PyPSA Modelling Track

Introduction to the PyPSA ecosystem

Dr. Martha Frysztacki

Energy Innovation Summit 2025

24.06.2025

Optimization problems in the energy transition

Challenges in Achieving Climate Goals	Profitability	Modelling Approach
What are the biggest challenges in the **energy transition**?	(How) can **solving** the problem be **profitable**?	How can the problem be **mathematically** formulated as an **optimization problem**?

CAPACITY EXPANSION PLANNING

Open Energy Transition
from the creators of PyPSA meets Earth

01	Resource Planning	• Identify optimal **resource sites**. Reduce reliability on fossil fuels.
02	Transmission Planning	• Connect optimal resources to loads. Stabilize the grid.
03	Storage Planning	• Balance demand and supply.

Challenges in
Achieving Climate Goals

CAPACITY EXPANSION PLANNING

Open Energy Transition
from the creators of PyPSA meets Earth

01	Resource Planning	• Identify optimal **resource sites**. Reduce reliability on fossil fuels. • Integration of low-cost renewables.
02	Transmission Planning	• Connect optimal resources to loads. Stabilize the grid. • Cost-efficient grid expansion. Consideration of different scenarios and technologies.
03	Storage Planning	• Balance demand and supply. • Local solutions. Resilience of systems. Determine right technologies at right place.

Challenges in Achieving Climate Goals → Profitability

CAPACITY EXPANSION PLANNING

Open Energy Transition
from the creators of PyPSA meets Earth

01	Resource Planning	• Identify optimal **resource sites**. Reduce reliability on fossil fuels. • Integration of low-cost renewables. • Integrate real-world GIS data on installation and resource potentials for solar, wind, bio-energy, etc.
02	Transmission Planning	• Connect optimal resources to loads. Stabilize the grid. • Cost-efficient grid expansion. Consideration of different scenarios and technologies. • Integrate **real grid data** and realistic expansion strategies. Calculate **power flow** under different scenarios.
03	Storage Planning	• Balance demand and supply. • Local solutions. Resilience of systems. Determine right technologies at right place. • Consider various storage technologies and cost projections.

Challenges in Achieving Climate Goals → Profitability → Modelling Approach

PRODUCTION COSTS / OPERATIONS (AND NETWORK STABILITY)

Open Energy Transition
from the creators of PyPSA meets Earth

01	Resource Operations	• Maximize feed-in from green energy sources
02	Transmission Operations	• Minimizes curtailment & redispatch
03	Storage Operations	• Reduce curtailment and schedule short and long term storage

Challenges in
Achieving Climate Goals

PRODUCTION COSTS / OPERATIONS (AND NETWORK STABILITY)

Open Energy Transition
from the creators of PyPSA meets Earth

01 Resource Operations

- Maximize feed-in from green energy sources.
- Low electricity and energy prices.

02 Transmission Operations

- Minimizes curtailment & redispatch.
- Increased grid stability.

03 Storage Operations

- Reduce curtailment and schedule short and long term storage
- Profit maximization: Buy/Sell when prices are low/high. Grid-friendly operation.

Challenges in Achieving Climate Goals → Profitability

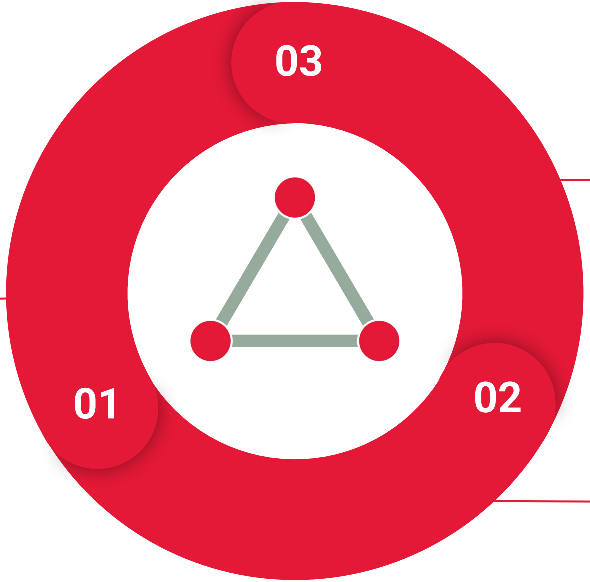
PRODUCTION COSTS / OPERATIONS (AND NETWORK STABILITY)

