Signals for spatio-temporal load shifting in 24/7 clean computing

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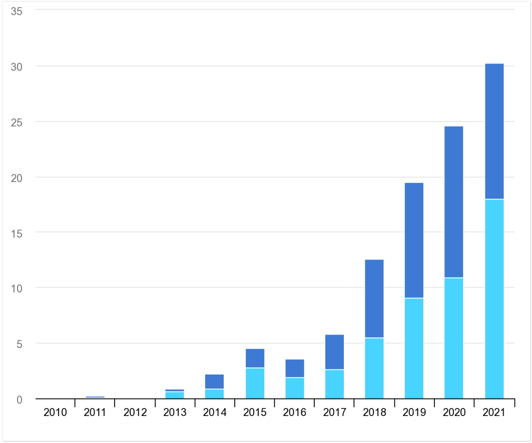
Buying more than just energy

- Many companies claim to be “powered by clean energy”. The meaning of these claims, however, **varies greatly**.
- Some companies procure “unbundled certificates”, such as Renewable Energy Certificates (RECs) or Guarantees of Origin (GOs) to **indicate sustainability** credentials.
- Many buyers recognise the problems associated with the unbundled certificates and **turn towards Power Purchase Agreements** (PPAs)
- The **ICT sector leads the way** in corporate renewable energy procurement. Based on the **IEA** estimates, Amazon, Microsoft, Meta and Google have become the four largest corporate purchasers of renewable energy, having contracted over 50 GW to data with PPAs.



Renewable energy capacity procured with power purchase agreements globally [GW].

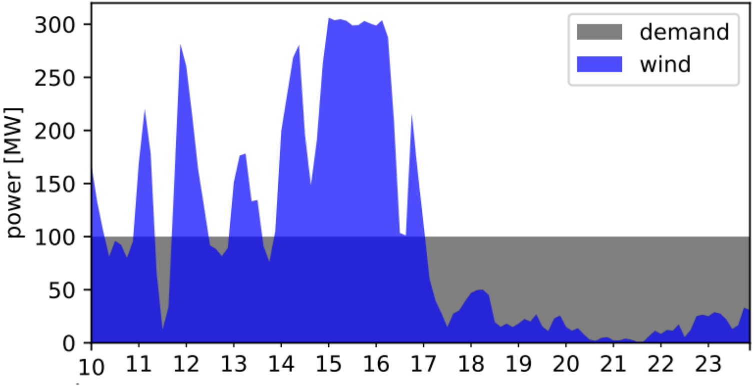
ICT sector (dark blue), all other sectors (light blue)

Image: IEA 2022

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

RE100

Great, so what's the problem?



- **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.

24/7 carbon-free energy

- There is growing interest from leaders in voluntary clean electricity procurement to cover their consumption with clean energy supply on a **24/7 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**.

The **24/7 Carbon-free Energy Compact** initiative was launched in 2021.
Now: 147 members.

