Modelling 24/7 Carbon-Free Procurement in Europe

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Modelling questions

In collaboration with Google we model 24/7 procurement in 4 EU countries up to 2030.

We want to find out:

- How can we achieve **hourly clean energy** matching?
- What is the **cost premium** versus annual matching?
- 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**?

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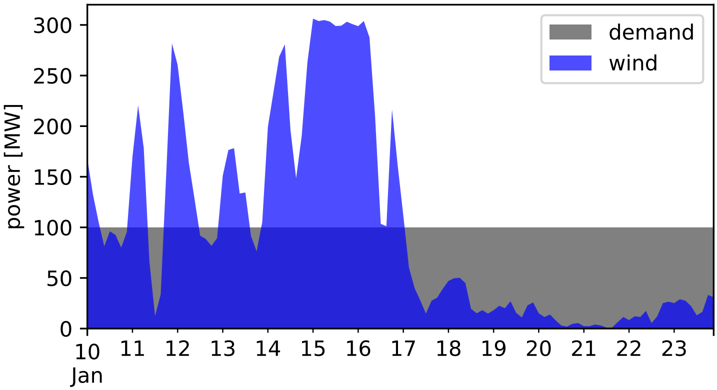
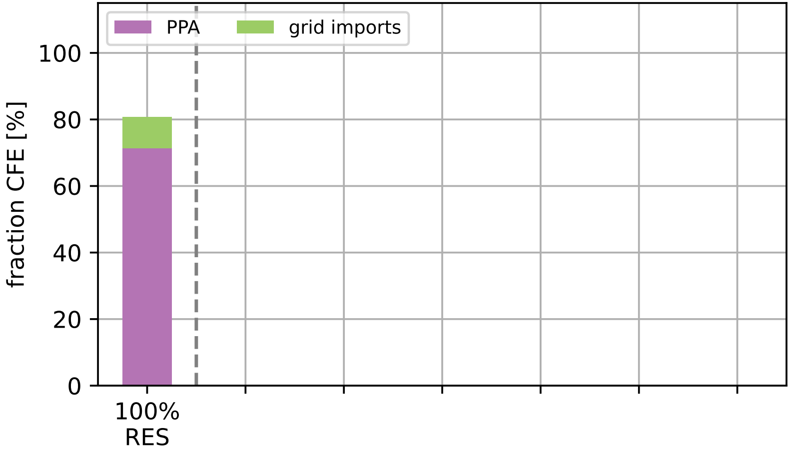
Today: Some preliminary results.

100% RES annual matching does not match hourly demand



- 100% RES PPAs result in periods of **oversupply** and **deficit**
- Hours of deficit must be met by **rest of system**
- These hours may have **high emissions** and **high prices**
- 24/7 carbon-free energy (CFE) matches demand on **hourly basis**

Results: fraction of demand met with carbon-free energy (CFE)



- Results for Ireland in 2030
- 100% RES has only **annual matching**
- 100% RES PPA covers **only 71%** of hourly demand with carbon-free energy (CFE)

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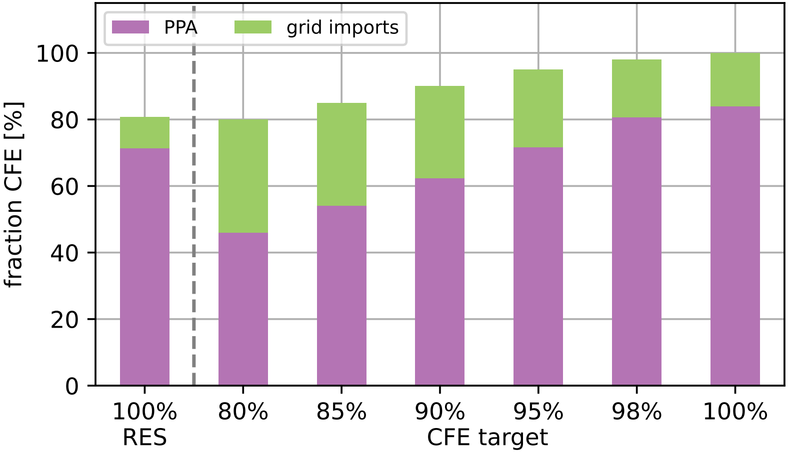
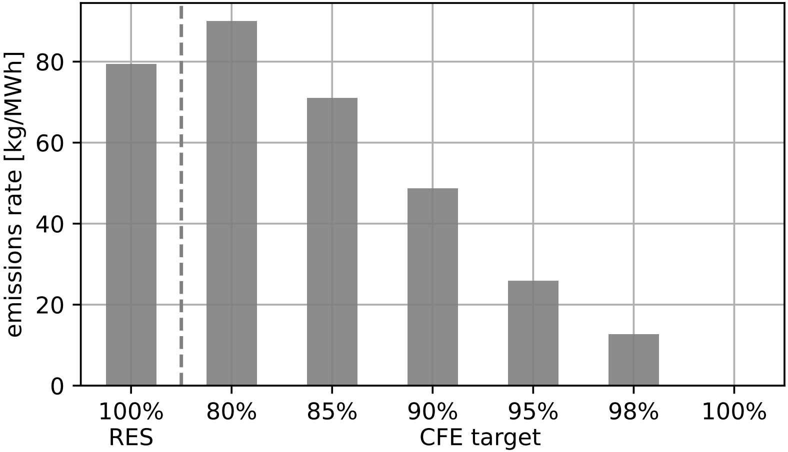


