A talk on 24/7 Carbon Free Energy matching

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RGI Civil Society Training Series
Balancing Connections: Introduction to flexibility in a renewables-based energy system
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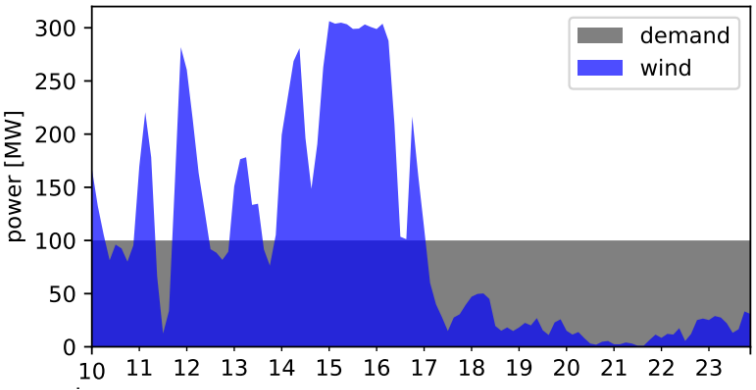
Buying more than just energy

- Many companies claim to be "powered by clean energy". The meaning of these claims, however, **varies greatly**
- Some companies procure "unbundled certificates", such as Guarantees of Origin to **indicate sustainability** credentials
- Many buyers recognise limitations of the unbundled certificates and **turn towards Power Purchase Agreements** (PPAs)

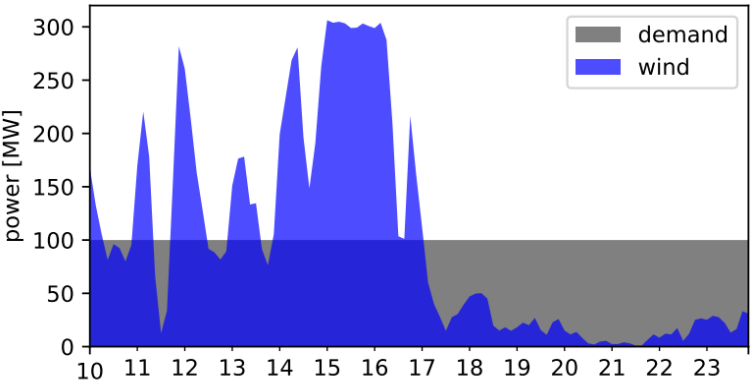
More than **400 companies** worldwide have pledged to match their electricity demand with renewable electricity on an **annual basis**

Great, so what's the problem? 1/2



- **Temporal mismatch**: 100% RES PPAs result in periods of oversupply and deficit.
- Hours of deficit must be met by rest of system – grid supply may have high emissions and high prices
- Extended period of supply deficit is expensive to bridge with battery storage.

Great, so what's the problem? 2/2



There are even more challenges:

- No **simultaneity**
- Lack of **additionality**
- Displaced **location**
- Exposure to **market risk**
- Need for **backup**

24/7 carbon-free energy

- There is growing interest in voluntary clean electricity procurement to cover consumption with clean energy supply on a **hourly basis**.
- Achieving 24/7 Carbon-Free Energy (CFE) means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources, **round-the-clock**.
- 24/7 CFE matching principles necessarily require **additionality** and **geographical matching** of renewable generation.

The **24/7 Carbon-free Energy Compact** initiative was launched in 2021.
Now: 167 members.

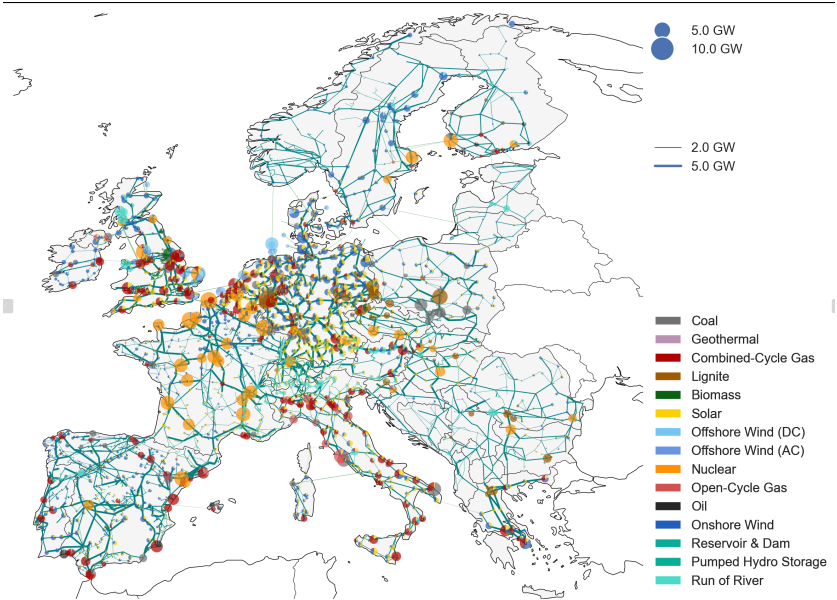
Open questions

We want to find out:

- How can we achieve **hourly clean energy** matching?
- What is the **cost premium** of 24/7 CFE?
- Can **long-duration storage** or **new dispatchable clean** technologies help?
- If many companies take a 24/7 approach, how does this effect the **rest of the system**?
- What role can **demand flexibility** play for 24/7 CFE?

Looking at this problem through the lens of energy modelling

Energy modelling world



PyPSA(-Eur) toolbox

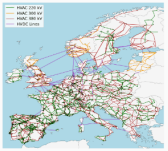
- PyPSA (Python for Power System Analysis) is an open source toolbox for for state-of-the-art energy system modelling
- PyPSA development and maintenance is coordinated by TU Berlin, **Department of Energy Systems**
- The tools used worldwide by research institutes, NGOs and private sector Our **list of users**.

PyPSA

A python software toolbox for simulating and optimising modern power systems.

