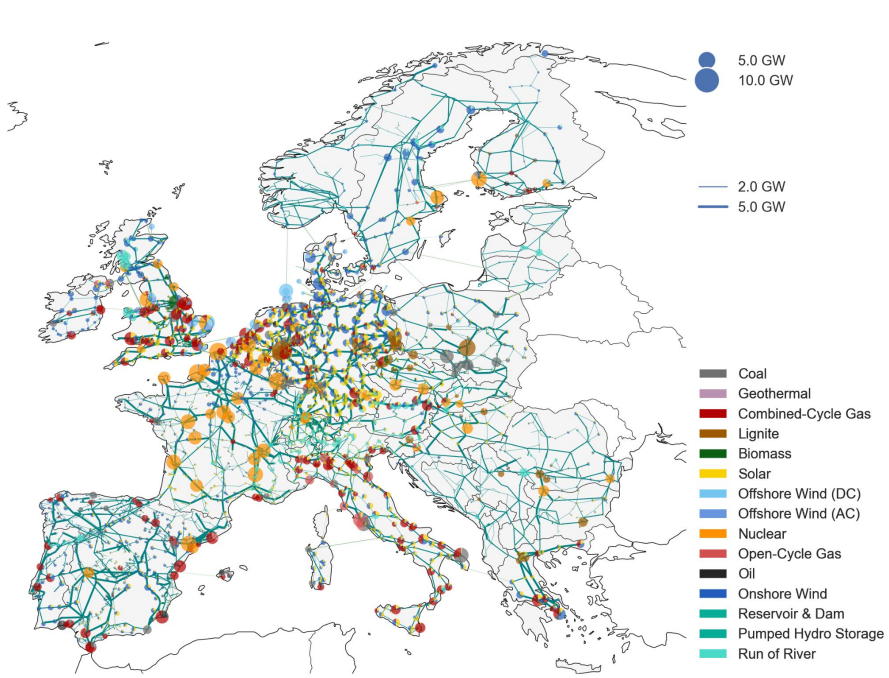
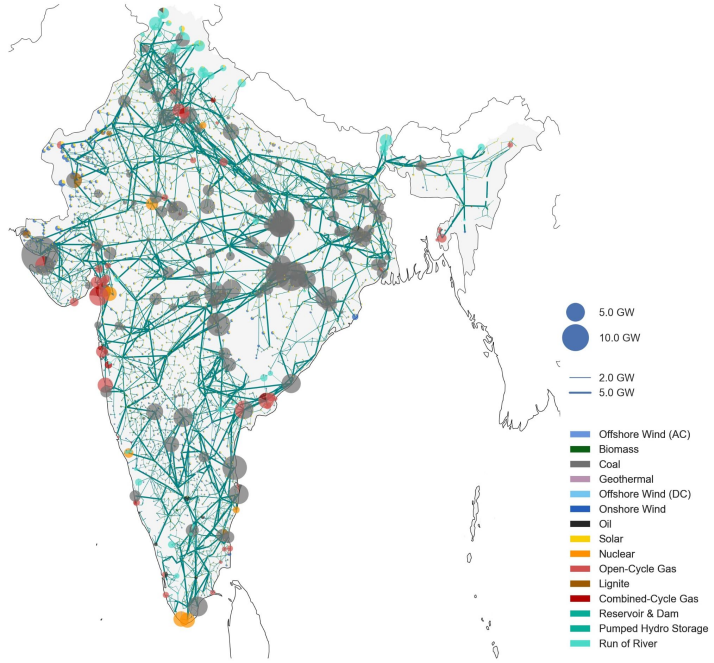
Open Energy Transition

from the creators of PyPSA meets Earth





Open Energy Transition Introduction

Discussion Document, November 2023

Open Energy Transition is an open energy modelling solution provider aiming to accelerate the World's transition to sustainable energy

Open Energy Transition

from the creators of PyPSA meets Earth

Maximilian Parzen

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- PhD in Energy System Modelling, University of Edinburgh
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- M.Sc. in Mathematics, University of Erlangen-Nuremberg & University of Zurich

AGENDA

- **PyPSA Universe Intro**
- **Open Energy Transition (OET) Intro**
- **Case Studies**

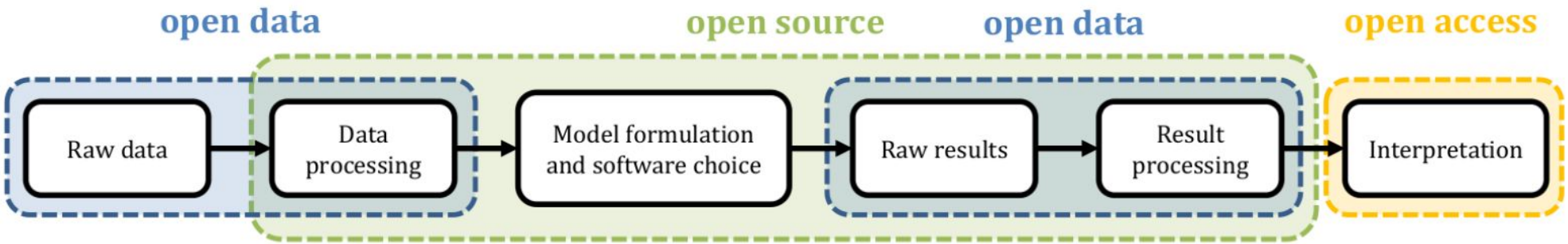
What is open modelling?

Open energy modelling means modelling with open software, open data and open publishing.

Open means that anybody is free to download the software/data/publications, inspect it, machine process it, share it with others, modify it, and redistribute the changes.

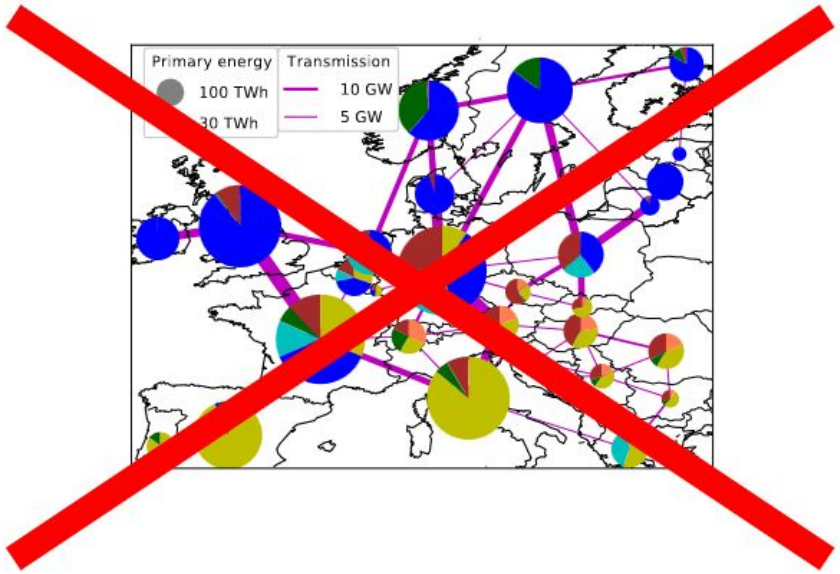
This is typically done by uploading the model to an online platform with an **open licence** telling users what their reuse rights are.

The **whole pipeline** should be open:

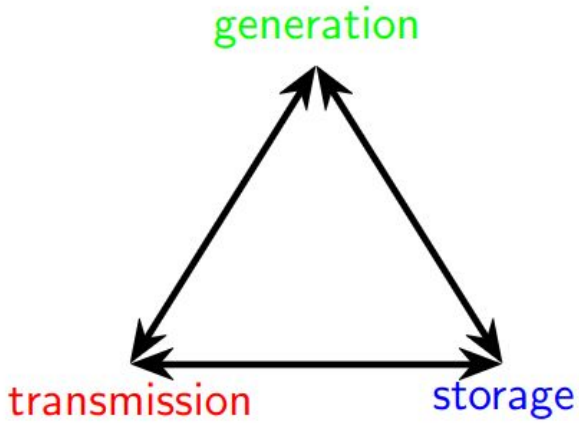


Modelling challenges: high space-time resolution and co-optimization

Challenge 1: Need spatial resolution to see grid bottlenecks & infrastructure trade-offs.
⇒ One node per country won't work.



Challenge 2: Need to co-optimise balancing solutions with generation.
⇒ Optimising separately is inefficient.



⇒ Need **very large** models, big data and methods for complexity management

Modelling challenges: high space-time resolution and co-optimization

Challenge 3. Need temporal resolution to see benefits of energy storage e.g. trade-offs to curtailments and peak generation saving

➢ Using only typical days or weeks won't work

PyPSA: Python for Power System Analysis

pypi v0.20.0 | conda-forge v0.20.0 | CI failing | CI with conda passing | codecov 70% | docs passing | license MIT

DOI 10.5281/zenodo.3946412 | chat on gitter | pre-commit.ci failure | code style black

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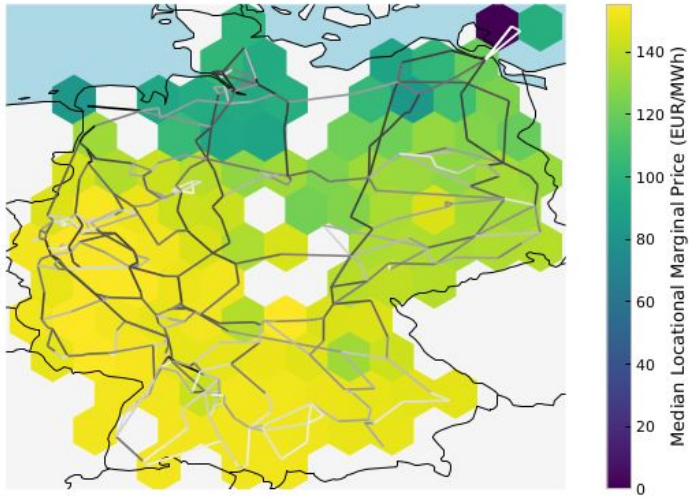
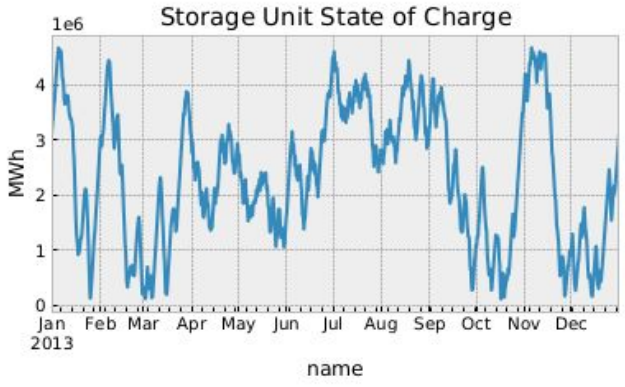
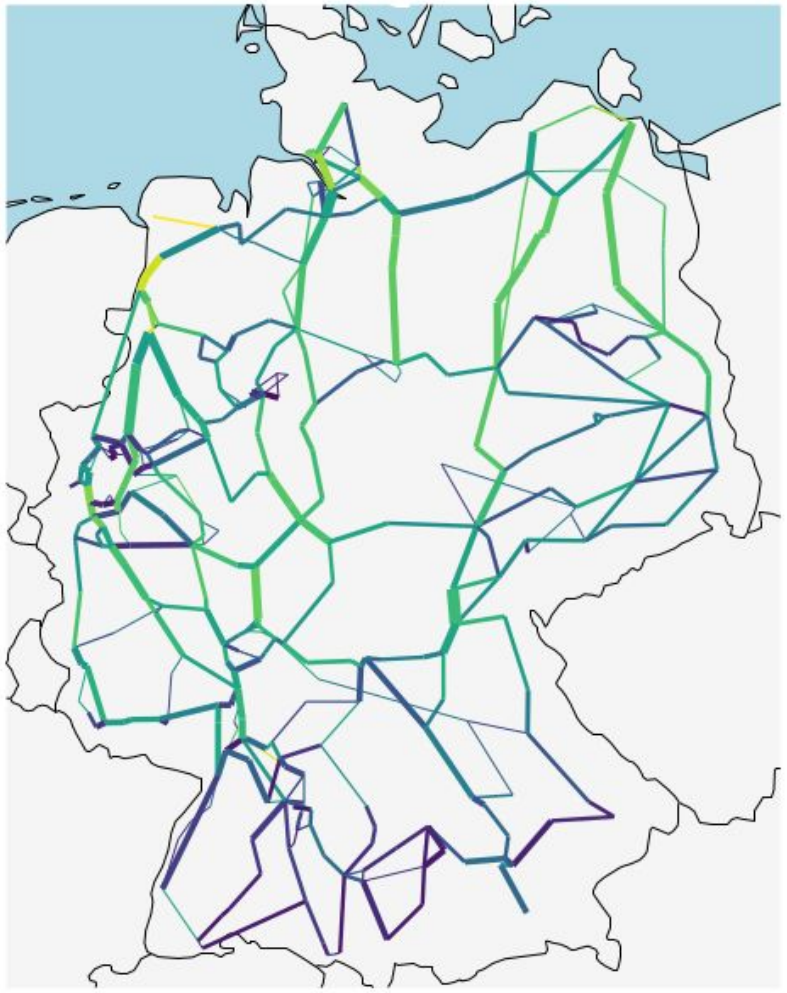
Open-source tool for modelling energy systems at high resolution.

