$$

Zeyen et al. (2023): Temporal regulation of renewable supply for electrolytic hydrogen

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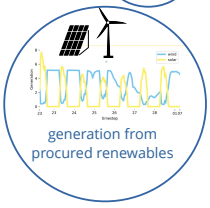

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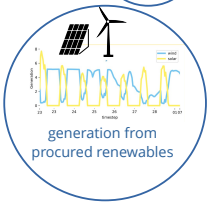

battery
charging
discharging

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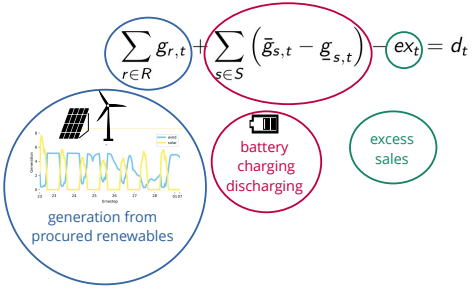

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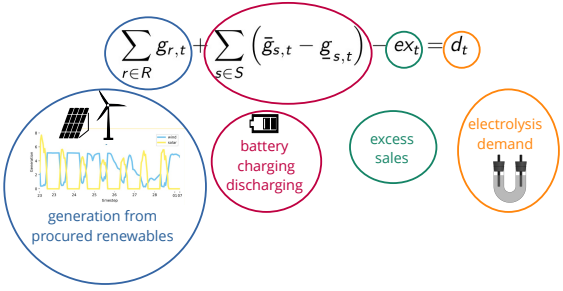

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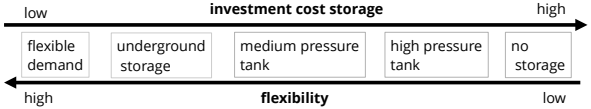
Temporal matching: flexibility changes everything



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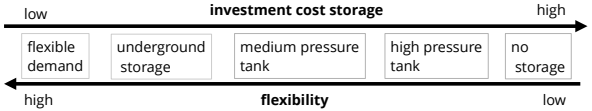
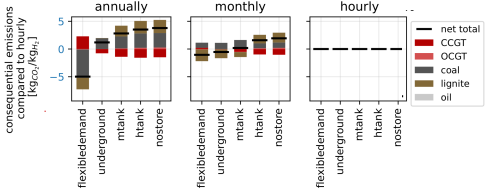
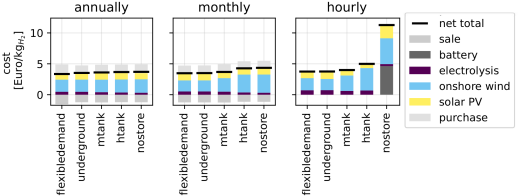


Emissions



Hydrogen production costs

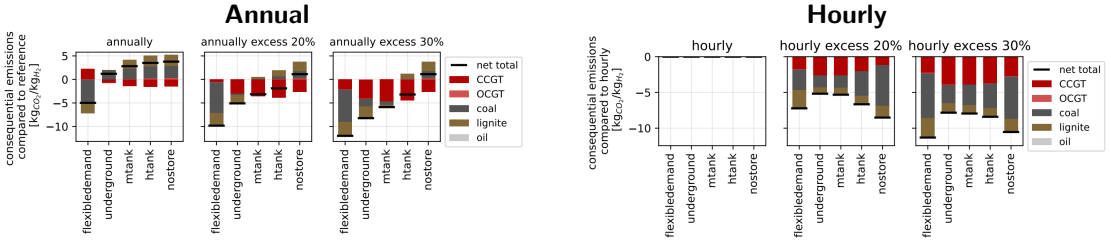


Flexibility **reduces** emissions and costs.

Zeyen et al. (2023): Temporal regulation of renewable supply for electrolytic hydrogen

Temporal matching: higher excess sales reduce emissions and costs

The **costs of hydrogen production decrease** by up to 30% in case of flexible demand + hourly matching due to the larger profits from excess sales.



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Temporal matching: considering grid CFE supply

Here, the **hourly matching constraint** is extended to include electricity consumption from the regional grid:

$$\sum_{r \in CFE, t \in T} g_{r,t} + \sum_{s \in STO, t \in T} \left(\bar{g}_{s,t} - \underline{g}_{s,t} \right) - \sum_{t \in T} ex_t + \sum_{t \in T} CFE_t \cdot im_t \geq x \cdot \sum_{t \in T} d_t$$

A "CFE score of the grid" CFE_t can be seen as the percentage of clean electricity in each MWh of imported electricity from the regional grid to supply participating 24/7 loads in a given hour.