Open and reproducible model-based research on 24/7 CFE

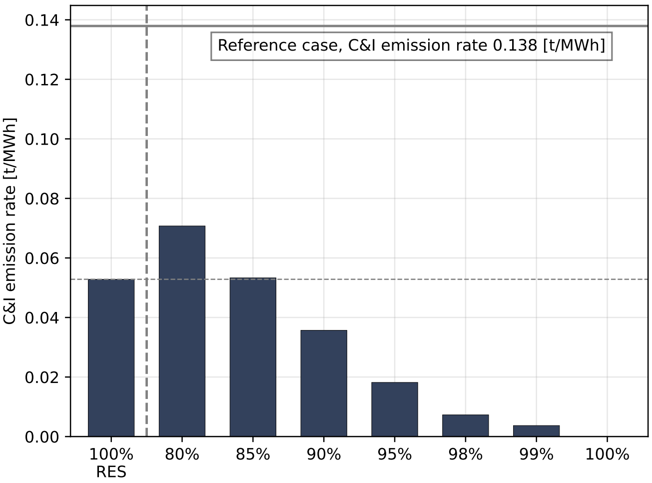
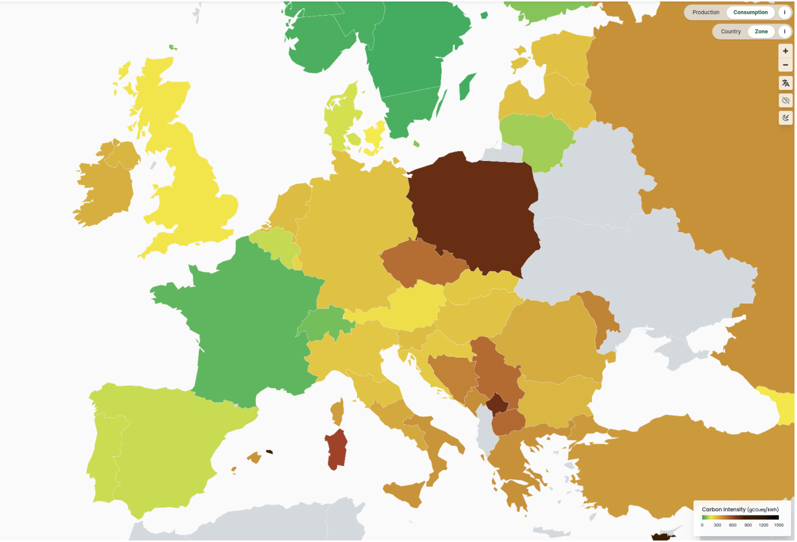


Figure from study "System-level impacts of 24/7 CFE procurement in Europe" (2022) **doi.org/10.5281/zenodo.7180098**

- Prior study highlights:
  - 24/7 CFE **reduces emissions** for participants and the system;
  - Reaching CFE for 90-95% of the time is possible with a small cost premium. Costs increase rapidly **above 95% CFE target**;
  - 24/7 CFE **stimulates innovation** and creates an early market for advanced technologies; LDES or clean firm technologies can help reducing the cost premium.
- Open question:
  What role can **demand flexibility** play for 24/7 CFE?

What signals do companies look at?



Carbon intensity of electricity consumed, 17 Feb 2024
Source: electricitymaps.com/map

Research on datacenter load flexibility use based on grid signals

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ELSEVIER

Electric Power Systems Research
Volume 212, November 2022, 108586

Using geographic load shifting to reduce carbon emissions

Julia Lindberg, Bernard C. Lesieutre, Line A. Roald

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https://doi.org/10.1016/j.epsr.2022.108586

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Mitigating Curtailment and Carbon Emissions through Load Migration between Data Centers

Jiajia Zheng • Andrew A. Chien • Sangwon Suh [4] • Show footnotes

Open Archive • Published: August 25, 2020 • DOI: https://doi.org/10.1016/j.joule.2020.08.001 •

Check for updates

Lindberg et al. (2022): doi.org/10.1016/j.epsr.2022.108586,
Zheng et al. (2020): doi.org/10.1016/j.joule.2020.08.001

ICT companies work on concepts and technical solutions

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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

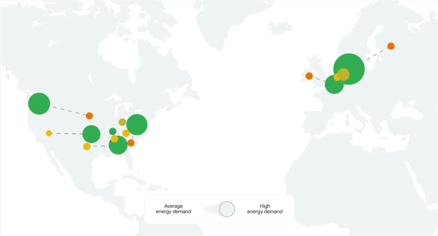
Addressing the challenge of climate change demands a transformation in how the world produces and uses energy. Google has been carbon neutral since 2007, and 2019 marks the third year in a row that we've matched our energy usage with 100 percent renewable energy purchases. Now, we're working toward 24x7 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