Fills missing gap between load flow software (e.g. PowerFactory, MATPOWER) and energy system modelling software (e.g. PLEXOS, TIMES, OSeMOSYS).

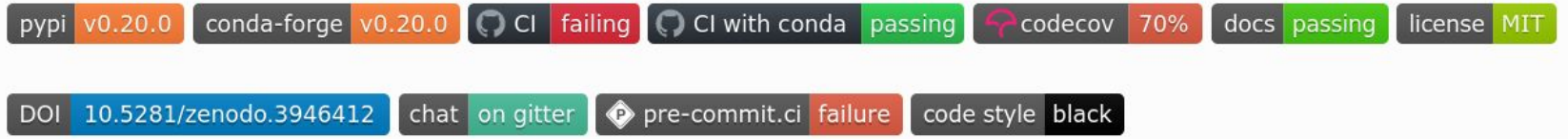
Good grid modelling is increasingly important, for integration of renewables and electrification of transport, heating and industry.







PyPSA: Python for Power System Analysis



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Capabilities

Capacity expansion (linear)

- single-horizon
- multi-horizon *(new)*

Market modelling (linear)

- Linear optimal power flow
- Security-constrained LOPF
- Unit commitment
- Dispatch & redispatch

Non-linear power flow

- Newton-Raphson

With components for

- Meshed AC-DC networks
- Generators with unit commitment
- Variable generation with time series
- Storage with efficiency losses and inflow/spillage for hydro
- Conversion between energy carriers (PtX, CHP, BEV, DAC)

Backend

- all data stored in pandas DataFrames
- framework built for performance with large networks and time series
- interfaces to major solvers (Gurobi, CPLEX, HiGHS), with and without pyomo
- highly customisable
- `pandas numpy scipy pyomo networkx matplotlib`

Comparison to other Software

open-source

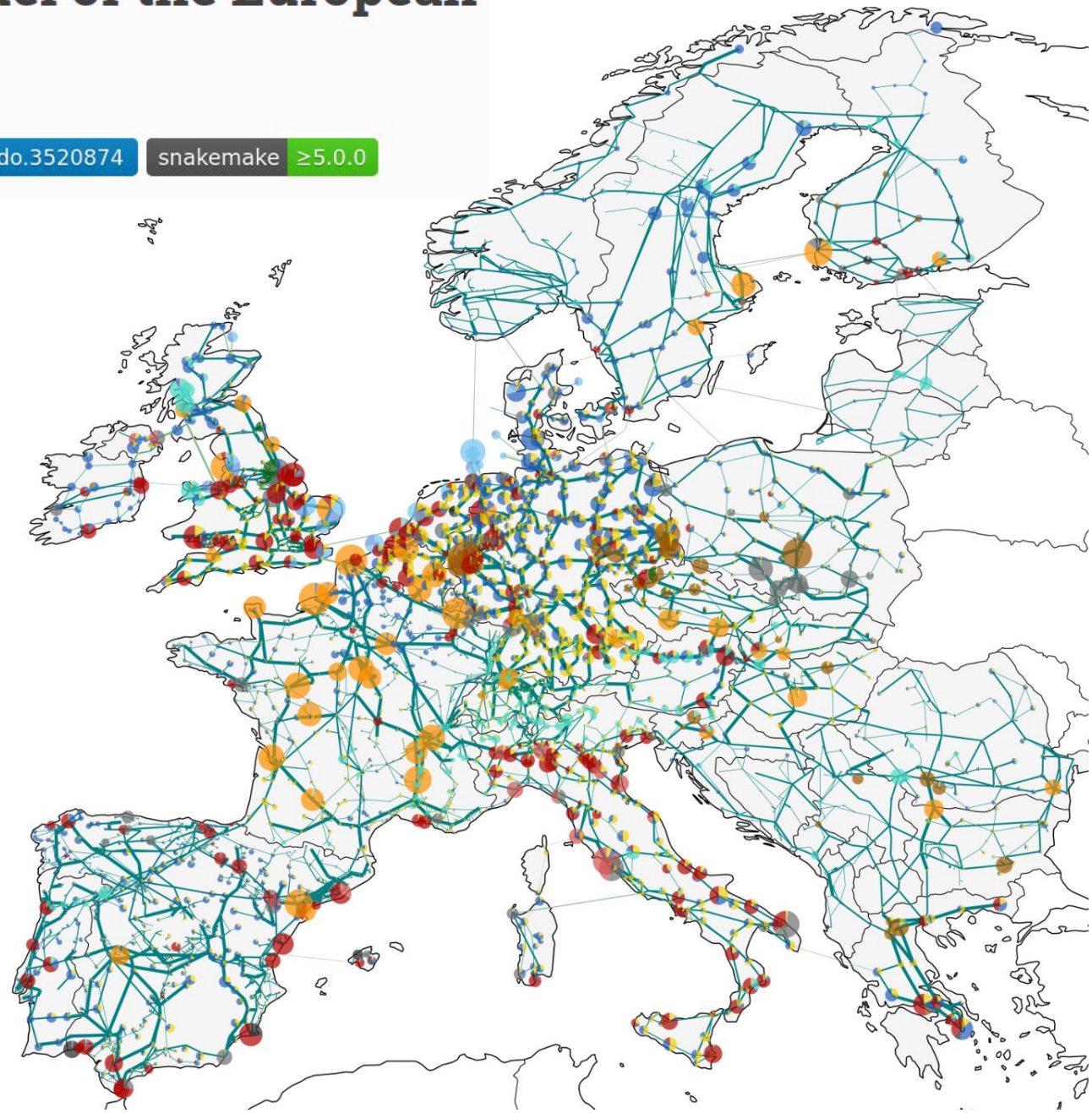
	Software	Language	Version	Free Software	Grid Analysis: Power Flow	Grid Analysis: Continuation Power Flow	Grid Analysis: Dynamic Analysis	Economic Analysis: Transport Model	Economic Analysis: Linear OPF	Economic Analysis: N-1 OPF	Economic Analysis: Nonlinear OPF	Economic Analysis: Multi-Period Optimisation	Economic Analysis: Unit Commitment	Economic Analysis: Investment Optimisation	Economic Analysis: Other Energy Sectors
	NEPLAN	–	5.5.8		✓		✓	✓	✓	✓	✓				✓
	PowerFactory	–	2017		✓		✓		✓	✓	✓				
	PowerWorld	–	19		✓		✓	✓	✓	✓	✓				
	PSS/E	–	33.10		✓		✓		✓	✓	✓				
Power system tools	PSAT	MATLAB	2.1.11	✓	✓	✓	✓		✓		✓	✓	✓		
Power system tools	MATPOWER	MATLAB	7.0	✓	✓	✓		✓	✓		✓				
Power system tools	PYPOWER	Python	5.1.4	✓	✓			✓	✓		✓				
Power system tools	pandapower	Python	2.2.2	✓	✓			✓	✓		✓				
Power system tools	PowerDynamics.jl	Julia	2.3.1	✓			✓								
Power system tools	PowerSimulations.jl	Julia	0.5.5	✓				✓	✓		✓	✓	✓		
Power system tools	PowerModels.jl	Julia	0.17.2	✓	✓				✓		✓	(✓)	✓		
Power system tools	**PyPSA**	Python	0.17.0	✓	✓			✓	✓	✓		✓	✓	✓	✓
Energy system tools	calliope	Python	0.5.2	✓				✓				✓		✓	✓
Energy system tools	oemof	Python	0.4.0	✓				✓				✓	✓	✓	✓
Energy system tools	OSeMOSYS	various	2020	✓				✓				✓		✓	✓
Energy system tools	PowerGAMA	Python	1.1	✓				✓	✓			✓			
	TIMES	GAMS	4.4.2	(✓)				✓	✓			✓	✓	✓	✓
	PLEXOS	–	8.1					✓	✓	✓		✓	✓	✓	✓
	PRIMES	–	2017					✓	✓			✓	✓	✓	✓

PyPSA-Eur: An Open Optimisation Model of the European Transmission System

release v0.6.0 | CI passing | docs passing | repo size 36.5 MB | DOI 10.5281/zenodo.3520874 | snakemake ≥5.0.0

Automated snakemake workflow to build PyPSA electricity system network from open data:

- all AC lines at and above 220 kV, substations and (planned) HVDC links,
- a database of existing power plants,
- time series for electrical demand,
- time series for wind/solar availability, and
- geographic wind/solar potentials
- Methods for model simplification



PyPSA-Eur-Sec: A Sector-Coupled Open Optimisation Model of the European Energy System