- Results for Ireland in 2030
- 100% RES has only **annual matching**
- 100% RES PPA covers **only 71%** of hourly demand with carbon-free energy (CFE)
- CFE target requires **hourly CFE**

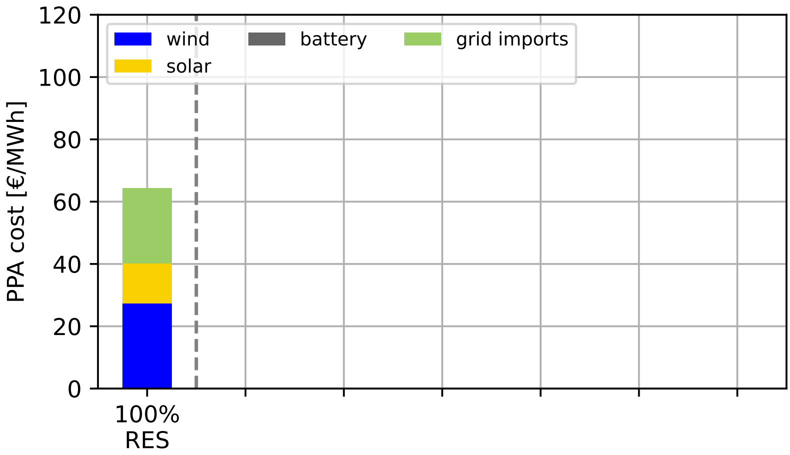
Average emissions of procured electricity



- Graphic shows **average emissions** rate of used electricity
- As CFE target is tightened, average emissions **drop to zero**

results for Ireland in 2030

Cost breakdown with existing technologies (wind, solar, battery)



- 100% RES builds wind and solar

results for Ireland in 2030

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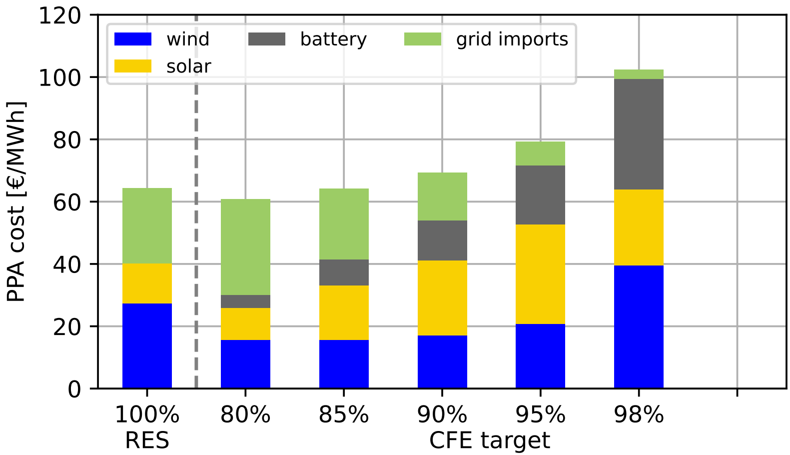