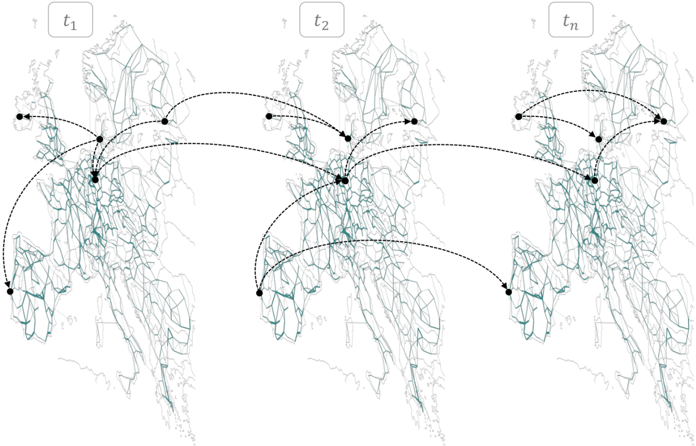
May 18, 2021 · 2 min read

Ross Koningstein
Co-founder, Carbon-Intelligent Computing



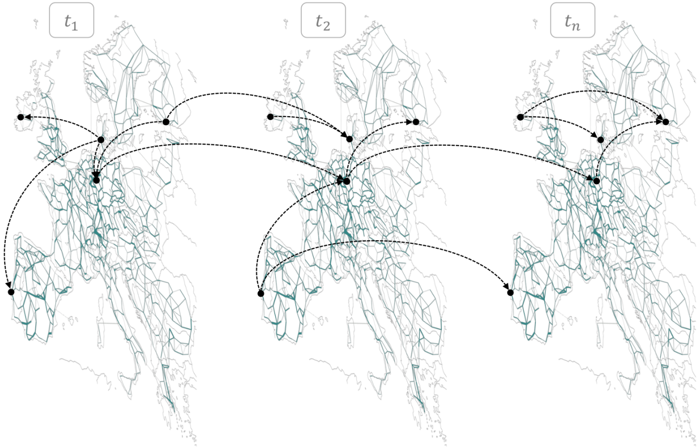
Sources:
blog.google/data-centers-work-harder-sun-shines-wind-blows
blog.google/carbon-aware-computing-location

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



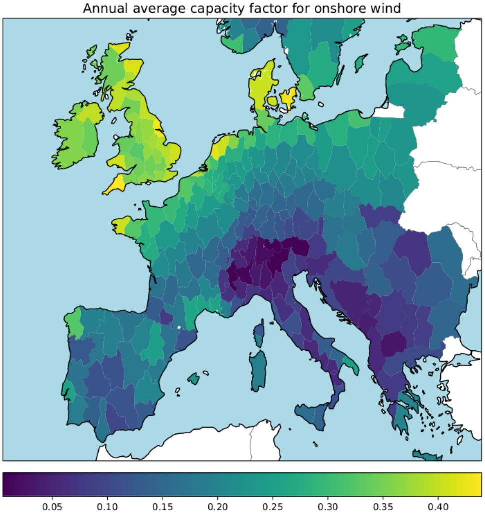
- Key focuses:
  - How can demand flexibility reduce the required **resources** and **costs** of 24/7 CFE matching?
  - What are the **signals** for optimal utilisation of demand flexibility?
  - What are the trade-offs and synergies from co-optimisation of **spatial** and **temporal** load shifting?
- Open-access research:
  - study: **zenodo.org/records/8185850**
  - code: **github.com/PyPSA/247-cfe**
- A follow-up research paper to be released in March 2024.