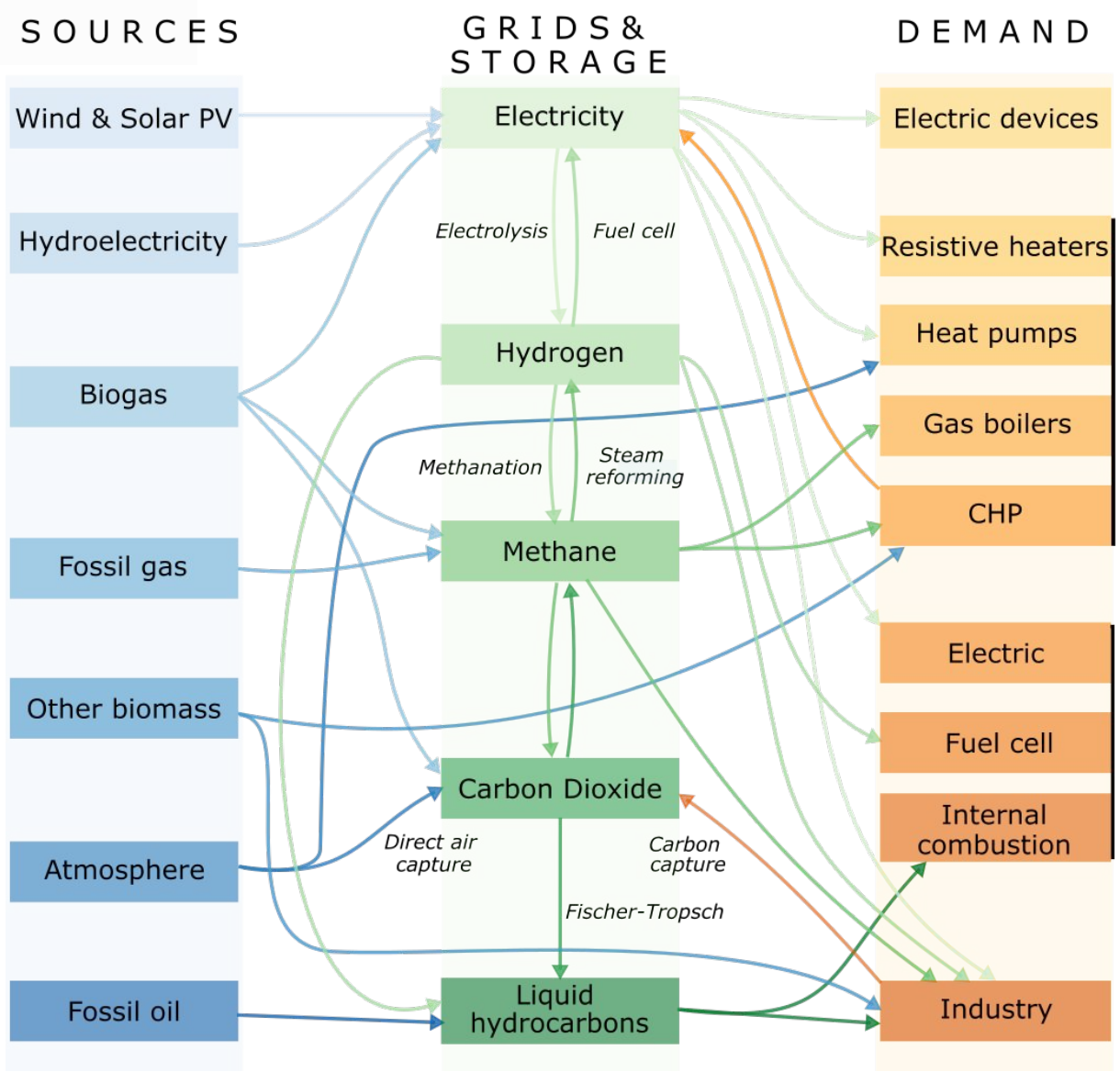
release v0.6.0 | docs passing | license MIT | repo size 4.91 MB | chat on gitter

INFO: MERGED NOW WITH PyPSA-EUR

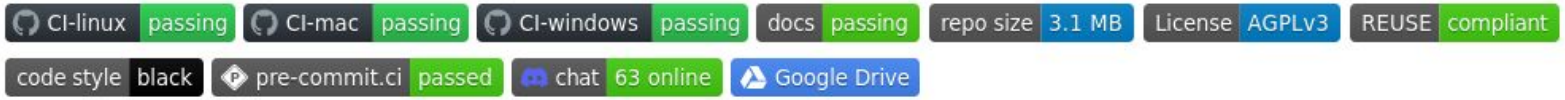
Need to decarbonise all sectors in Europe obeying spatial and temporal constraints.

Extends PyPSA-Eur power system with

- transport sector
- heating sector
- industry sector
- international shipping and aviation
- industrial feedstocks and biomass
- better carbon management
- hydrogen and gas networks
- pathway optimisation (myopic)

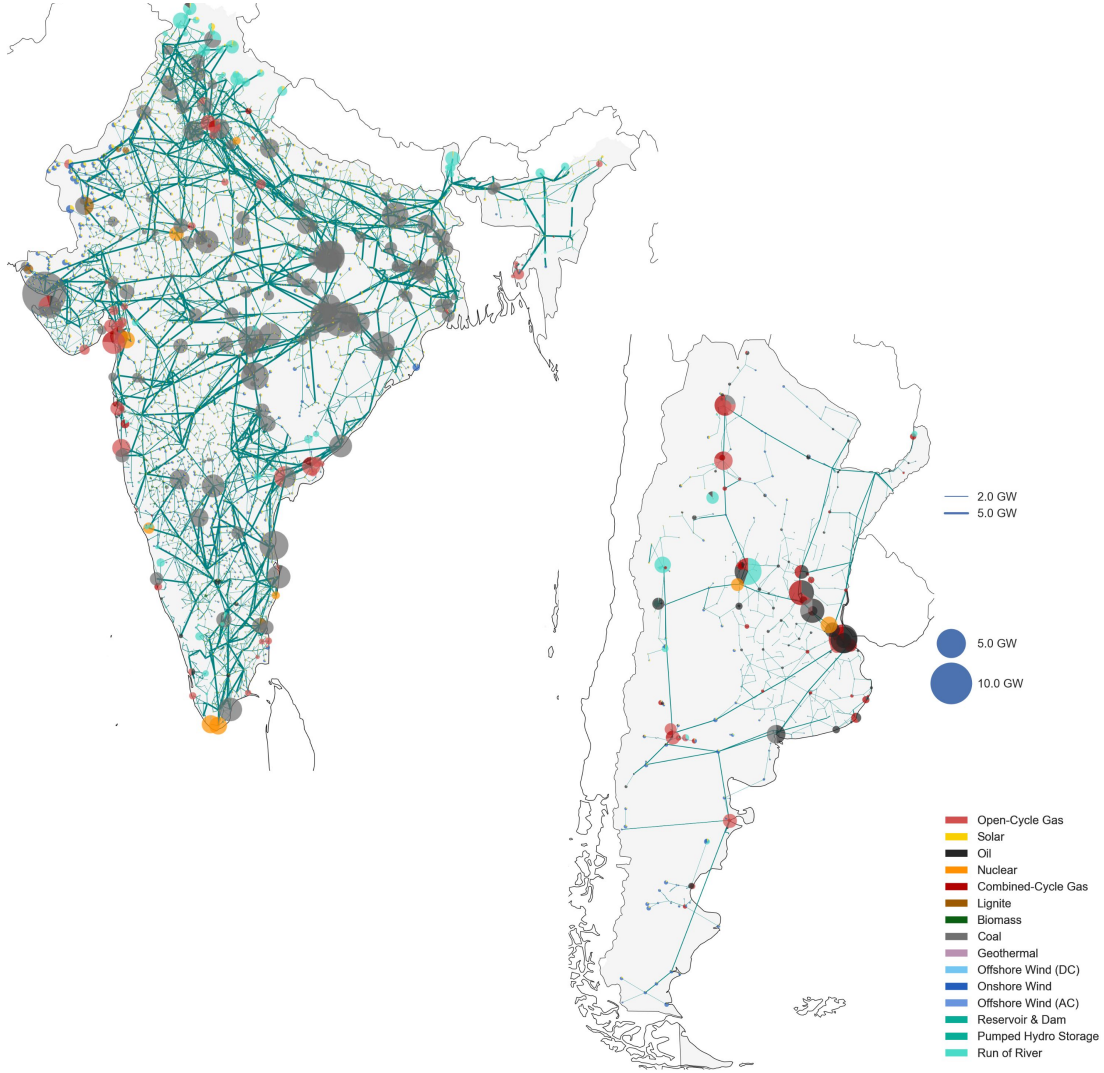


PyPSA-Earth. A Flexible Python-based Open Optimisation Model to Study Energy System Futures around the World.



Extends PyPSA-Eur for the rest of the world with

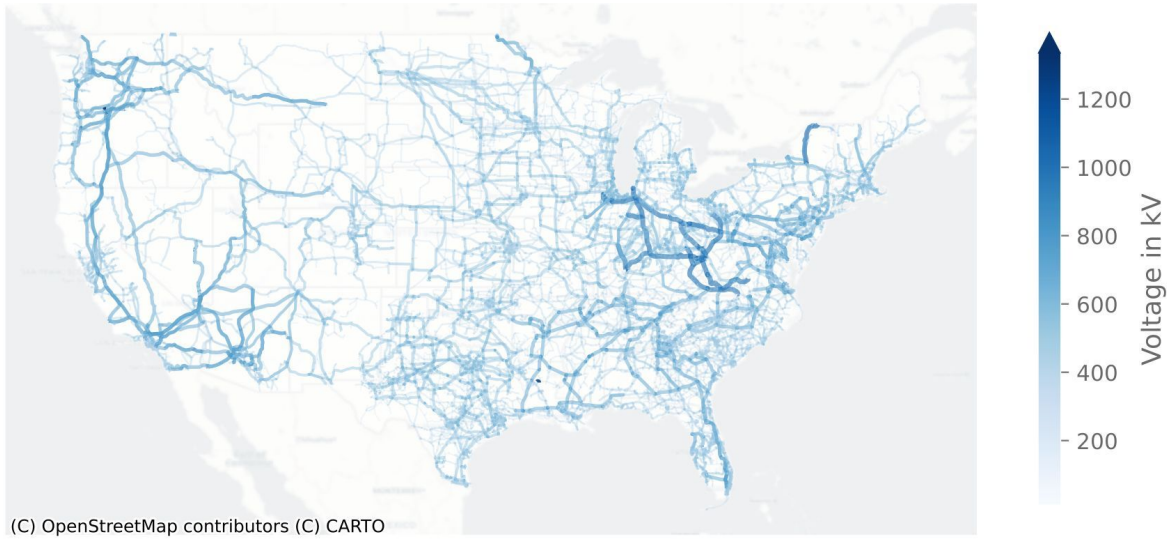
- Plenty of new datastreams e.g. OpenStreetMap and GADM data
- Experimental new methods e.g. Monte-Carlo Methods and Network Meshing Strategies
- New collaboration approaches e.g. weekly public meetings on Discord



earth-osm. Python tool to extract large-amounts of OpenStreetMap data

Features:

- Extracts power infrastructure data from OSM
- Cleans and Standardizes the data (coming soon)
- No API rate limits (data served from GeoFabrik)
- Provides a Python API
- Supports multiprocessing
- Outputs .csv and .geojson files
- Aggregate data per feature or per region
- Easy to use CLI interface




```
conda install --channel=conda-forge earth-osm
```