Documentation »

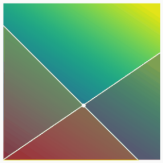
PyPSA-Eur



A Sector-Coupled Open Optimisation Model of the European Energy System

Documentation »

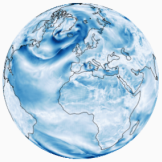
Linopy



Linear optimization interface for N-D labeled variables.

Documentation »

Atlite



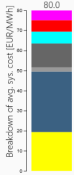
A Lightweight Python Package for Calculating Renewable Power Potentials and Time Series

Powerplantmatching

A toolset for cleaning, standardizing and combining multiple power plant databases.

Documentation »

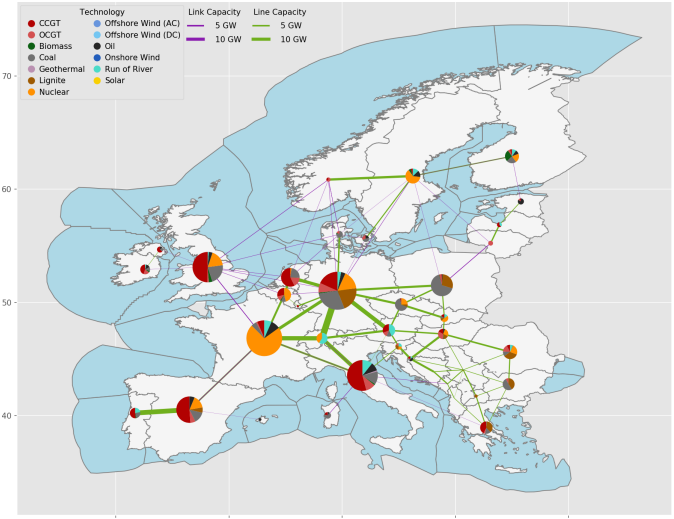
Model Energy



An online toolkit for calculating renewable electricity supplies.

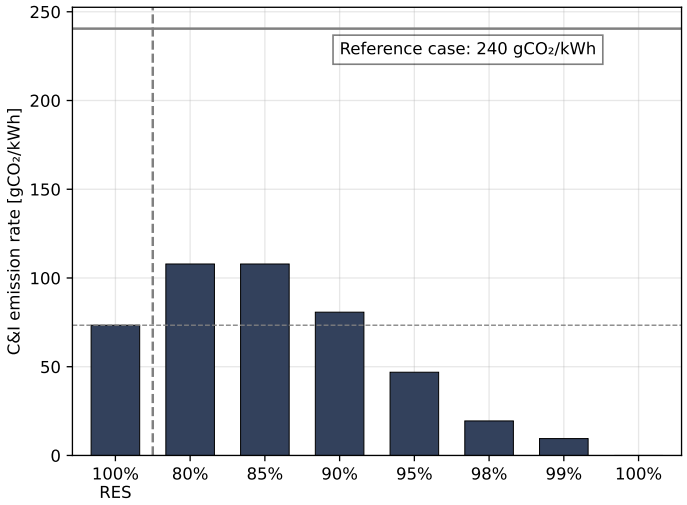
24/7 CFE: clean generation capacity procurement, costs and system impacts

Scenario setup:
"System-level impacts of 24/7 CFE procurement in Europe" (2022)



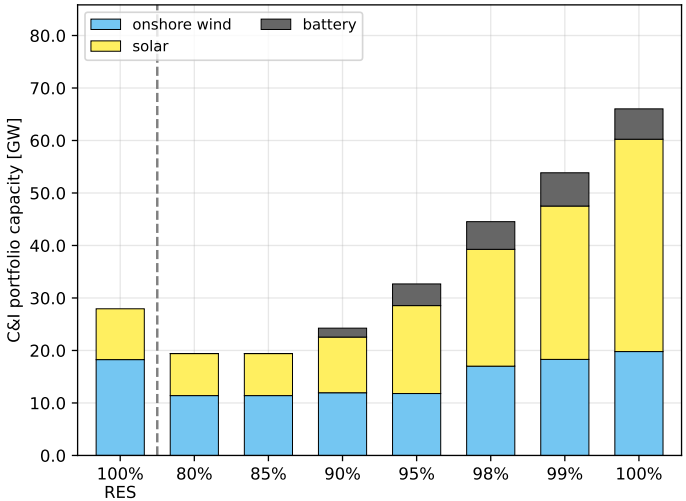
- We model the European power system with **capacity expansion** for the years **2025** & **2030**
- Consumers following 24/7 approach can be located in one of the **four zones**: Ireland, Denmark (zone DK1), Germany and the Netherlands
- A set of constraints to model a situation when a **fraction of corporate and industry (C&I) demand** in a selected zone commits to 24/7 CFE (i.e. C&I have an aggregated demand profile)
- Study: **doi.org/10.5281/zenodo.7180098**
- Paper: **doi.org/10.1016/j.esr.2024.101488**

Average emissions of procured electricity



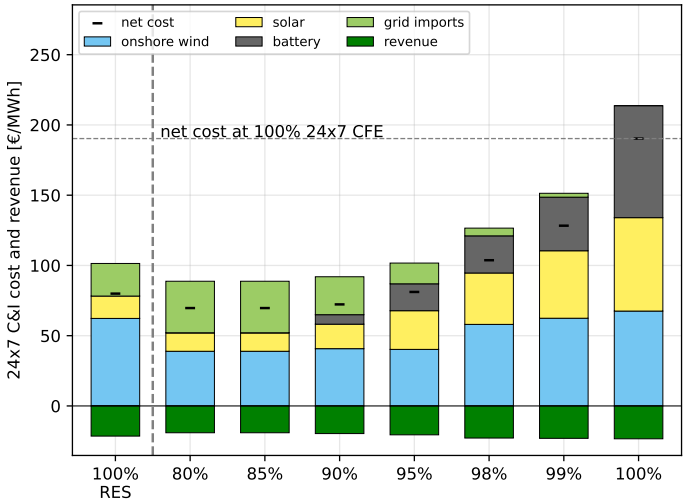
- Procurement affects **average emissions rate** of used electricity
- Reference system has average emissions rate at 240 $kgCO_2/MWh$
- 100% annual RES reduces rate to 73 $kgCO_2/MWh$
- As CFE target tightens, emissions **drop to zero**