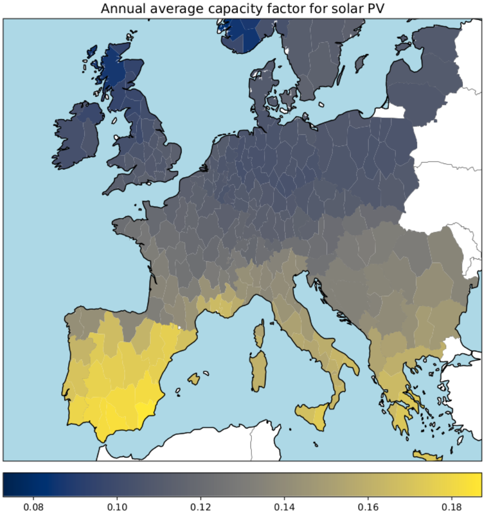
Methods and study design



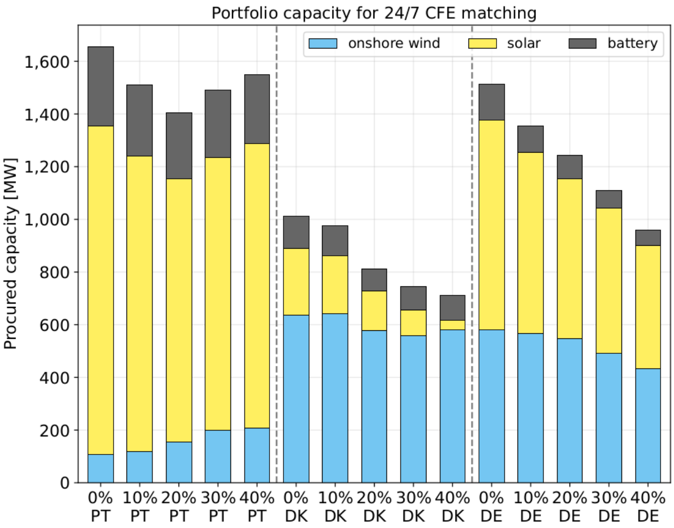
- The study is done with **PyPSA** – an open-source framework for modelling modern energy systems.
- Model scope: **ENTSO-E area** power system clustered to individual bidding zones, **hourly** temporal resolution.
- Geographically scattered datacenters that are managed collectively. An operating company follows **24/7 CFE strategy** in all locations.
- **Spatial** and **temporal** load shifting mechamisms.
- **"Flexible workloads"**, i.e. electricity loads that can potentially be shifted in space or in time, are assumed to be in a range of {0% .. 40%}.

Signal 1: quality of local renewable resouces





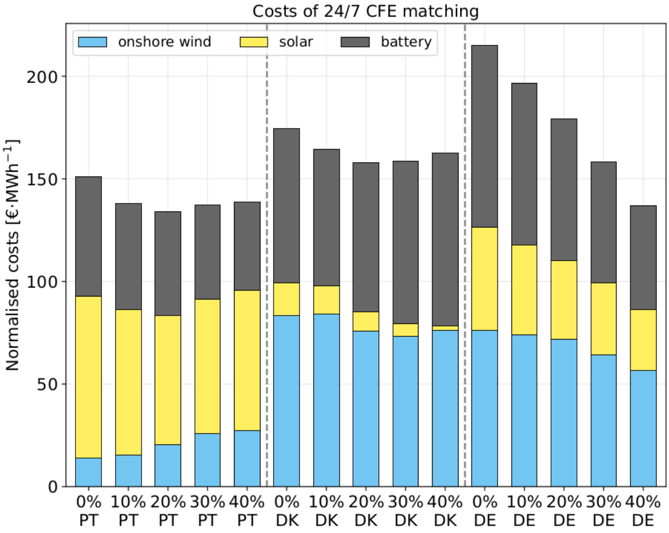
Procurement as a function of load flexibility (locations: PT-DK-DE)