Extract osm data

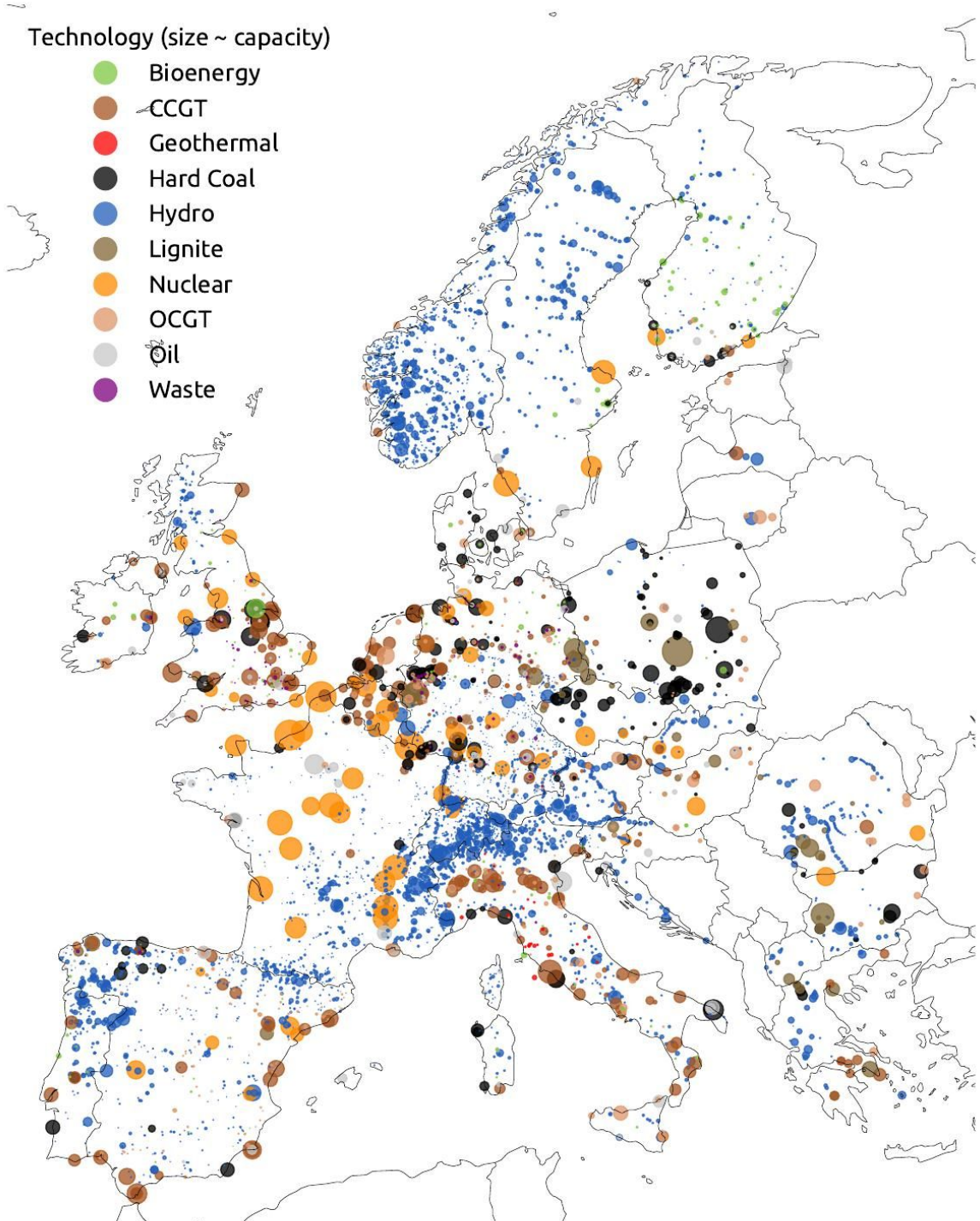
```
# Example CLI command
earth_osm extract power --regions benin monaco  --features substation line
```

Welcome to powerplantmatching's documentation!

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

```
import powerplantmatching as pm

df = pm.powerplants(from_url=True)
```

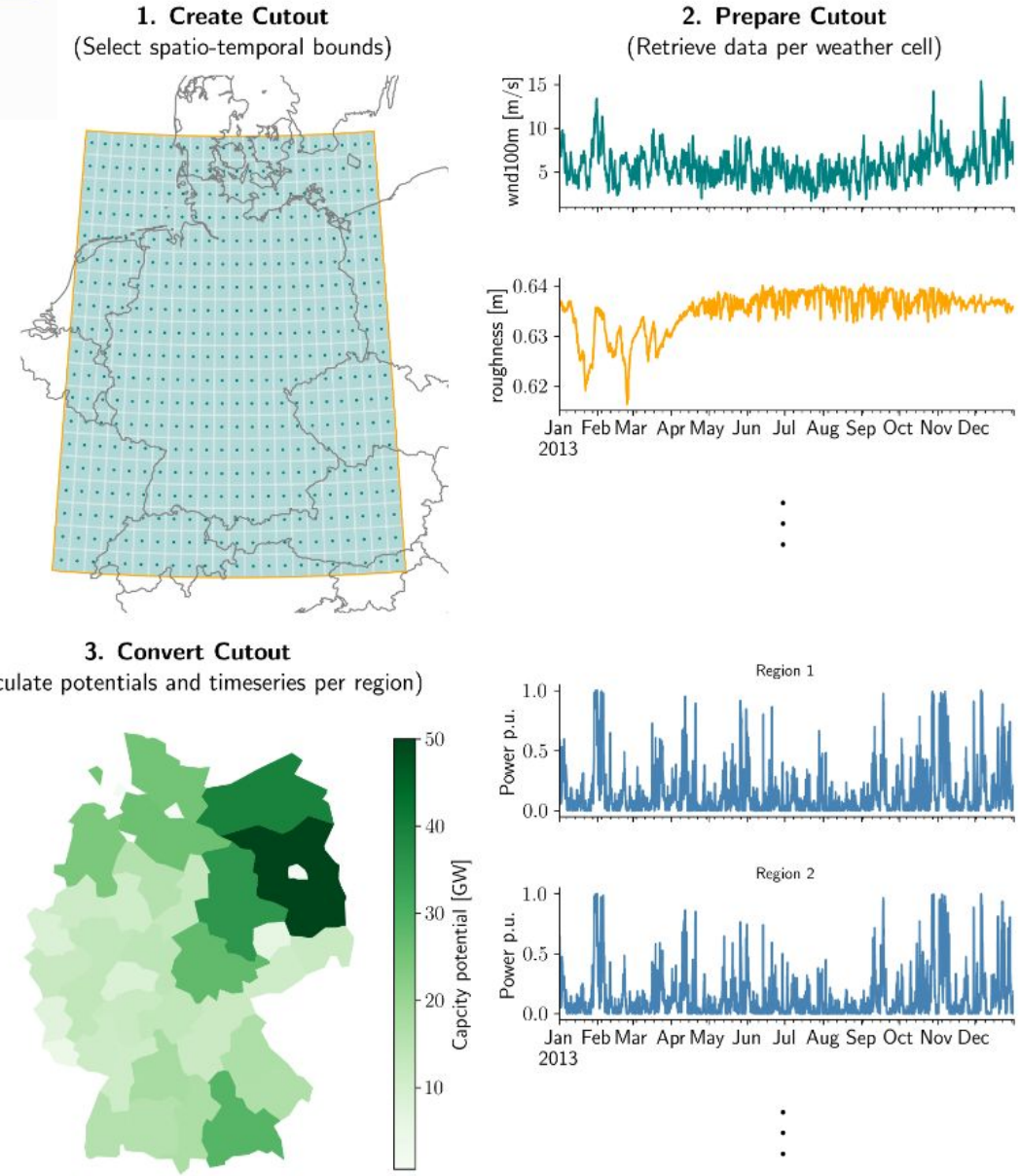


Atlite: Convert weather data to energy systems data

Python library for converting **weather data** (e.g. wind, solar radiation, temperature, precipitation) into **energy systems data**:

- solar photovoltaics
- solar thermal collectors
- wind turbines
- hydro run-off, reservoir, dams
- heat pump COPs
- dynamic line rating
- heat demand (HDD)

It can also perform **land eligibility analyses**.



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It can also perform **land eligibility analyses**.

Technology-data base

release v0.4.0 | docs passing | license GPL-3.0 | repo size 76.3 MB | chat on gitter

- compiles techno-economic assumptions on energy system components
  - investment costs, FOM costs, efficiencies, lifetimes
  - for given years, e.g. 2030, 2040, 2050
  - from mixed sources (mostly Danish Energy Agency)
  - outputs have standardized cost years, technology names, and units

531 lines (531 sloc) | 73.1 KB — Raw | Blame

Search this file...

	technology	parameter	value	unit	source
2	Ammonia cracker	FOM	4.3	%/year	Ishimoto et al. (2020): 10.1016/j.ijhydene.2020.09.017 , table 7.
3	Ammonia cracker	investment	1062107.74	EUR/MW_H2	Ishimoto et al. (2020): 10.1016/j.ijhydene.2020.09.017 , table 6.
4	Ammonia cracker	lifetime	25.0	years	Ishimoto et al. (2020): 10.1016/j.ijhydene.2020.09.017 , table 7.

https://github.com/PyPSA/technology-data/blob/master/outputs/costs_2030.csv

Open Energy Transition (OET) Intro

Open Energy Transition is an open energy modelling solution provider aiming to accelerate the World's transition to sustainable energy

Open Consultancy

- We perform energy planning studies with best open tools and data,
- enable secure data integration in open source software

Aim: Enable people to build on studies and tools even after the consultation

Software Development

- We develop and maintain open source software,
- create visualization platforms,
- computing infrastructure,
- data infrastructure
- customized solutions

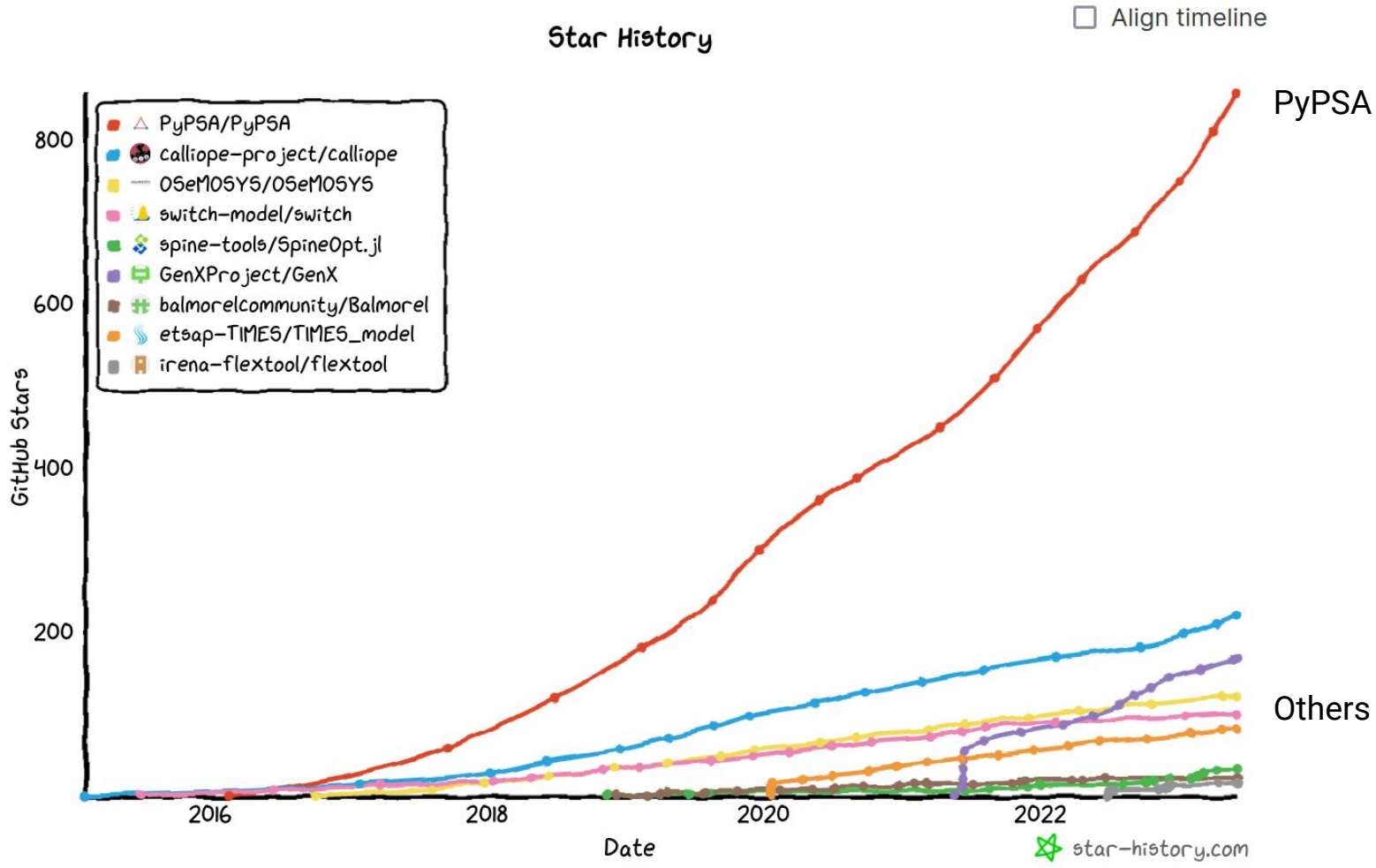
Aim: Make open tools user-friendly and decision-ready using cutting-edge technology. Close requirement gaps to other tools.