- 100% RES builds wind and solar
- Higher CFE targets **include battery storage**
- 98% CFE has **cost premium of 59%** over 100% RES

results for Ireland in 2030

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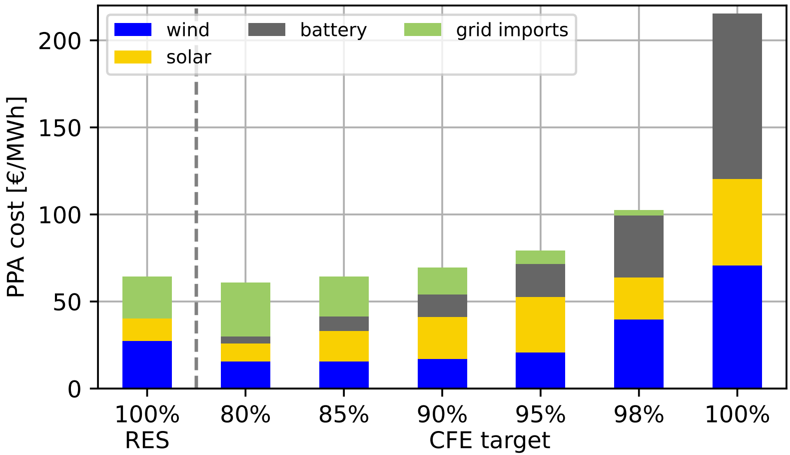
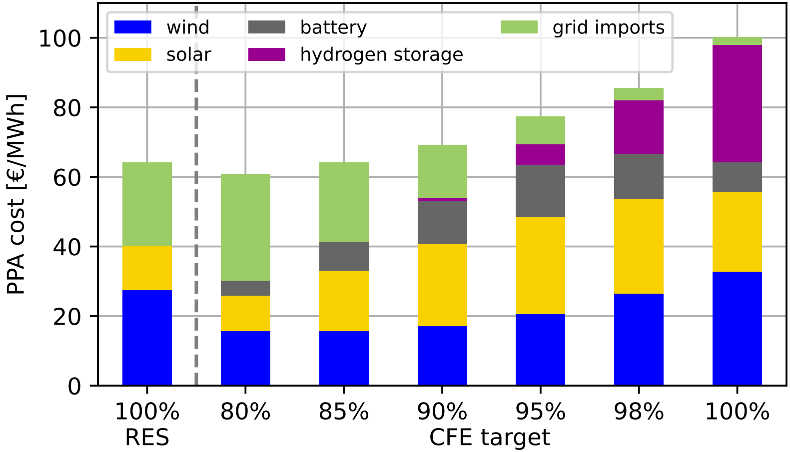


- 100% RES builds wind and solar
- Higher CFE targets **include battery storage**
- 98% CFE has **cost premium of 59%** over 100% RES
- Last 2% more than **doubles cost**

results for Ireland in 2030

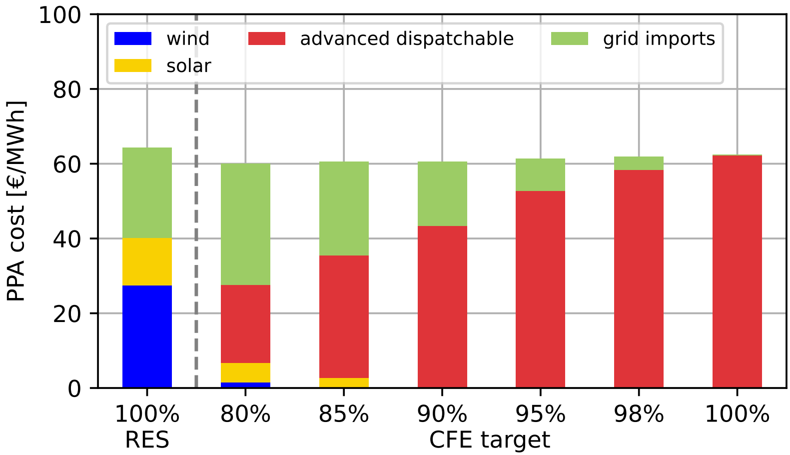
Cost breakdown with long duration energy storage (LDES)