Portfolio of procured capacity



- 100% RES for 10% of C&I demand (3.8 GW load) is met with 28 GW of **onshore wind and solar**
- Above 90% CFE **batteries enter the mix**
- With only wind, solar and batteries, a **large portfolio** is needed to bridge dark wind lulls (*Dunkelflauten*)

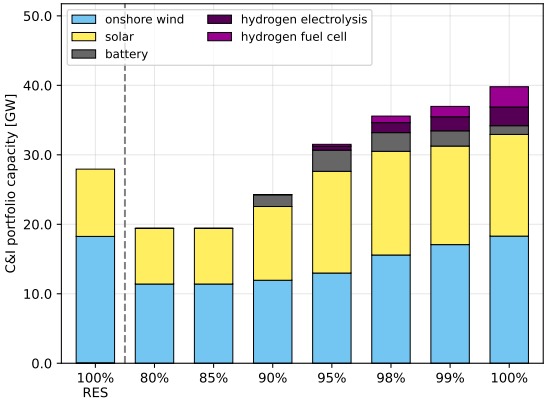
24/7 CFE cost breakdown

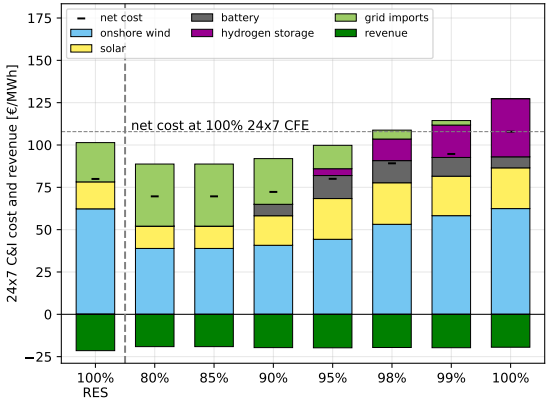


- The **cost breakdown** shows the average costs of meeting demand with the policy, including grid electricity consumption costs netted by revenue selling to the grid
- There is only a **small cost premium** going to 90-95% CFE matching
- But the last 2% of hourly CFE matching more than **doubles the cost**

Including long-duration storage (LDES)

Adding **long-duration energy storage (LDES)** to the mix (represented here by hydrogen storage in salt caverns at 2.5 €/kWh) **reduces the portfolio size** for 100% CFE and **limits the cost premium to 50%** over annual RES matching.





What role can demand flexibility play for 24/7 CFE?

ICT companies work demand flexibility concepts and technical solutions

DATA CENTERS AND INFRASTRUCTURE

Our data centers now work harder when the sun shines and wind blows

Apr 22, 2020 · 3 min read

Ana Radovanovic
Technical Lead for Carbon-Intelligent Computing

Share

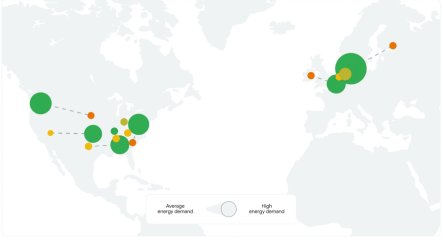
Addressing the challenge of climate change demands a transformation in how the world produces and uses energy. Google has been carbon neutral since 2007, and 2019 marks the third year in a row that we've matched our energy usage with 100 percent renewable energy purchases. Now, we're working toward 24x7 carbon-free energy everywhere we have data centers, which deliver our products to billions of people around the world. To achieve 24x7 carbon-free energy, our data centers need to work more closely with carbon-free energy sources like solar and wind.

SUSTAINABILITY

We now do more computing where there's cleaner energy

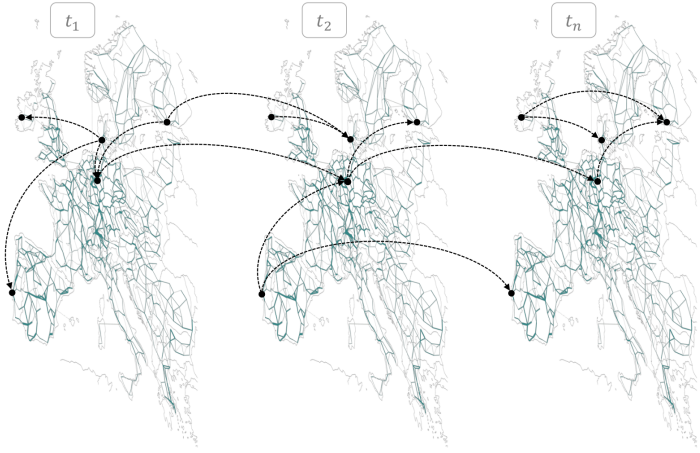
May 18, 2021 · 2 min read

Ross Koningstein
Co-founder, Carbon-Intelligent Computing



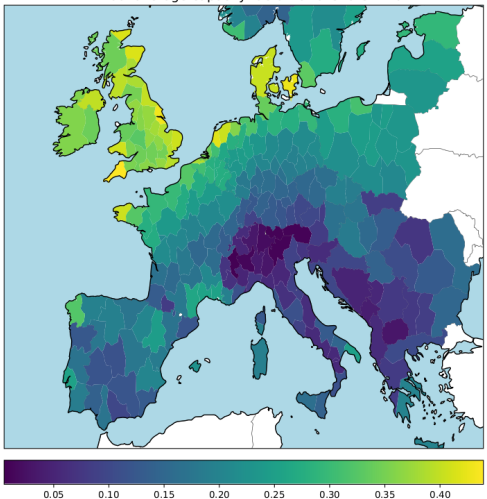
Sources:
blog.google/data-centers-work-harder-sun-shines-wind-blows
blog.google/carbon-aware-computing-location