Support and Training

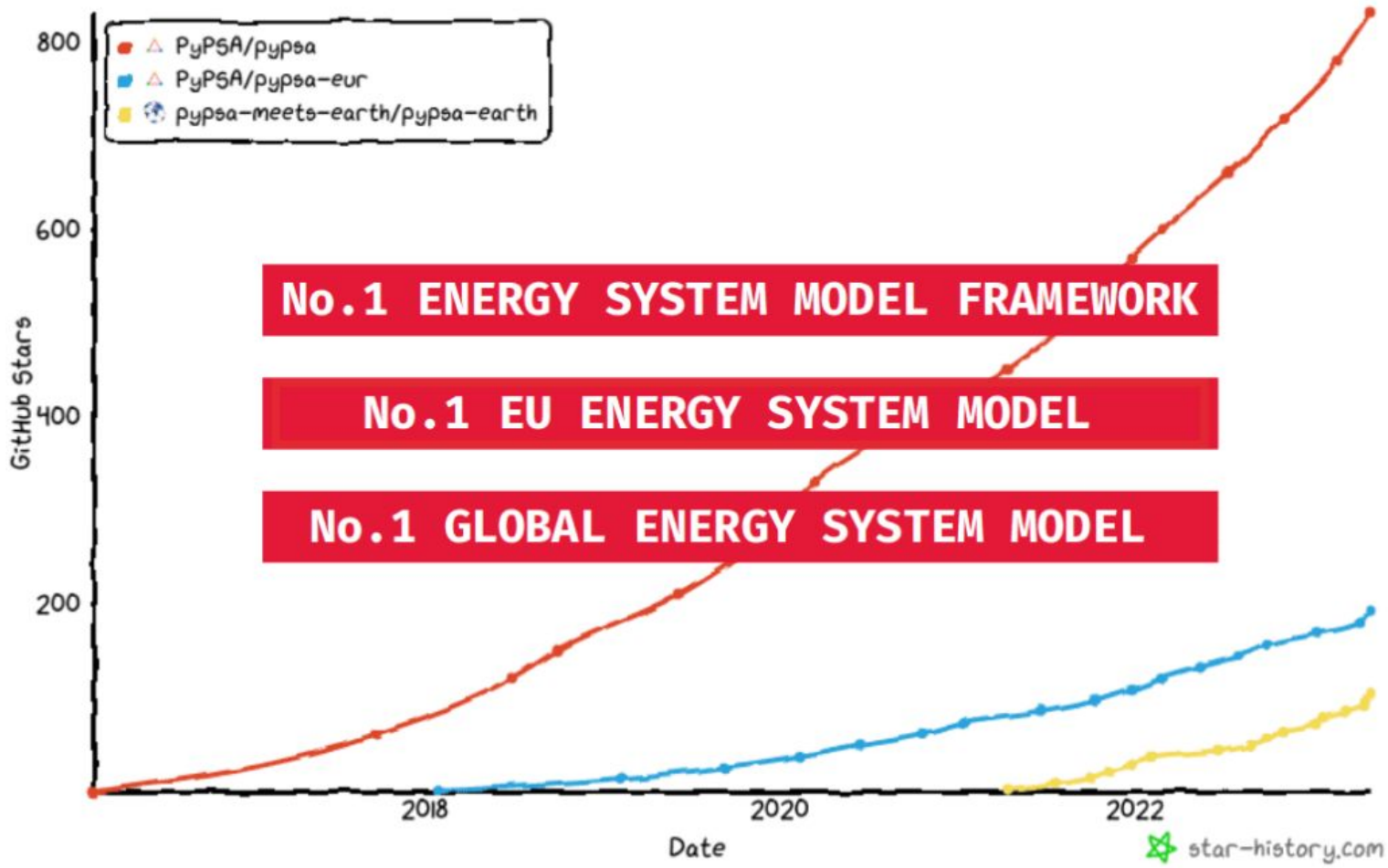
- We offer reliable on demand support for open source software and train people to adopt cutting-edge open tools

Aim: Help you to maximise impact with open-source software and open data

PyPSA is a popular open source toolbox for simulating and optimising modern power and energy systems



Models build on PyPSA experience similar popularity



Maybe you know these institutions? They (& others) use PyPSA

NEWS

"While ENTSOG is free to select any modelling tool for the assessment of the benefits of candidate hydrogen projects, it is recommended, when possible and relevant, the use of an open source tool (for instance, PyPSA [5]) to foster transparency."

– JRC EU Commission, Harmonised system-wide cost-benefit analysis for candidate hydrogen projects, May 2023

NEWS

"Canada's Energy Regulator uses open-source tool PyPSA for their first long-term outlook modelling for net-zero by 2050"

– Maximilian Parzen, LinkedIn post on Canada's Energy Future 2023 which was published on June 2023

Case Studies

Python for Power System Analysis: Worldwide Usage

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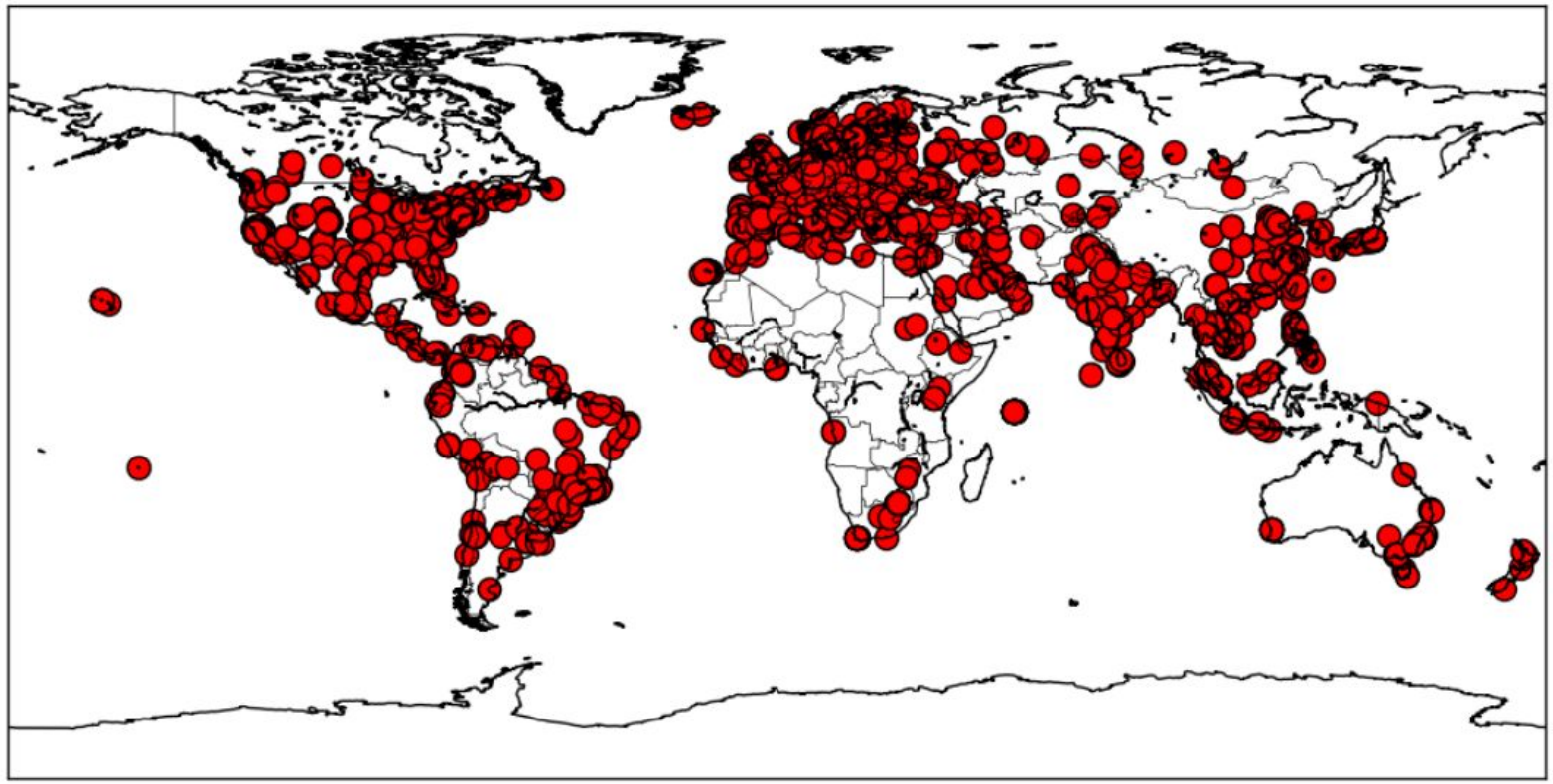
PyPSA is used worldwide by **dozens of research institutes and companies** (TU Delft, KIT, Shell, TSO TransnetBW, TERI, Agora Energiewende, RMI, Ember, Instrat, Fraunhofer ISE, Climate Analytics, DLR, FZJ, RLI, Saudi Aramco, Edison Energy, spire and many others). See **list of users**.