- LDES with storage investment cost < 10 €/kWh **limits PPA cost increase**
- With 2 €/kWh hydrogen storage in caverns, cost premium of 100% CFE is **only 56%**

results for Ireland in 2030

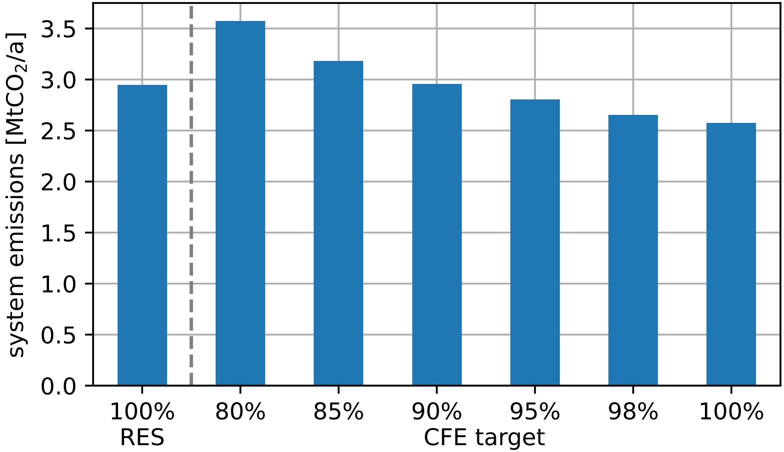
Cost breakdown with advanced dispatchable generators



- Advanced geothermal or nuclear could **further limit cost**
- Firm generation could **remove CFE cost premium**
- Results very **sensitive** to cost assumptions (here nuclear LCOE is 88 €/MWh)

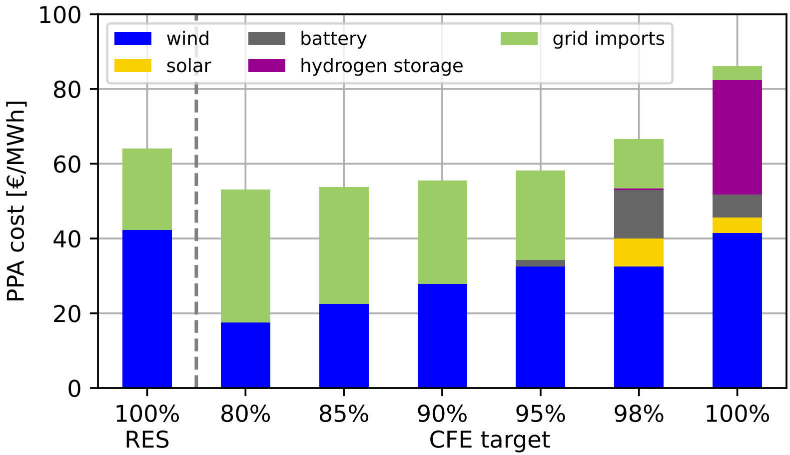
results for Ireland in 2030

Results: System emissions in Ireland



- Irish electricity emissions when 1 GW of C&I load follows different strategies
- **System emissions reduce** with higher CFE targets as system-friendly CFE eats into fossil backup in system

Results: other countries show similar effects (e.g. Denmark)



- Other countries broadly follow same trends, depending on **local resources**
- In Denmark in 2030 **grid is cleaner**, so CFE uses grid more
- With LDES cost premium is **just 34%**

results for Denmark in 2030

Conclusions

- 24/7 CFE procurement **reduces emissions** both for buyer and for rest of system
- 80-90% hourly CFE target has **only small cost premium** over annual RES matching
- 100% hourly CFE target **increases costs** by 0-60%, depending on technologies available
- 24/7 approach **triggers investment in new technologies** the system will need later: long-duration storage and dispatchable clean generation
- 24/7 approach **benefits the rest of the system**, reducing emissions and flexibility needs

Backup

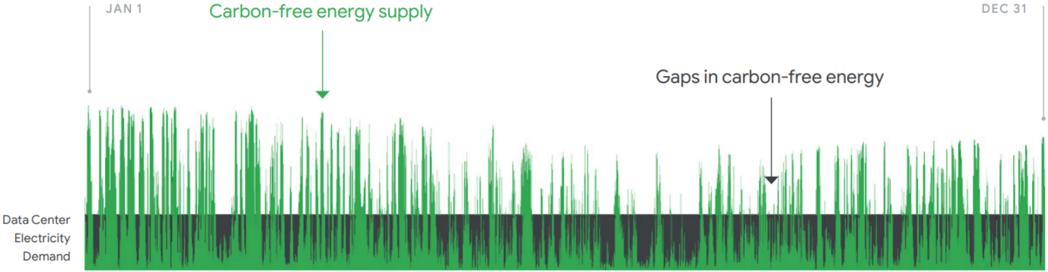
Code availability

The code is already available online with an MIT licence:

https://github.com/PyPSA/247-cfe

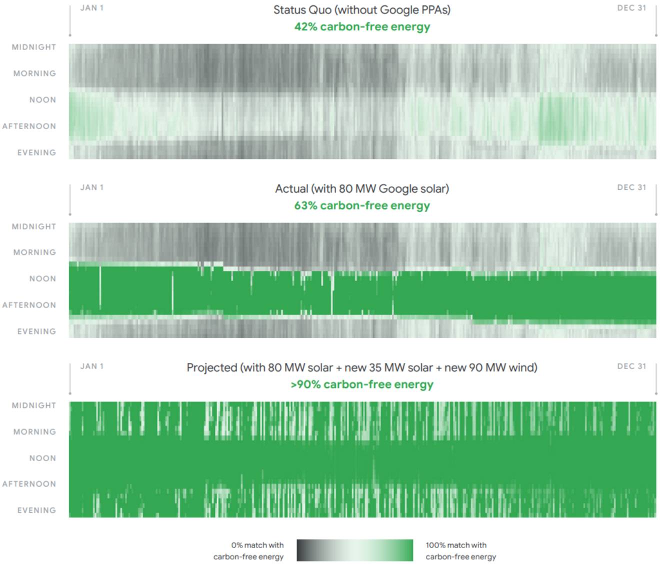
Yearly versus hourly matching

Companies often match their demand on a **yearly** basis with renewable energy, but on an **hourly** basis they still have hours when they rely on the fossil-dominated grid.



Google 24/7 CFE

Yearly versus hourly matching



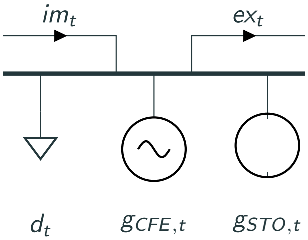
- By combining wind and solar, or using storage or dispatchable low-carbon resources, they can improve the hourly matching.
- These examples compare grid energy, versus yearly renewable PPAs, versus a 90% carbon-free energy (CFE) PPA.

Google 24/7 CFE

Implementation of C&I demand and supply

The hourly C&I demand d_t for hour t can be met by procured CFE generators $s \in CFE$ dispatching $g_{s,t}$ MW but also storage discharging $\bar{g}_{s,t}$ and charging $\underline{g}_{s,t}$ for storage technologies $s \in STO$ as well as from imports from the grid im_t. The excess from the local supply ex_t can either be sold to the grid or curtailed

$$\sum_{s \in CFE} g_{s,t} + \sum_{s \in STO} \left(\bar{g}_{s,t} - \underline{g}_{s,t} \right) - ex_t + im_t = d_t \qquad \forall t$$



Methodology for RES and CFE constraints

The 100% RES constraint ensures that the sum of all dispatch $g_{s,t}$ for RES generators $s \in RES$ over the year $t \in T$ is greater than the sum of demand d_t at the data center

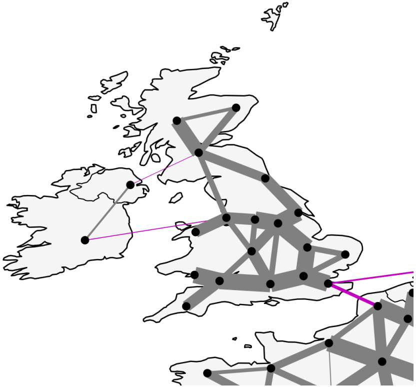
$$\sum_{s \in RES, t \in T} g_{s,t} \geq \sum_{t \in T} d_t$$

The $x \cdot 100\%$ carbon-free energy (CFE) constraint sums over CFE generators $s \in CFE$ but also storage discharging $\bar{g}_{s,t}$ and charging $\underline{g}_{s,t}$ for storage technologies $s \in STO$ as well as the excess from the data center ex_t (could be sold to grid or curtailed) and import from the grid im_t multiplied by the grid's CFE factor CFE_t (the fraction of CFE technology running at time t)

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

The grid CFE factor CFE_t is affected by capacity built at data center, so has to be updated iteratively (starting with $CFE_t = 0 \, \forall t$, convergence is very good after 1 iteration).