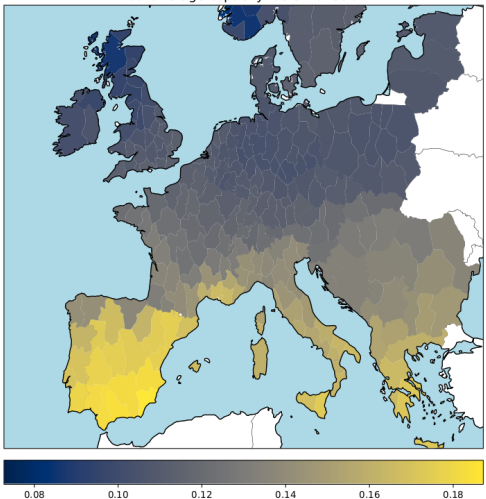
Study: The value of space-time load-shifting flexibility for 24/7 carbon-free electricity procurement (July 2023)



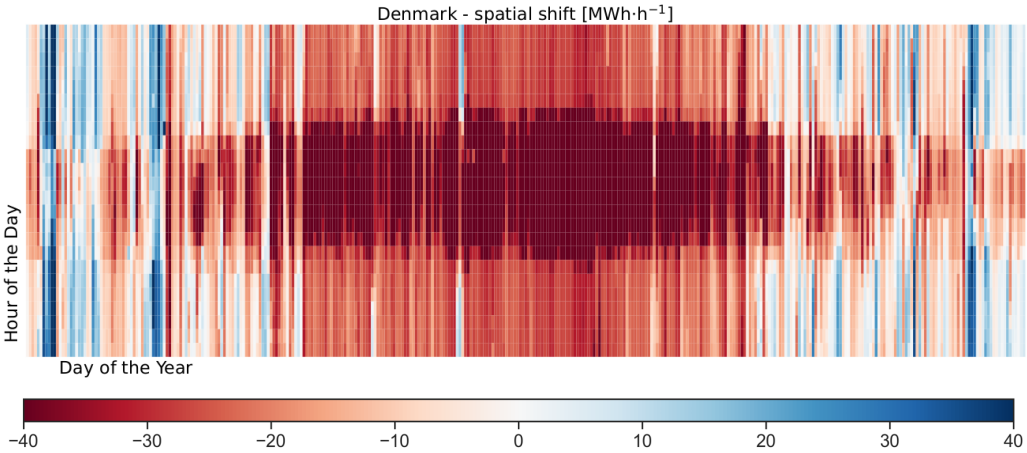
- Key focuses:
  – How can demand flexibility reduce the required **resources** and **costs** of 24/7 CFE matching?
  – What are the **signals** for optimal utilisation of demand flexibility?
  – What are the trade-offs and synergies from co-optimisation of **spatial** and **temporal** load shifting?
- Open-access study:
  🔓 study: **zenodo.org/records/8185850**
  🔓 code: **github.com/PyPSA/247-cfe**
- Follow-up research paper: "Spatio-temporal load shifting for truly clean computing"
  🔓 study: **arxiv.org/abs/2405.00036**
  🔓 code: **../space-time-optimization**

Quality of local renewable resouces

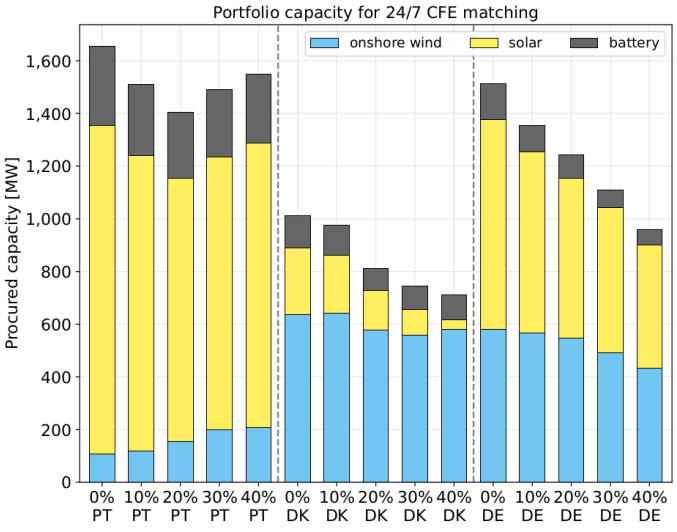




Time-series of optimized spatial load shifts (locations: PT-DK-DE)



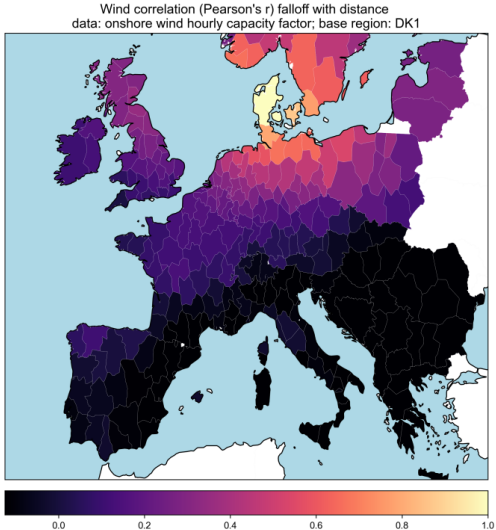
Procurement as a function of load flexibility (locations: PT-DK-DE)

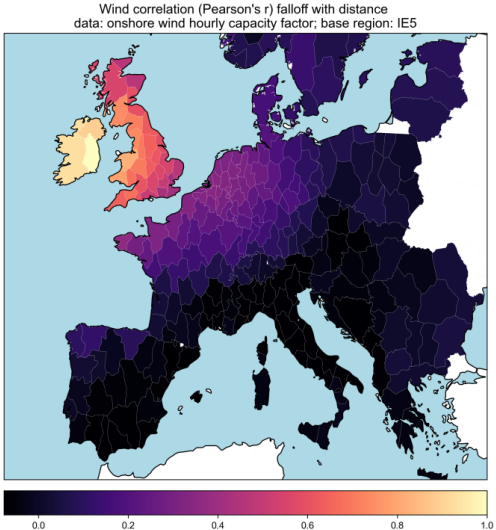


- Optimal procurement strategies to match 100 MW load with 24/7 CFE displayed per datacenter location and share of flexible loads {0% .. 40%}
- The required portfolio capacity is **significantly reduced** when load shifting becomes possible
- Demand flexibility facilitates the **efficiency and affordability** of 24/7 CFE matching