- 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

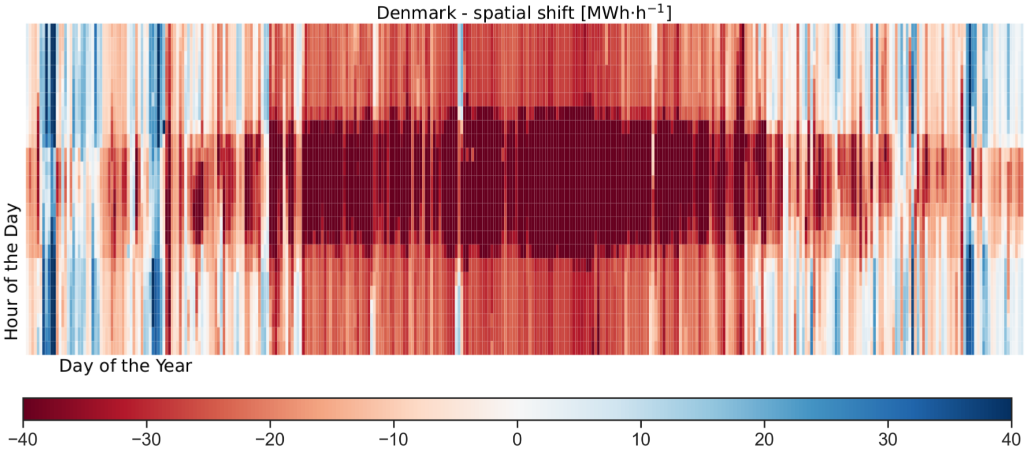
Costs as a function of load flexibility (locations: PT-DK-DE)



- The cost breakdown on the left shows the average costs (per MWh of consumption) of meeting demand with the 24/7 CFE.
- Demand flexibility is **especially helpful for resource-constrained locations** where hourly matching with renewable energy is difficult.

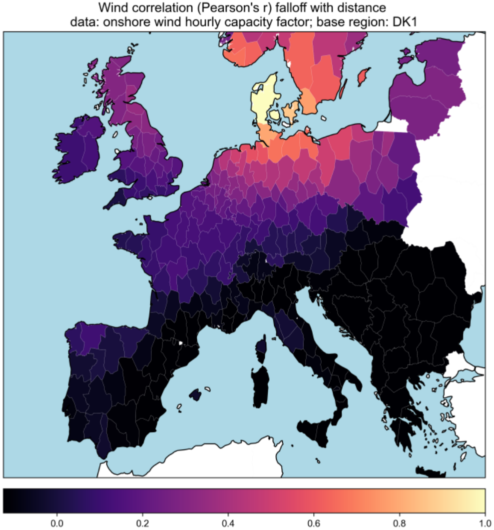
Scenario: 24/7 CFE with 100% score,
commercially available technologies,
2025 DEA technology cost assumptions
co-optimised spatial & temporal load shifts

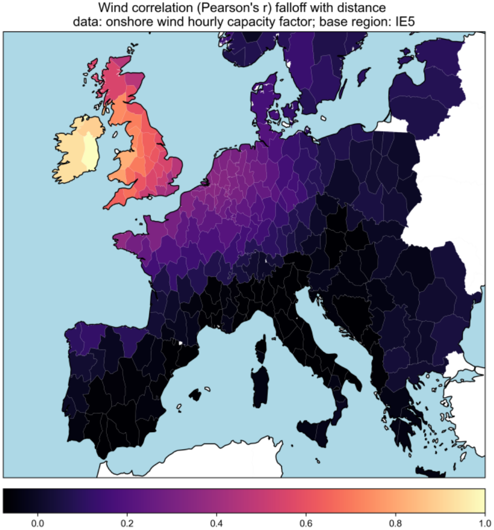
Time-series of optimized spatial load shifts