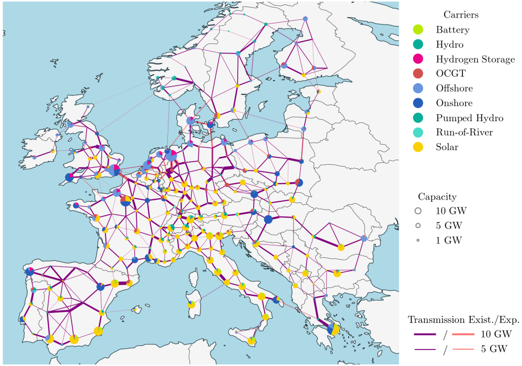
Test case: Ireland



- Test case with island of Ireland as isolated system
- Data center attached to country of Ireland node with 1 GW baseload profile (25% of country's average load, $\sim$ 40% of C&I in country Ireland)
- CO_2 certificate price exogenous of 130 €/tCO_2
- Rest of system is brownfield (i.e. today's fleet with lifetime to 2030 is included)

Python for Power System Analysis (PyPSA)

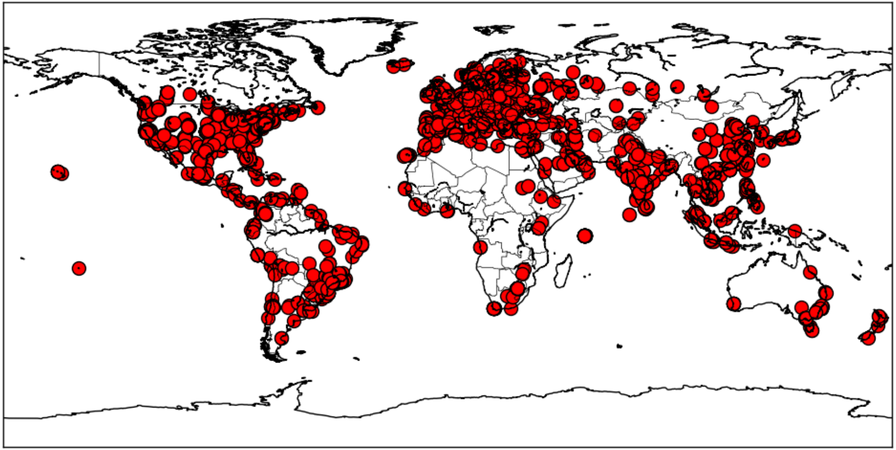
- **Open source** tool for modelling energy systems at **high resolution** developed at TU Berlin.
- Fills missing gap between **power flow software** (e.g. PowerFactory, MATPOWER) and **energy system simulation software** (e.g. PLEXOS, TIMES, OSeMOSYS).
- Good grid modelling is increasingly important, for integration of **renewables** and **electrification** of transport, heating and industry.



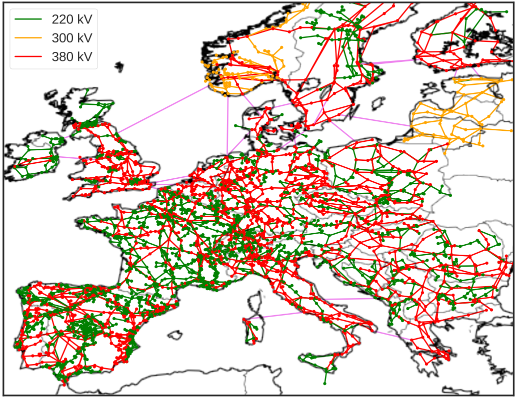
PyPSA is available on [GitHub](https://github.com/PyPSA/PyPSA).

Python for Power System Analysis: Worldwide Usage

PyPSA is used worldwide by **dozens of research institutes and companies** (TU Delft, KIT, Shell, TSO TransnetBW, TERI, Agora Energiewende, RMI, Fraunhofer ISE, Climate Analytics, DLR, FZJ, RLI, Saudi Aramco, Edison Energy, spire and many others). See **list of users**.



PyPSA-Eur: Open Model of European Energy System



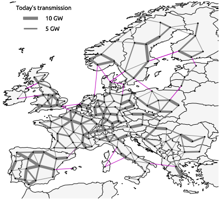
Basic **validation** of grid model in **Hörsch et al, 2018)**, **github.com/PyPSA/pypsa-eur**

- Grid data based on **GridKit** extraction of ENTSO-E interactive map
- **powerplantmatching** tool combines open databases using matching algorithm DUKE
- Renewable energy time series from open **atlite**, which processes terabytes of weather data from e.g. new ERA5 global reanalysis
- Geographic **potentials** for RE from land use GIS availability
- All energy demand and supply options (power, transport, heating and industry)
- See **other slidedeck** for full details

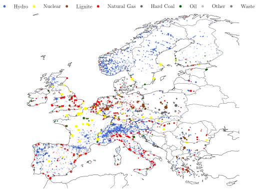
Data-driven energy modelling

Lots of different types of data and process knowledge come together for the modelling.