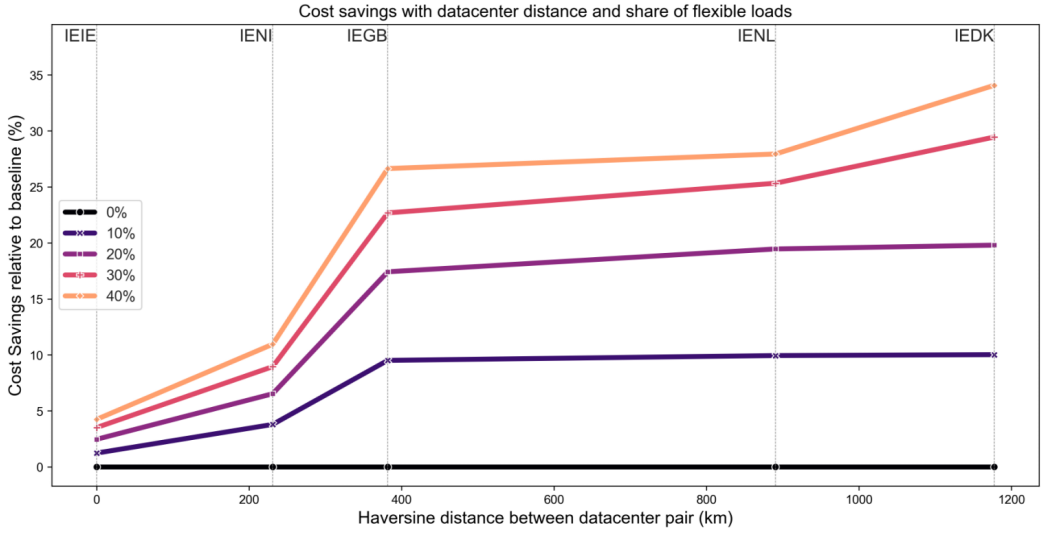
Scenario: 24/7 CFE with 100% score, commercially available technologies, 2025 DEA technology cost assumptions co-optimised spatial & temporal load shifts

Low correlation of wind power generation over long distances

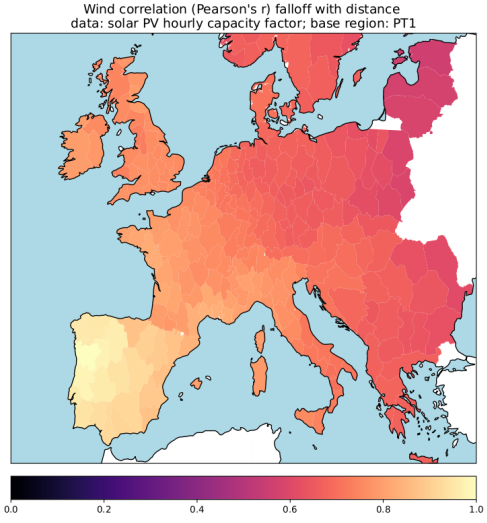


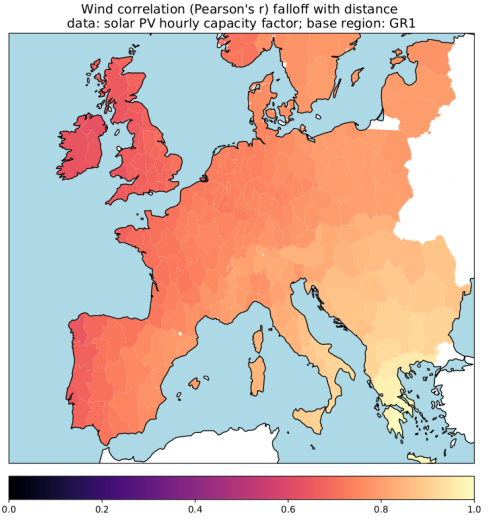


Cost savings as a function of distance between datacenter pair

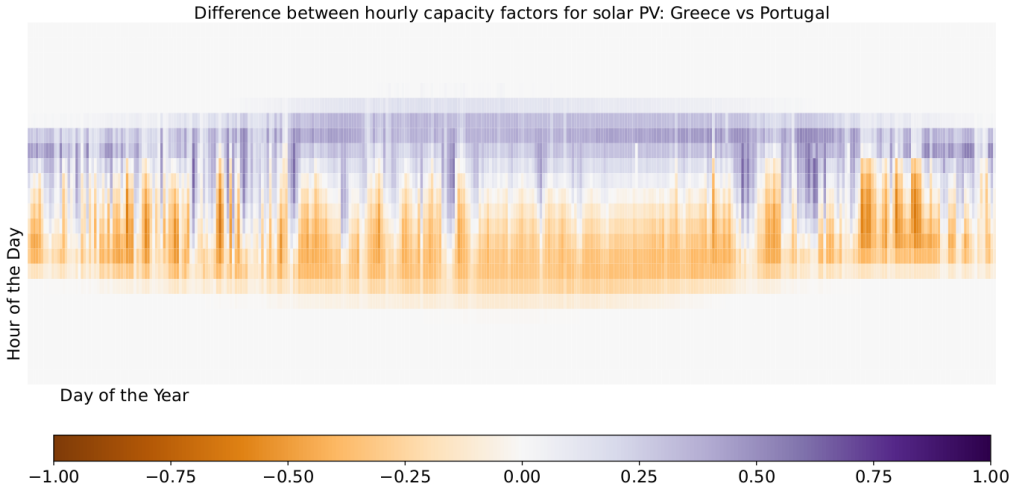


Time lag in solar radiation peaks due to Earth's rotation (1/2)