Open Energy Transition

from the creators of PyPSA meets Earth

01	Resource Operations	• Maximize feed-in from green energy sources. • Low electricity and energy prices. • Proficient estimates of renewable energy feed-in in high temporal and spatial resolution.
02	Transmission Operations	• Minimizes curtailment & redispatch. • Increased grid stability. • Consideration of security constraints and reserve margins. Stability and frequency analysis.
03	Storage Operations	• Reduce curtailment and schedule short and long term storage • Profit maximization: Buy/Sell when prices are low/high. Grid-friendly operation. • Consider different weather scenarios. Analyse price responses and storage potentials at critical times.

Expansion planning & operations should be co-optimized



Resources

Sourced at available and profitable sites, where the **connection to the grid** is good at profitable, high **renewable potentials**

Storage

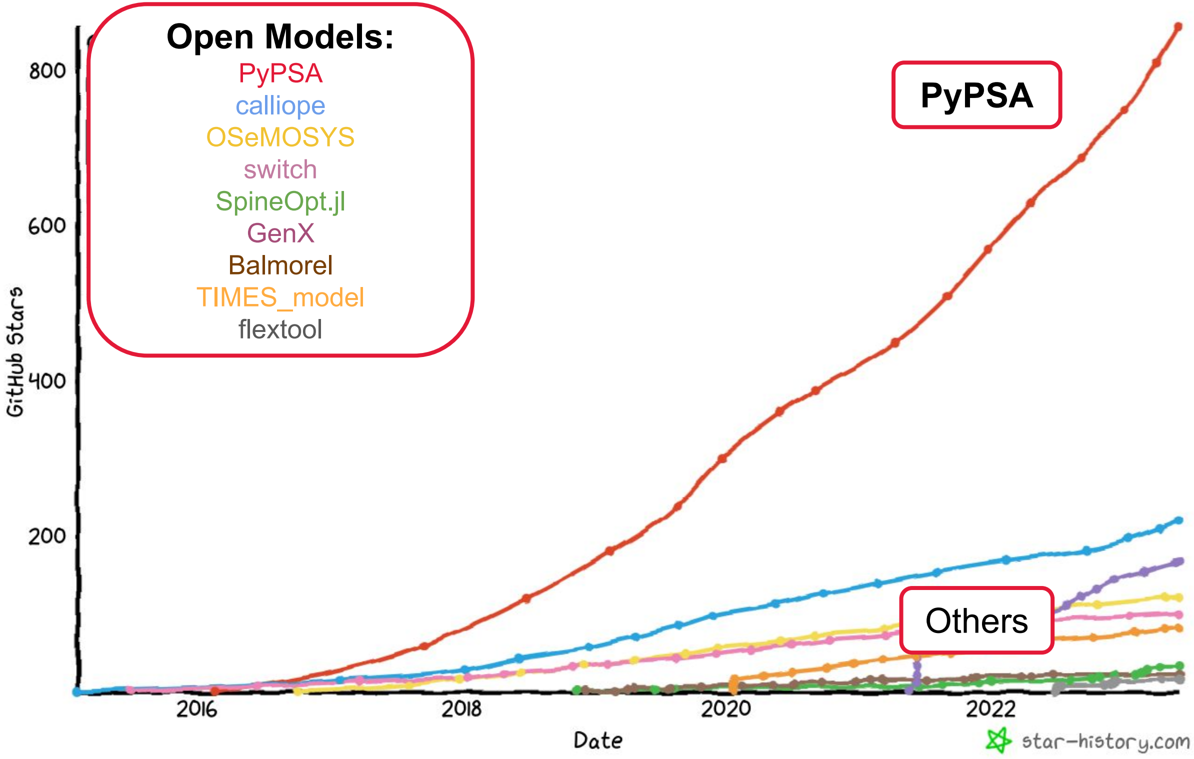
Sourced at available and **profitable sites** where the **connection to the grid** is good where it can help **balance varying supply and demand**

Transmission

Depends on the **location and availability of energy** and **time-dependent** energy loads

Which Open Models are popular?