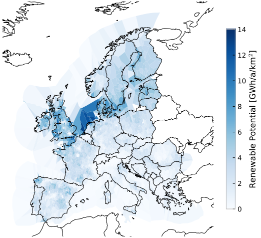
clustered network model



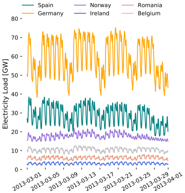
power plants and technology assumptions



renewable potentials and hourly time series for each region

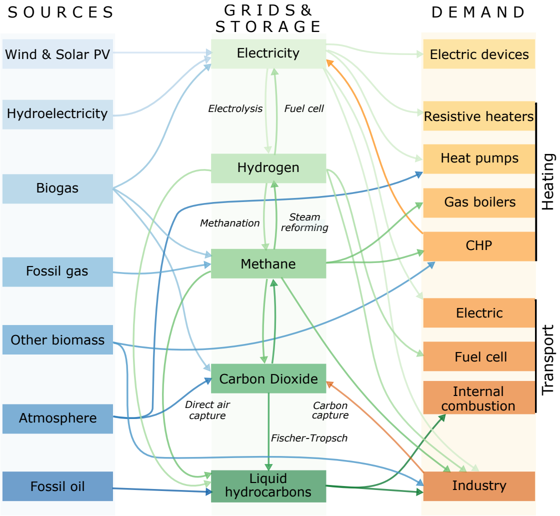


demand projections time series

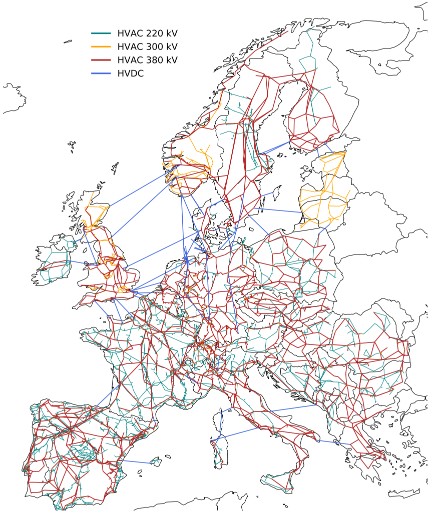


What is PyPSA-Eur-Sec?

Model for Europe with all energy flows...



and bottlenecks in energy networks.



More information

All input data and code for PyPSA-Eur-Sec is open and free to download:

1. `https://github.com/pypsa/pypsa`: The modelling framework
2. `https://github.com/pypsa/pypsa-eur`: The power system model for Europe
3. `https://github.com/pypsa/pypsa-eur-sec`: The full energy system model for Europe

Publications (selection):

1. M. Victoria, K. Zhu, T. Brown, G. B. Andresen, M. Greiner, *"Early decarbonisation of the European energy system pays off,"* Nature Communications (2020), **DOI**, **arXiv**.
2. T. Brown, D. Schlachtberger, A. Kies, S. Schramm, M. Greiner, *"Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system,"* Energy 160 (2018) 720-739, **DOI**, **arXiv**.
3. J. Hörsch, F. Hofmann, D. Schlachtberger and T. Brown, *"PyPSA-Eur: An open optimization model of the European transmission system,"* Energy Strategy Reviews (2018), **DOI**, **arXiv**.
4. D. Schlachtberger, T. Brown, M. Schäfer, S. Schramm, M. Greiner, *"Cost optimal scenarios of a future highly renewable European electricity system: Exploring the influence of weather data, cost parameters and policy constraints,"* Energy (2018), **DOI**, **arXiv**.
5. T. Brown, J. Hörsch, D. Schlachtberger, *"PyPSA: Python for Power System Analysis,"* Journal of Open Research Software, 6(1), 2018, **DOI**, **arXiv**.
6. D. Schlachtberger, T. Brown, S. Schramm, M. Greiner, *"The Benefits of Cooperation in a Highly Renewable European Electricity System,"* Energy 134 (2017) 469-481, **DOI**, **arXiv**.