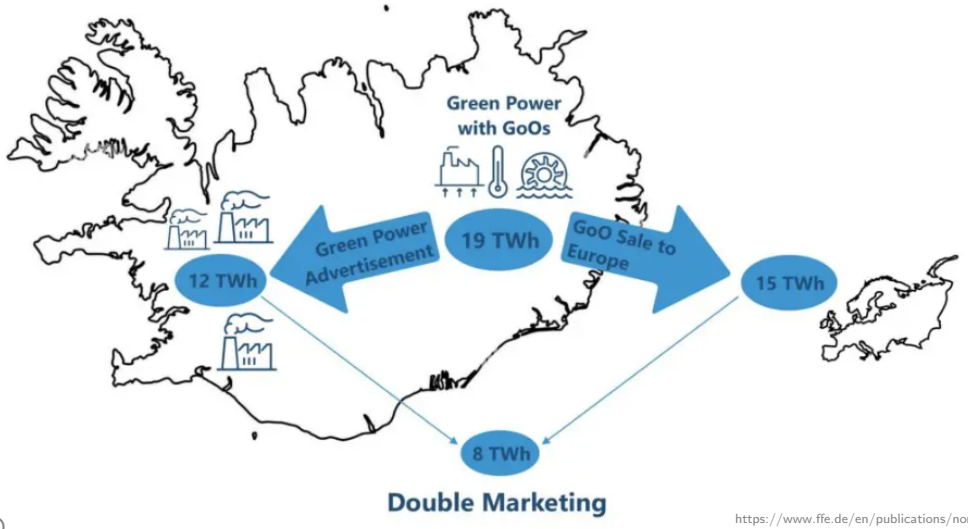
Challenges:

– Choosing a **geographical scope** to calculate CFE_t

– Considering a **residual mix**

– $\sum_{t \in T} CFE_t \cdot im_t$ is a **nonconvex term**

II Pillar - Geographical matching



https://www.ffe.de/en/publications/norway-and-the-double-marketing-of-renewable-energies/

Geographical matching

Microsoft signs 24/7 nuclear power deal with Constellation for Boydton data center

Matched carbon-free energy brings facility close to round-the clock carbon-free energy

June 30, 2023 By: **Peter Judge** 1 Comment

Microsoft has signed an agreement with nuclear power producer Constellation Energy, to bring a data center in Boydton Virginia closer to operating on 100 percent carbon-free energy round the clock.

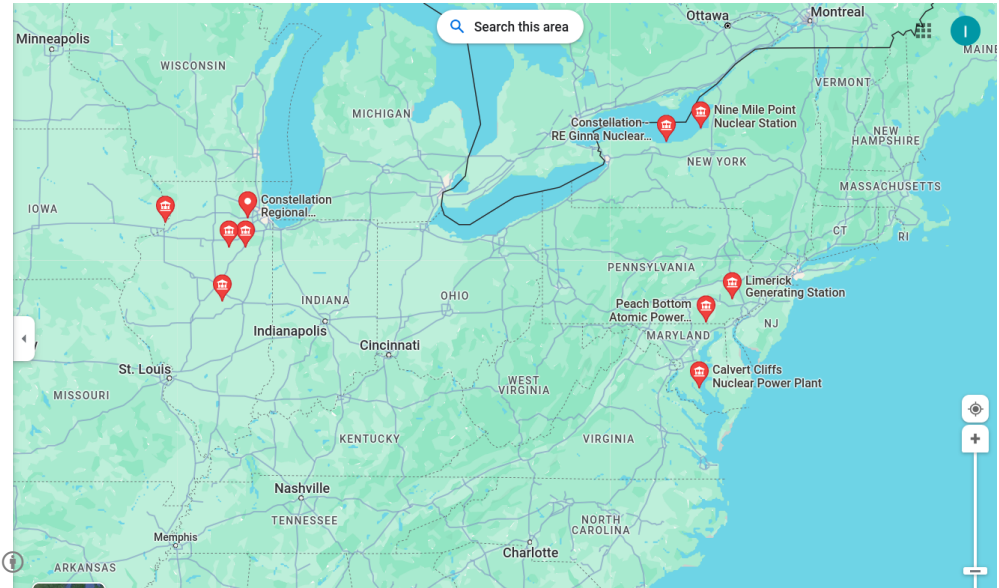
The Boydton facility will receive up to 35 percent in "environmental attributes" based on Constellation's nuclear power production, which will complement Microsoft's recent wind and solar energy purchases to put the data center very close to 100 percent carbon-free electricity 24/7.

Constellation is the largest provider of carbon-free energy (CFE) in the US, with 86 percent of its output coming from the 15 nuclear power stations it owns across the US.

None of these nuclear plants are in Virginia, but the company uses a CFE matching platform to

datacenterdynamics "Microsoft signs 24/7 nuclear power deal with Constellation for Boydton data center" (June 30, 2023)

Geographical matching



Geographical matching for green hydrogen production

How far can renewable generation and electrolysis be apart?