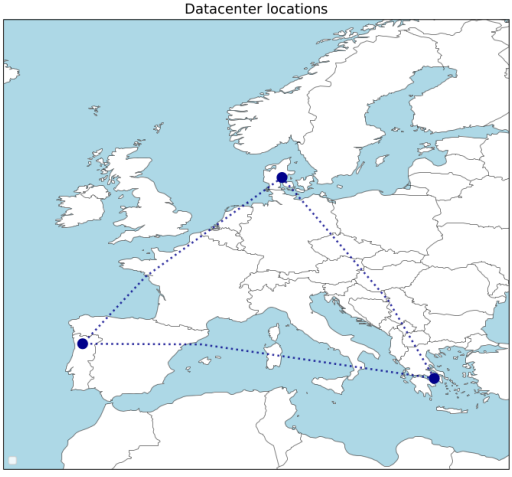


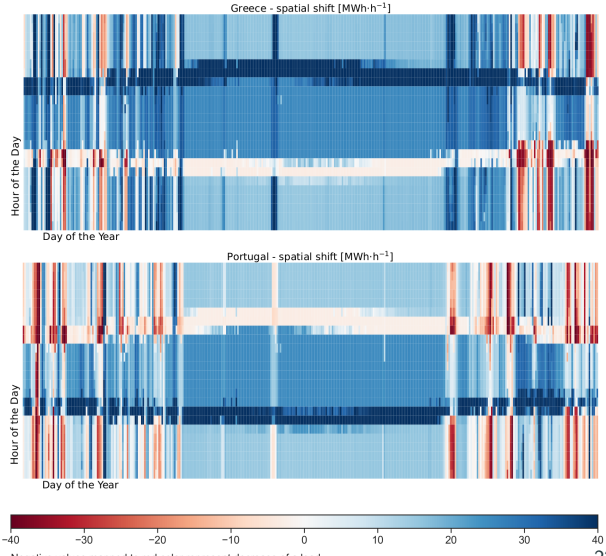


Time lag in solar radiation peaks due to Earth's rotation (2/2)



Time-series of optimized spatial load shifts (locations: DK-PT-GR)





Takeaways and resources

24/7 CFE resources:
– European 24/7 CFE Hub: **https://247.eurelectric.org/**
– EnergyTag: **https://energytag.org/**
– Climate Group — 24/7 Coalition: **https://www.theclimategroup.org/support-247**

Check out Princeton University Zero Lab's great work on 24/7 CFE:
https://acee.princeton.edu/24-7/

Hourly matching research for hydrogen:
Temporal regulation of renewable supply for electrolytic hydrogen by Elisabeth Zeyen et al, 2024, Environ. Res. Lett. 19, 024034

Learn more about our project:
Webpage: **https://irieo.github.io/247cfe.github.io/**
🔓 **Code:** This project—each study, paper and slide deck—is done in a spirit of open and reproducible research

Annex

How is 24/7 carbon-free electricity (CFE) measured?

Technische Universität Berlin

Electricity in an hour is counted as **carbon-free (CFE)** if:

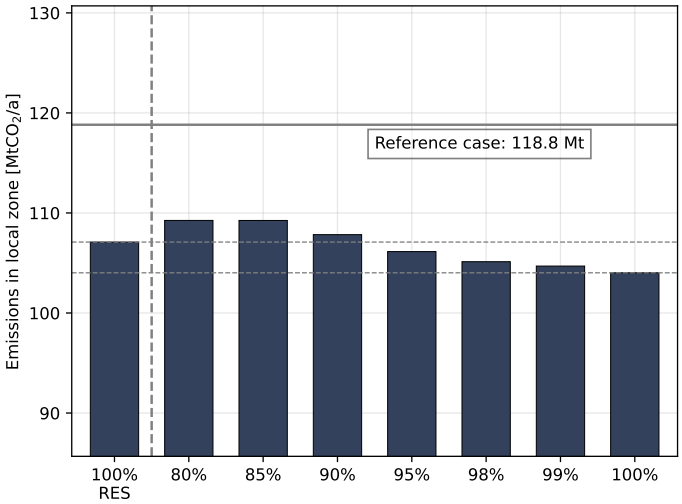
- Directly contracted carbon-free assets are generating (generation above company demand is ignored)
- Energy consumed from the grid is carbon-free (counted according to mix in local bidding zone and any imports)

CFE fraction in each hour is averaged to **CFE score** for year.

In any given hour, a data center's energy profile takes one of the following forms:

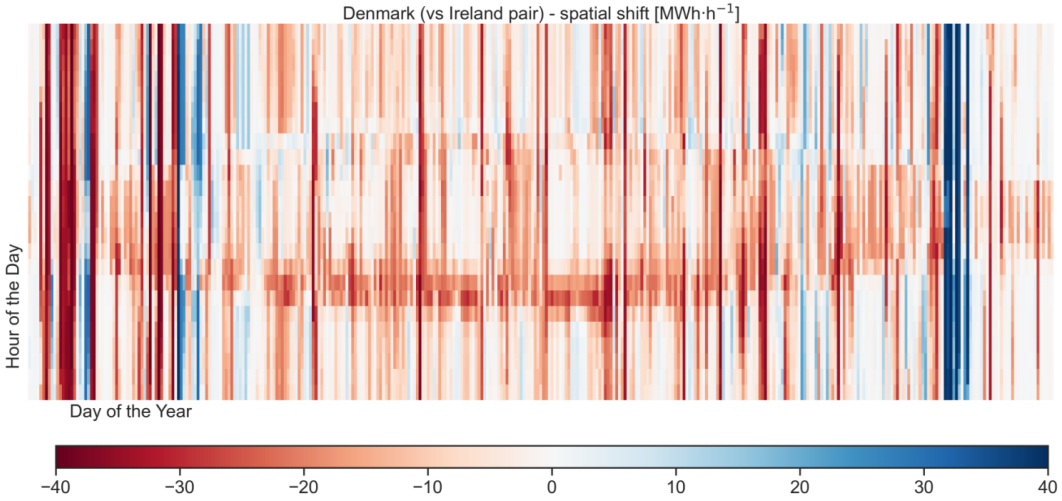
Google 2021, 24/7 CFE: Methodologies and Metrics