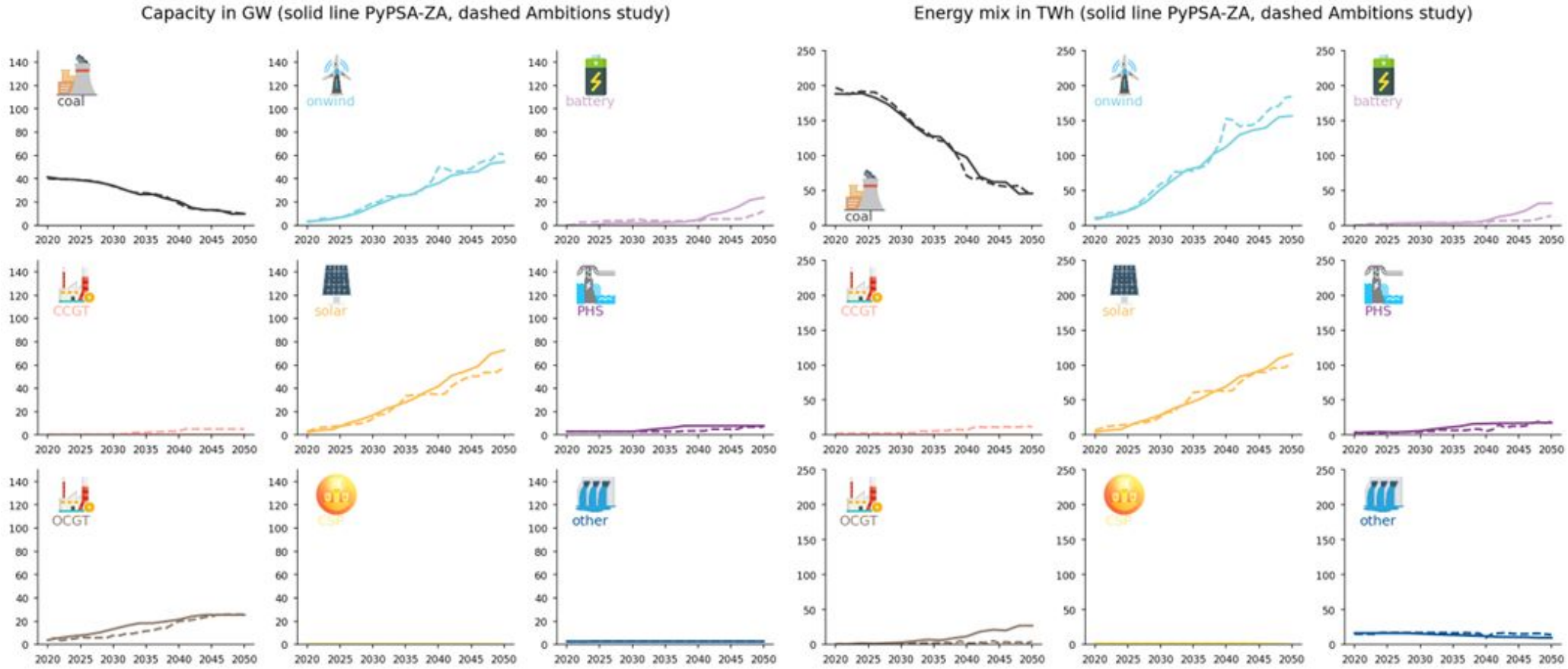


11

Example - Reproducing PLEXOS results

Open Energy Transition
from the creators of PyPSA meets Earth

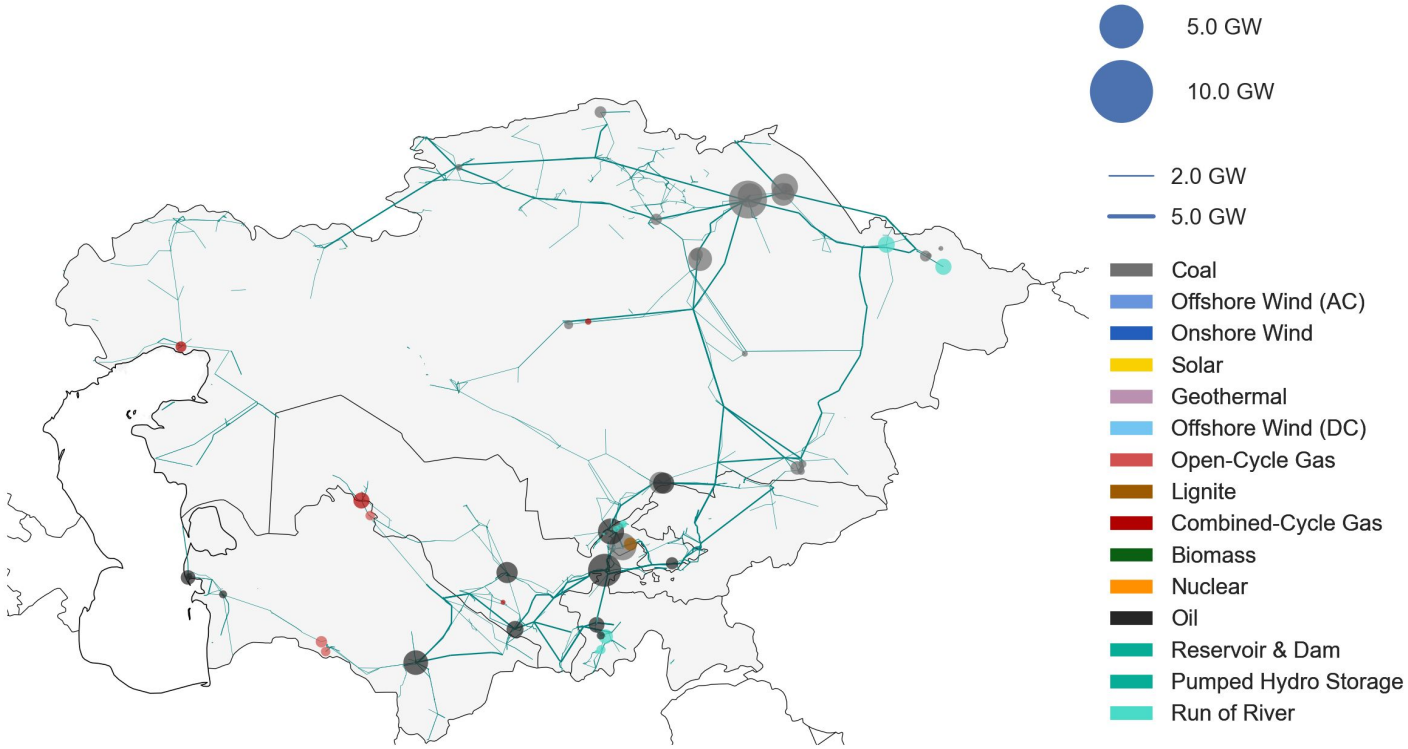
South-African consultancy used a tailored PyPSA-ZA model to demonstrate that PyPSA can replicate commercial state-of-the-art PLEXOS scenarios. Why? They believe in open-source benefits like **customization/ vendor independency** and wanted to **build trust** in open-source with this activity. **OET** can deliver that for any regions.



Example - Exploring more ambitious renewable targets

Open Energy Transition
from the creators of PyPSA meets Earth

OET supports German NGO with PyPSA-Earth for exploring viable renewable energy systems in Kazakhstan. Why? It's cheaper, benefits of transparency, **support is available**, and long-term sustainable since **people can reuse** and **build up on existing work**.



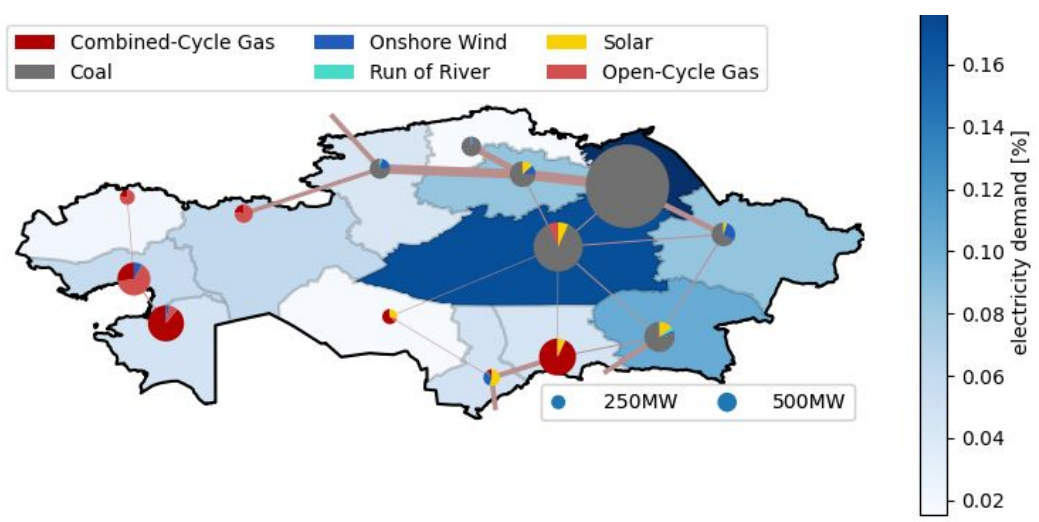
Example - Reproducing the Kazakh Power System

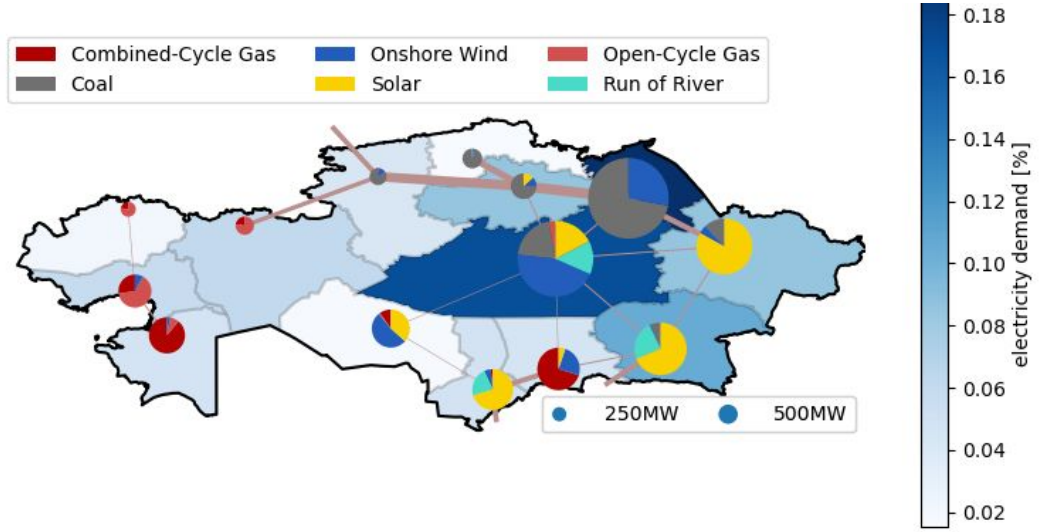
Open Energy Transition
from the creators of PyPSA meets Earth

OET built a tailored PyPSA-KZ model to demonstrate that PyPSA can **replicate todays operation** of the electricity grid. Why? A validated open-source model **builds trust** and is the perfect start to model future

carrier	PyPSA [TWh]	national report [TWh]	error [TWh]	PyPSA [%]	national report [%]	error [%]
gas	20.358883	21.73	1.371117	18.753352	20.103617	1.350265
coal	74.573022	74.47	0.103022	68.692087	68.896290	0.204203
onwind	1.718037	1.08	0.638037	1.582550	0.999167	0.583383
hydro	10.862888	9.51	1.352888	10.006225	8.798224	1.208001
solar	1.048470	1.30	0.251530	0.965786	1.202701	0.236915

carrier	installed capacity [GW]	capacity projection (2030) [GW]
Combined-Cycle Gas	3.48000	3.480000
Open-Cycle Gas	1.62540	1.625400
Coal	12.96700	12.967000
Onshore Wind	0.64870	8.239741
Run of River	0.06278	2.132999
Solar	0.82182	4.568450