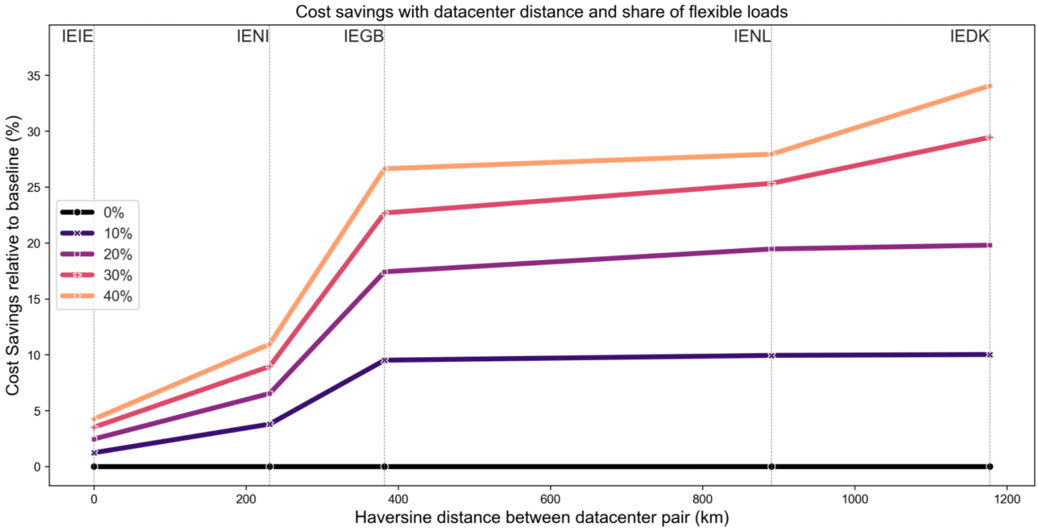
Negative values mapped to red color represent decrease of a load
Positive values mapped to blue color represent increase of a load