System emissions are also reduced (power sector values for Germany)

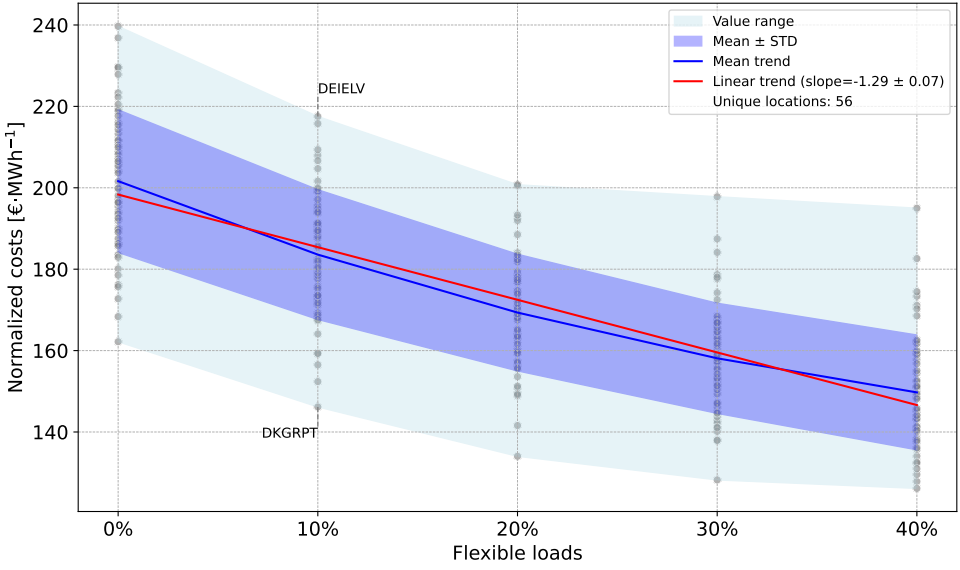


- **CO_2 emissions in the local bidding zone** are also reduced by CFE procurement
- If 10% of C&I follows 24/7, total system emission are reduced further compared to 100% RES
- Two effects are responsible: **volume effect** of more CFE with high targets; **profile effect** of the timing of feed-in at highly-emitting times

Time-series of optimized spatial load shifts (locations: DK-IE)



Results can be generalized beyond specific load locations



Also in the study on DSM for 24/7 CFE

- Scenarios for **co-optimised** and **isolated** utilisation of space-time load-shifting;
- Scenarios for 24/7 CFE with **98% and 100%** matching targets;
- Scenarios with different **24/7 technology options** (e.g., Long Duration Energy Storage);
- 24/7 CFE **cost breakdowns** and **procurement strategies** for individual locations;
- **Synergies** and **trade-offs** between spatial and temporal load shifting;
- Analysis of **net load migration** across locations;
- Simulated **energy balances** for selected datacenters.

Barriers to advanced clean technology commercialization

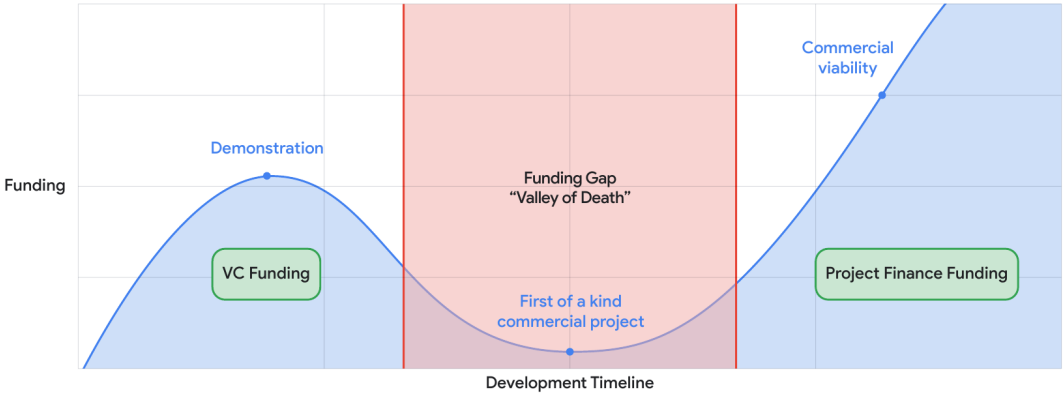
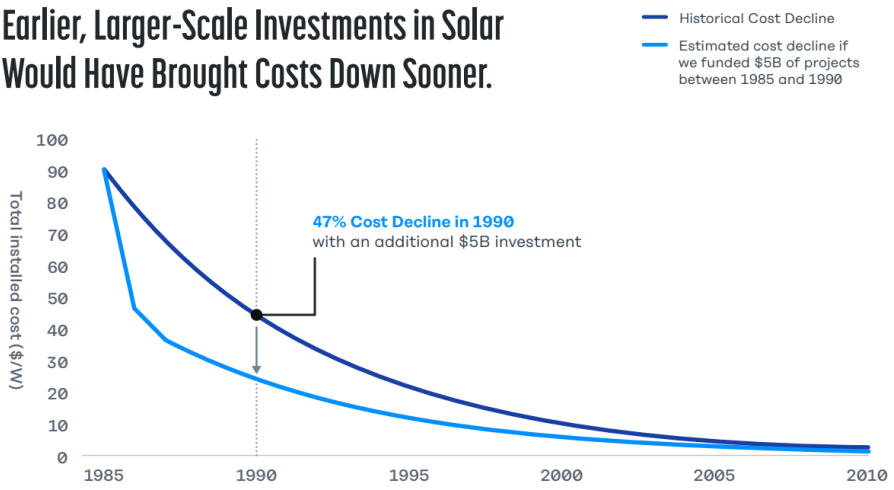