Example - Exploring future continental infrastructure requirements

PyPSA example: TransnetBW used PyPSA-Eur-Sec

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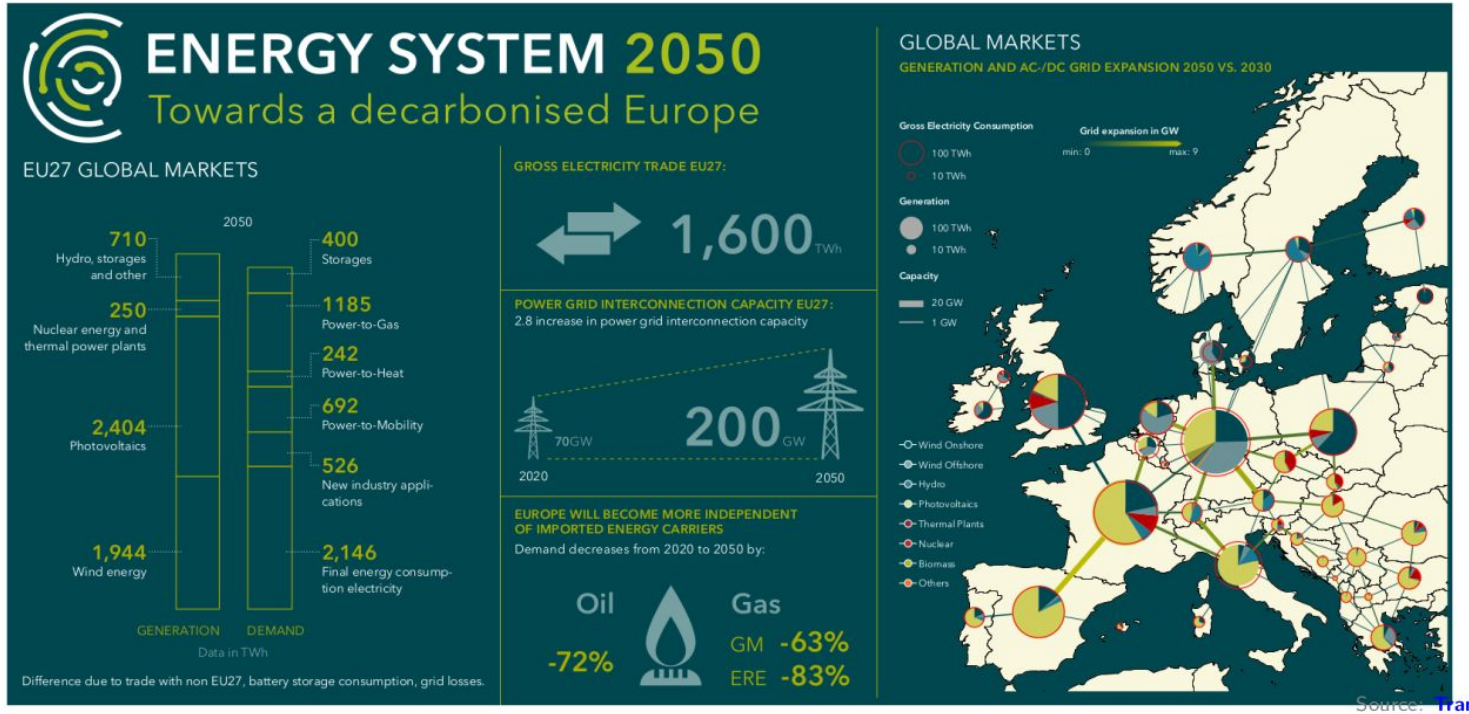
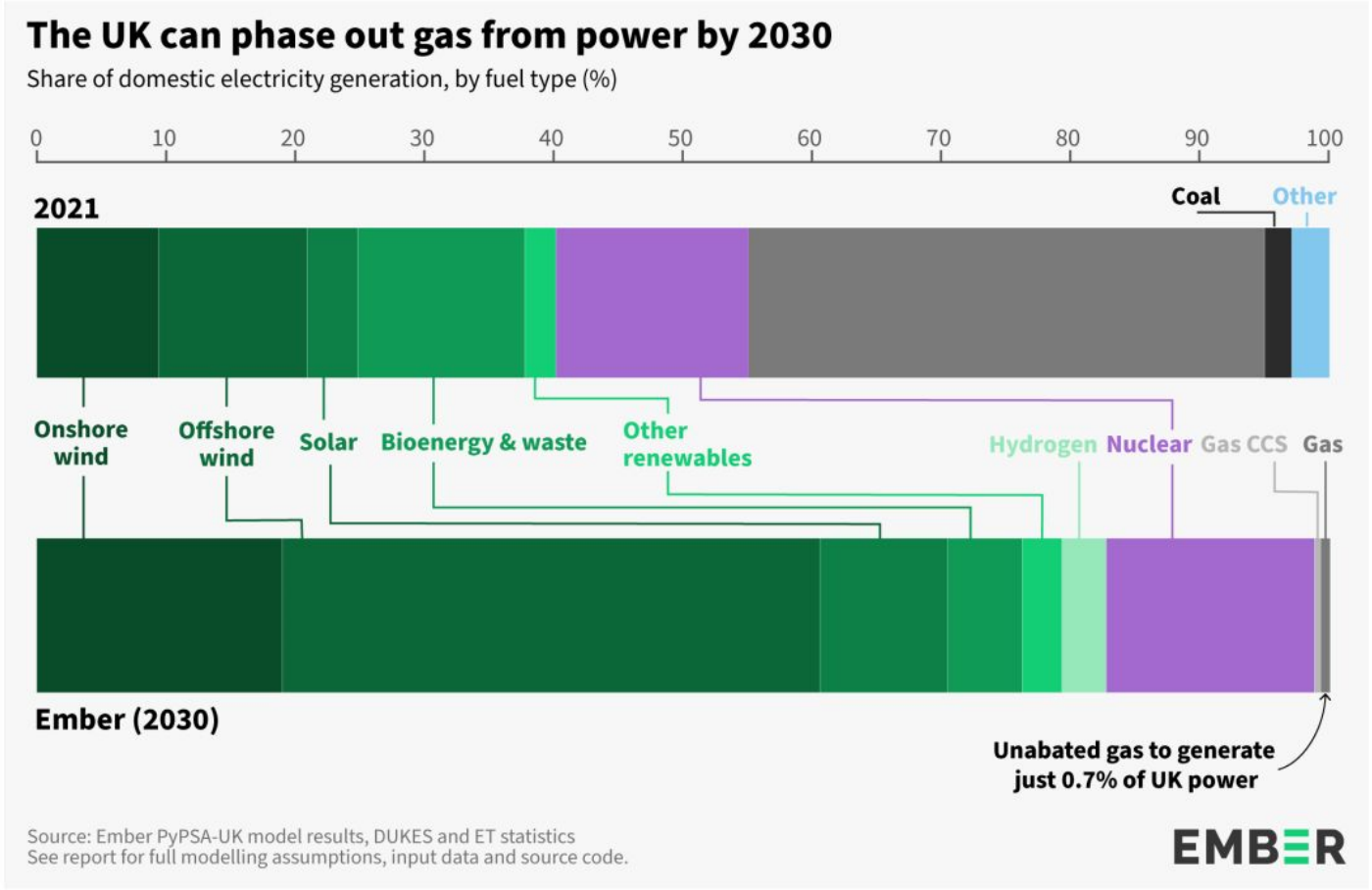
German **Transmission System Operator (TSO) TransnetBW** used an open model (PyPSA-Eur-Sec) to model the European energy system in 2050. Why? Easier to build on an existing model than reinvent the wheel.



Source: TransnetBW, 2022 [12]

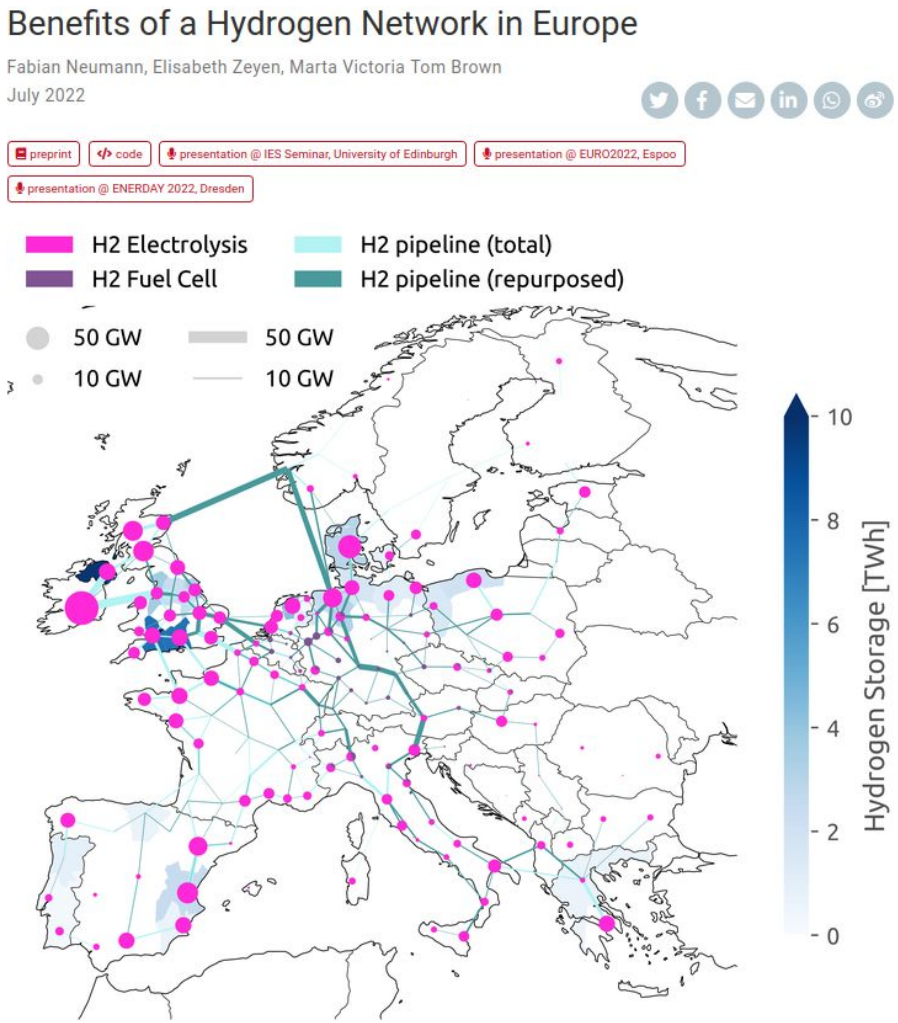
Example - Gas-phase out modelling

NGO Ember used PyPSA to model a gas phase out in the UK by 2030, releasing all code on **github**.



Source: **Ember, 2022**

Example - Exploring green hydrogen infrastructure requirements



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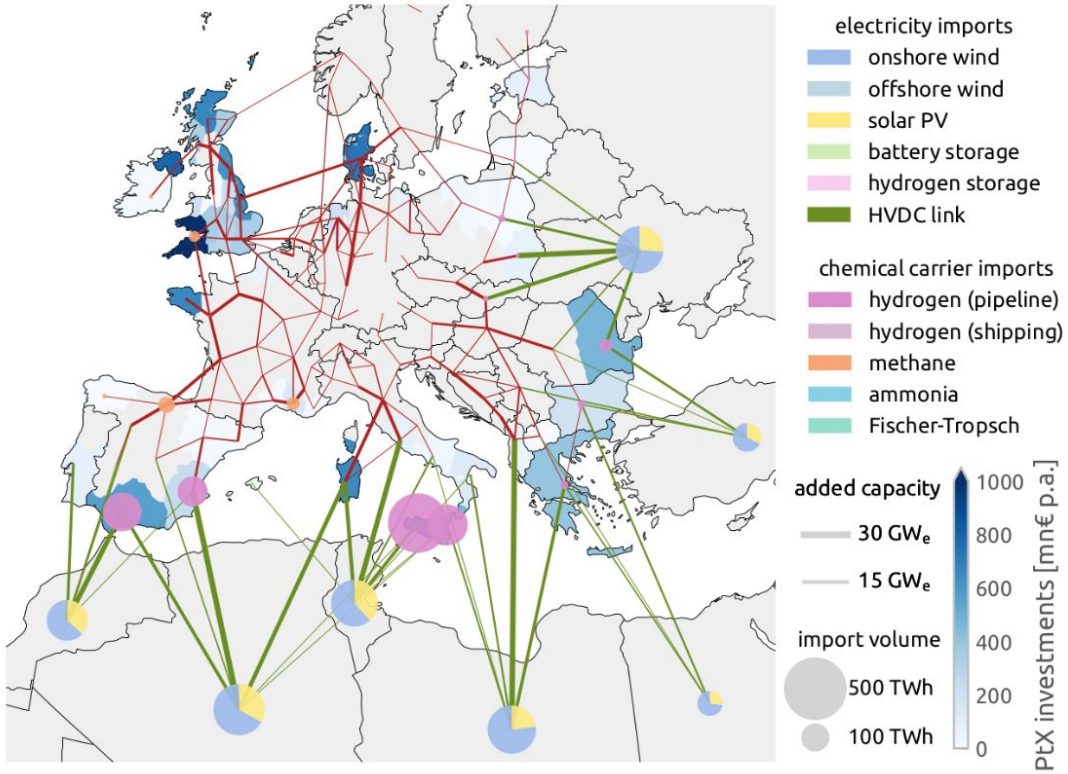
Example - Exploring import and export potentials and their energy system impact

With e-fuel imports instead of autarky



- Allowing imports of electricity, green hydrogen, e-fuels, **changes infrastructure needs completely**
- PtX out-sourced from Europe
- Electricity imported too, providing seasonal balancing

Source: Hampp, Brown, Neumann; 2022/3

Example - Technology assessments under competition e.g. 20 energy storage technologies