Signal 2: low correlation of wind power generation over long distances

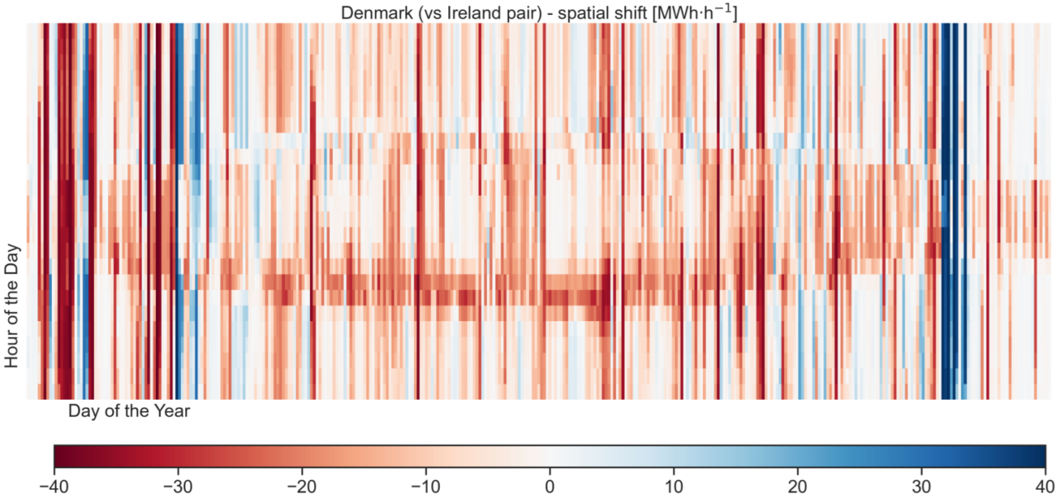




Cost savings as a function of distance between datacenter pair

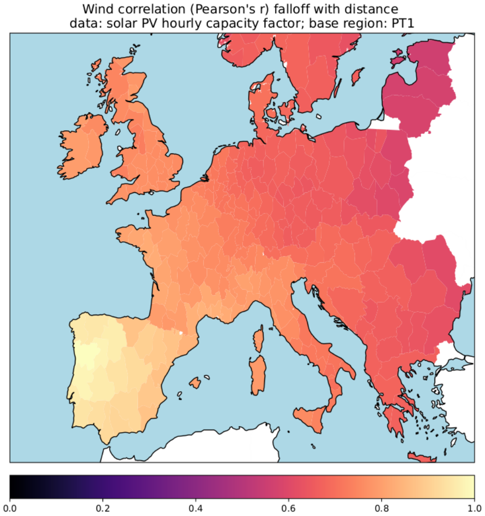


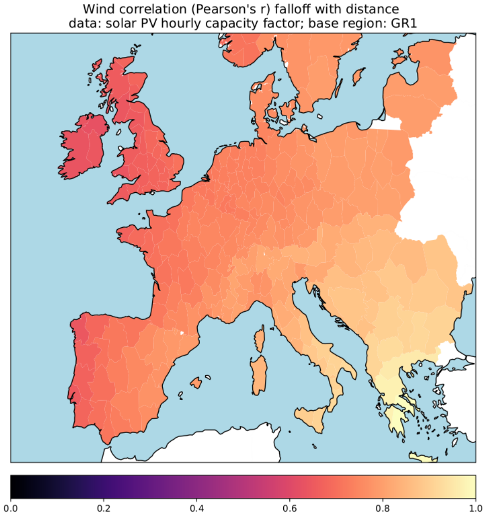
Time-series of optimized spatial load shifts (locations: DK-IE)



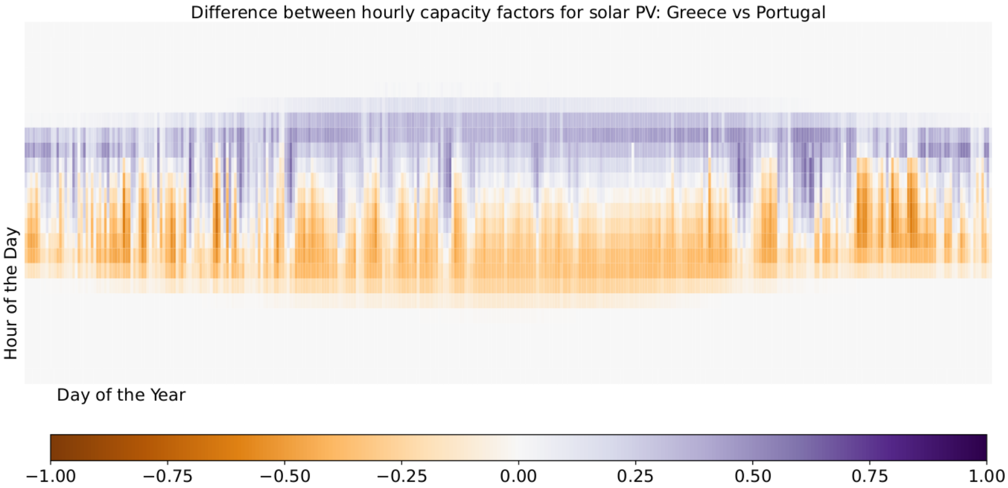
Negative values mapped to red color represent decrease of a load
Positive values mapped to blue color represent increase of a load

Signal 3: time lag in solar radiation peaks due to Earth's rotation (1/2)