Illustration: Google (2023)
see also Prime Coalition (2022) study

Another perspective



Source: Breakthrough Energy analysis; data from MIT and IRENA

Illustration: B. Gates (2021)

see also: https://www.howsolargotcheap.com/

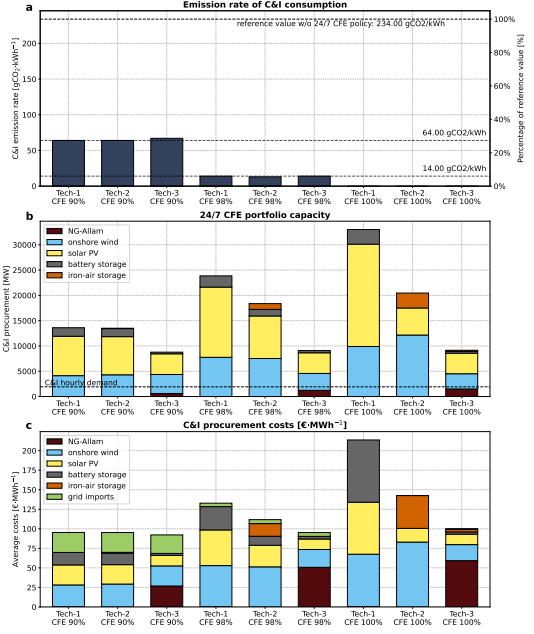
Research questions

- Key focuses:
  - What role can 24/7 CFE play in accelerating advanced clean electricity technologies?
  - How can 24/7 CFE procurement facilitate **technology learning**?
  - What are the associated **system decarbonization** effects?

- Open research:

  🔓 Study to be released soon: **247cfe.github.io/**

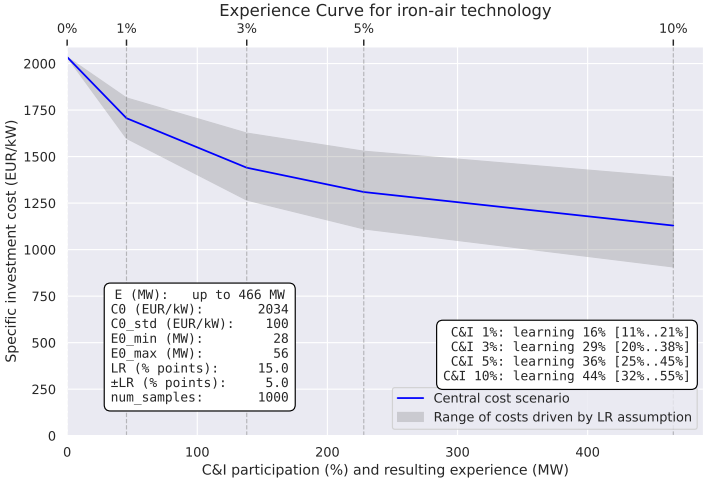
  🔓 Code: **github.com/PyPSA/247-cfe**

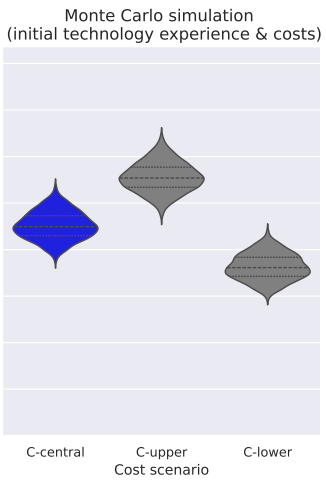


- With only wind, solar and batteries, a **large portfolio** is needed to bridge dark wind lulls (*Dunkelflauten*)
- This makes the last 2% of hourly CFE matching to come with a **high cost premium**
- Adding **LDES** to the mix (here: iron-air battery) or **clean firm generation** technology (here: NG-Allam plant) **reduces the portfolio size** and **limits the cost premium**
- Procurement affects **average emissions rate** of used electricity. Background grid (here: Germany 2025) has 234 gCO_2/kWh. As CFE target tightens, emissions of 24/7 CFE participants **drop to zero**

Scenario: Germany 2025
5% of C&I demand (1900 MW) follow 24/7 CFE
24/7 CFE with 90%, 98% 100% score
p1 commercially available technologies
p2 above plus LDES
p3 above plus clean firm generator

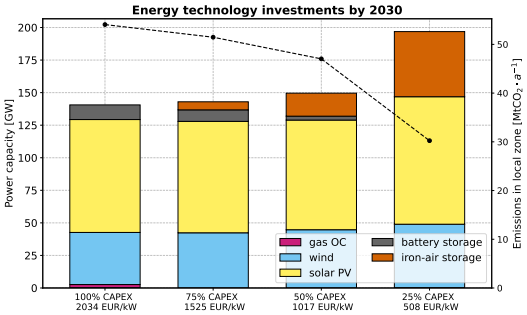
Impact of 24/7 CFE procurement on technology learning





Scenario: 24/7 CFE with 100% score
[0%..10%] of C&I demand follow 24/7 CFE
Learning model & Monte Carlo parametrisation are on figure

Impact of technology learning on background energy system



- Iron-air battery storage breaks even into technology investment mix with 25% CAPEX reduction (basis level: $2300/kW)
- **System-level emissions drop**: iron-air storage substitutes fossil-based peakers, and allows for efficient use of renewable excess energy
- For this effect, announced capacity of iron-air battery **has to be doubled twice**[1] with $LR \approx 0.15$
  [1] 56.5 MW / 5.65 GWh is planned by 2025
- ca. **EUR 0.35B investment** required to bring iron-air technology for economical break-even (an estimate based on LR, initial experience & costs, background system assumptions)

Scenario: Germany 2030
Varying CAPEX of iron-air battery
no C&I demand

“Virtuous circle” kickstarted by first 24/7 CFE commitments