Open Energy Transition
from the creators of PyPSA meets Earth

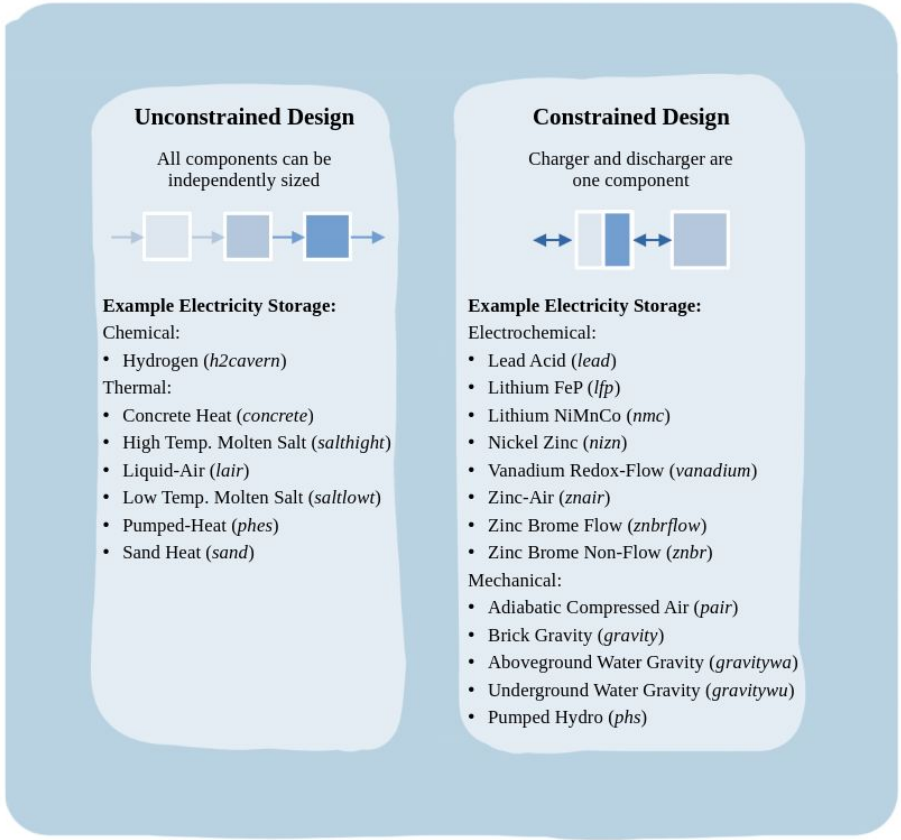
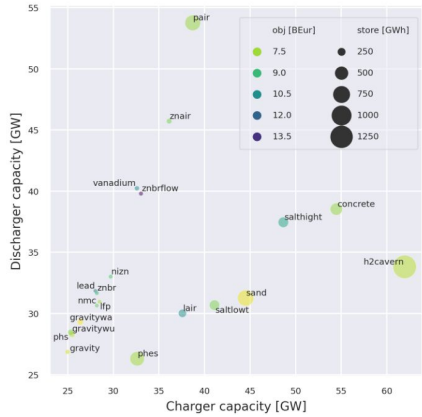
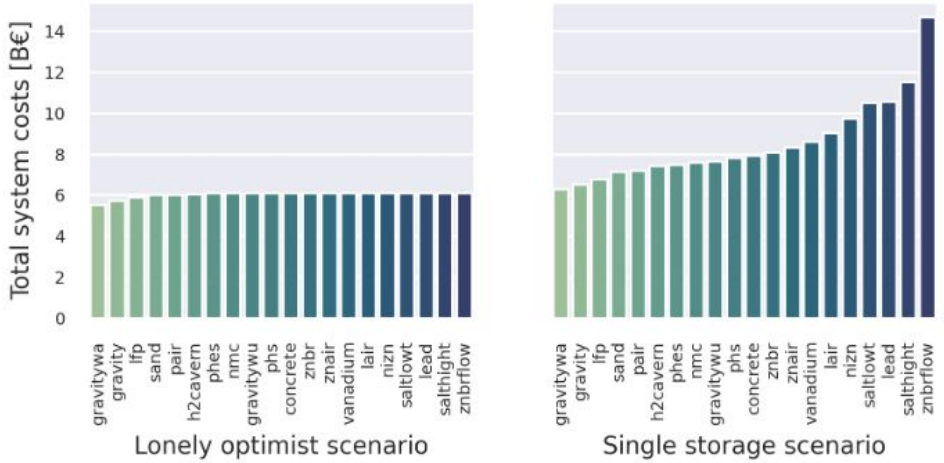


Figure 2: Illustration of energy storage technologies with abbreviations used in this study.

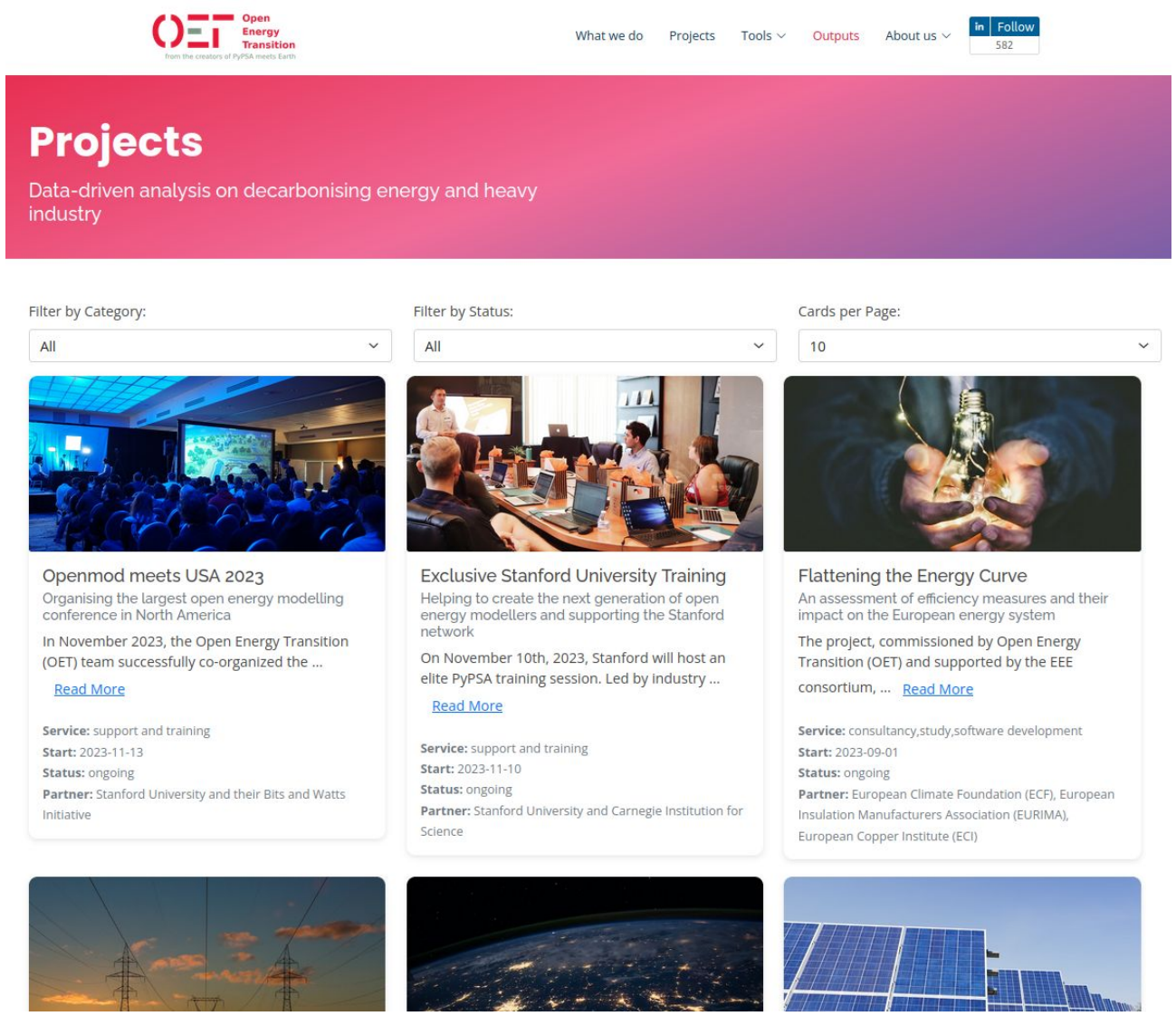




Parzen 2023. The Value of Competing Energy Storage in Decarbonized Power Systems. https://arxiv.org/abs/2305.09795

More projects on our website:

https://openenergytransition.org/projects.html



Conclusion

Open Energy Transition
from the creators of PyPSA meets Earth

- Open data and software is great for decision-makers
- Open solutions are trusted by industry & research
- PyPSA is flexible and offers novel insights for decision-makers
- OET can help you making the best out of open energy modelling

Thanks for listening. Contact us at:

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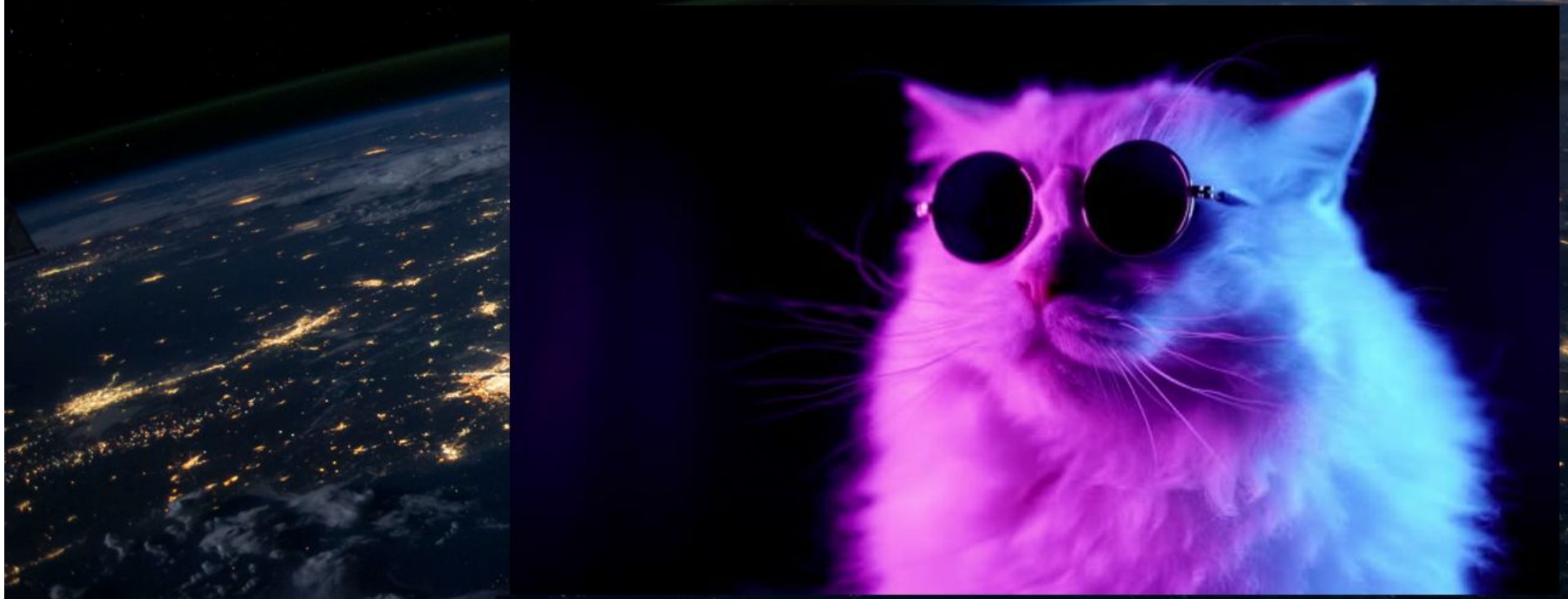
Visit our website: https://openenergytransition.org

YOU ARE ONLY COOL IF YOU USE/CONTRIBUTE TO OPEN DATA 'N' OPEN SOURCE



More details in the manifesto: **https://openmod-initiative.org/manifesto.html**