- Regulation in the EU: Geographical matching within one **bidding zone**.
- Model implementation is straightforward.

Challenges: Especially in large bidding zones there can be **transmission bottlenecks** actually hindering the transport of renewable generation to the electrolysis.

ACER, 2021

III Pillar - Additionality

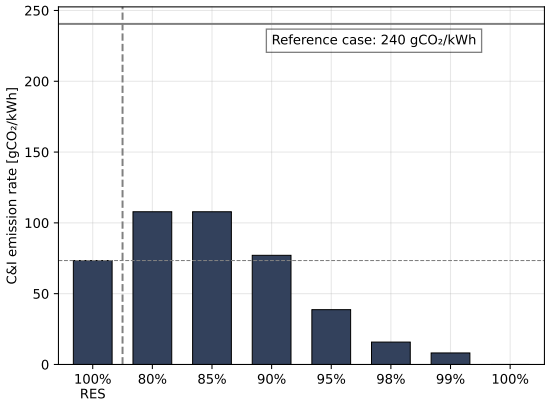
- **Idea**: carbon-free energy supply enabling the deployment of clean electricity generation (or clean hydrogen production) should be new—**and additional**—to the grid, i.e., it would *not* have occurred without the action of the claiming party.
- **Real world**: Complicated, there is no conterfactual
- **Models**: Complex (really!)

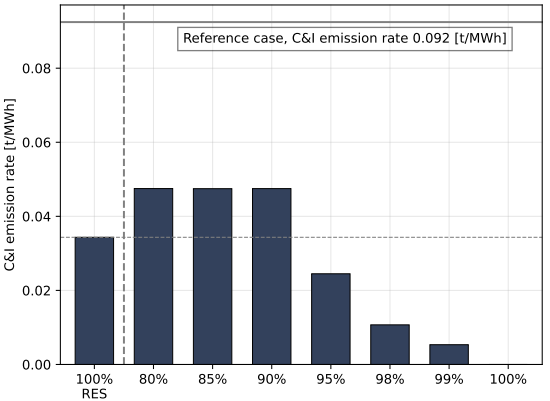
Additionality: definition challenges

- **Voluntary clean electricity procurement**: "Generally speaking, Google seeks to sign contracts to purchase both electricity and carbon-free attributes from clean energy projects that are in the development stage" (Google, 2021).
- **EU Delegated Act for Renewable Hydrogen**: "Hydrogen producer need to conclude power purchase agreements (PPA)s with new and unsupported renewable generation capacities."

Challenge: Hard to define if renewables are truly additional or would have been built in any case to reach national renewable generation targets.
NB: What should be additional: capacity (MW) or energy (MWh)?

Additionality: how to model a background grid 1/2?





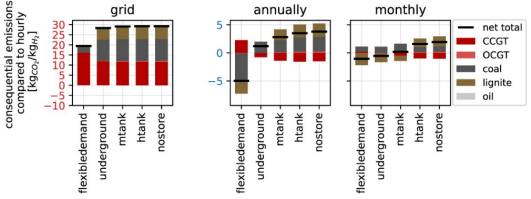
An illustrative example of 24/7 CFE matching in Germany 2025. Left: constrained RES expansion (aligned with the national plan), Right: unconstrained RES expansion

https://zenodo.org/records/7180098
https://zenodo.org/records/10407831

Additionality: how we model a background grid 2/2?

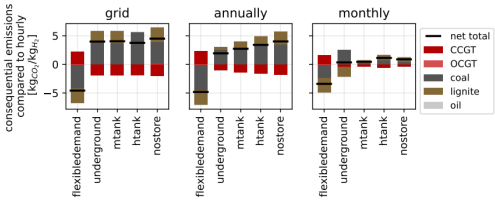
Two step optimisation

Clear additionality



One step optimisation

RES compete for good resources



There are many studies who analysed the impact on how additionality is modelled in more detail, e.g. Giovanello et al. (2024), Langer et al. (2024).

Take aways

1. Do not take results for granted, try to challenge everything!
   "We must fight our biases to see the solutions" (Auke Hoekstra)
2. Talk to others in research community, share your concerns!
   "A problem shared is a problem halved" (Old saying)

ChatGPT4 hallucination, 2024

Contacts, Resources, Acknowledgements

References: **Temporal regulation of renewable supply for electrolytic hydrogen (2023)**
References: **More about the 24/7 CFE research project (2022-2024)**

Code: This work done in a spirit of open and reproducible research:
🔓 code: **github.com/PyPSA/247-cfe**
🔓 code: **https://zenodo.org/records/8324521**

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Dr. Iegor Riepin, iegor.riepin@tu-berlin.de