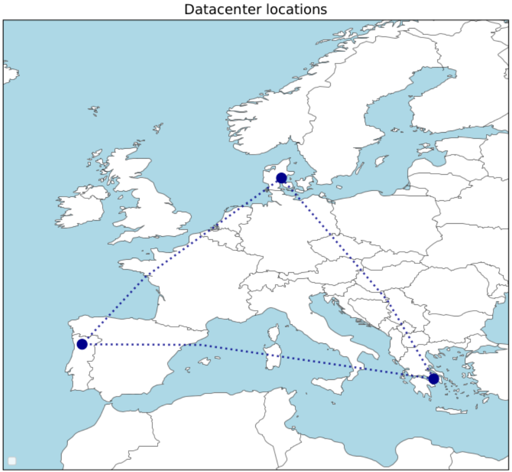


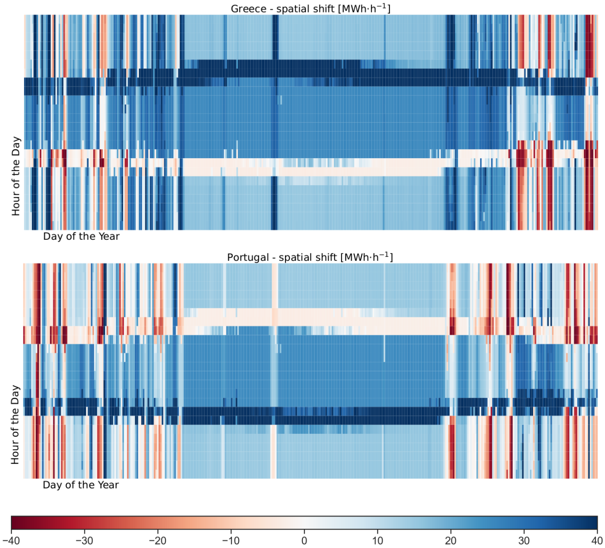


Signal 3: time lag in solar radiation peaks due to Earth's rotation (2/2)



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





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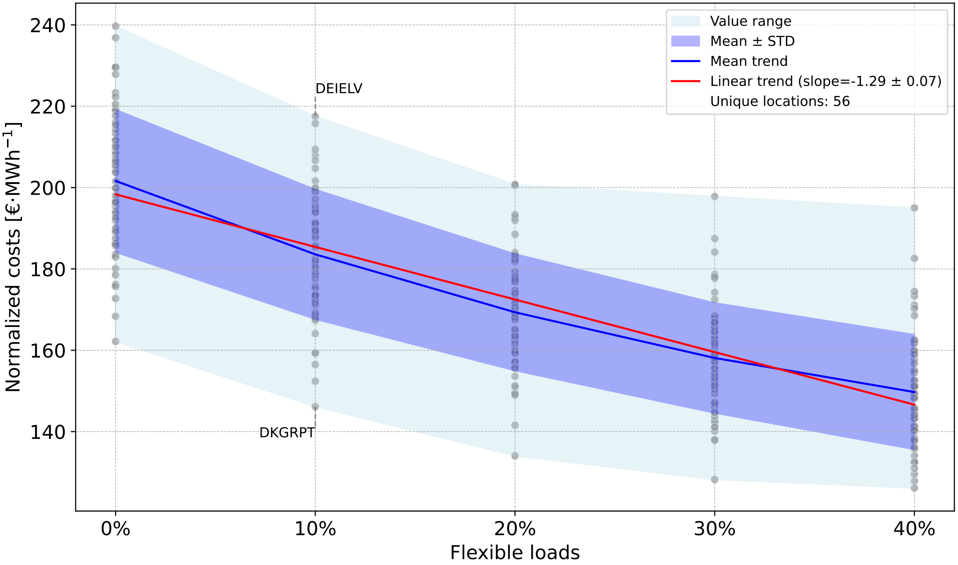
Results can be generalized beyond specific load locations



Also in the study

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- 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.

Take aways

There are **three signals** companies can factor into their procurement & load shaping strategies for 24/7 CFE matching:

– quality of local renewable resources;

– low correlation of wind power generation over long distances;

– time lag in solar radiation peaks due to Earth's rotation.

Overall, space-time load-shifting flexibility:

– enables **better access to clean electricity** and creates **more options** for consumers to match demand with carbon-free electricity around-the-clock;

– **lowers the costs** of 24/7 CFE matching and makes it **more attractive** to a wider range of companies.

Contacts, Resources, Acknowledgements

Learn more about our project: 247cfe.github.io/

Code: This study is done in a spirit of open and reproducible research:
study: zenodo.org/records/8185850
code: github.com/PyPSA/247-cfe
A follow-up research paper to be released in March 2024.

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