Open Energy Transition
from the creators of PyPSA meets Earth



Major **advantages of PyPSA**:

- **co-optimization & sector coupling**
- **industry support**
- **global model coverage**
- excellent research **contributions**
- detailed **documentation**
- **fully open source**: data & model

⭐ Open source energy planning is coming!

- More than 500k downloads per year for PyPSA and pandapower alone*
- Used by system operators, traders, regulators, manufacturers, universities
- People start implementing alternative solutions to proprietary software across the world (e.g., OET enhances or replaces proprietary software tools with open-source solutions)

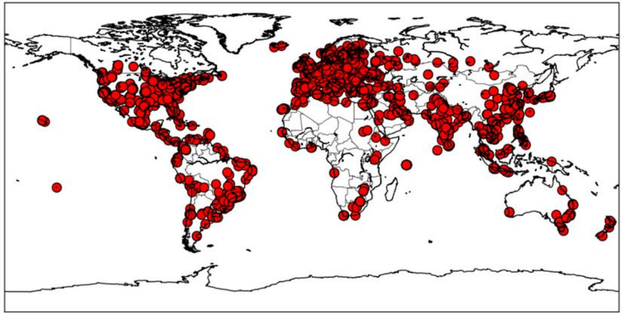


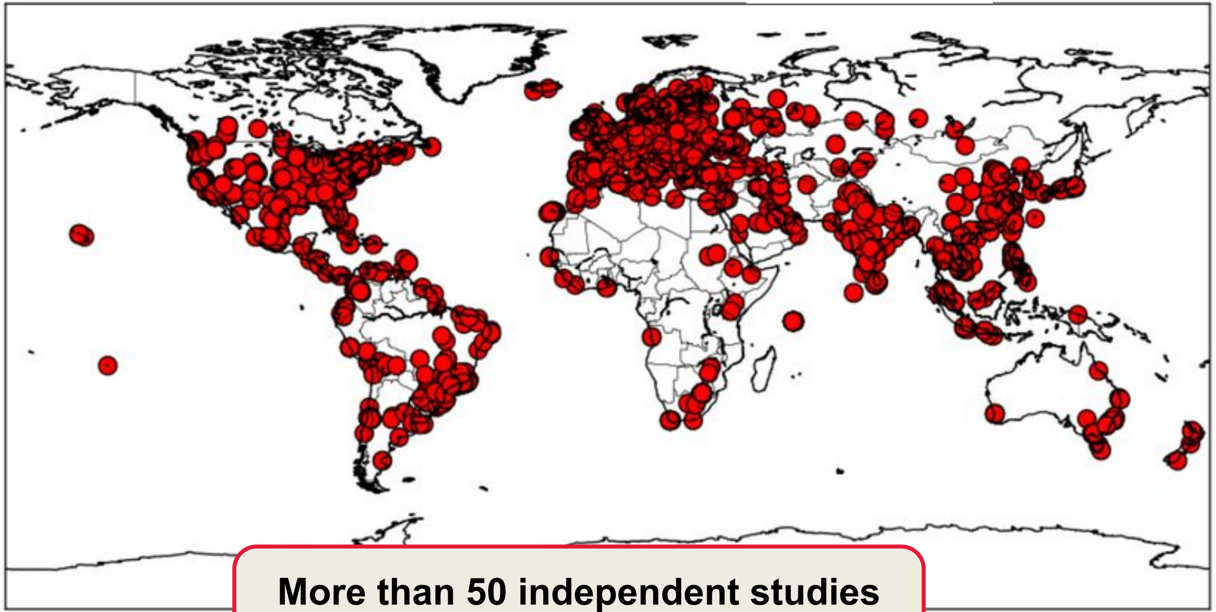
Fig. Showing PyPSA download locations @credit to Tom Brown

*based on PyPI estimates from PyPSA and pandapower

Research & Industry Projects conducted with PyPSA

Open Energy Transition
from the creators of PyPSA meets Earth

TRANSNET BW
CLIMATE ANALYTICS
Technische Universität Berlin
Shell
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Agora Energiewende



More than 50 independent studies were conducted with PyPSA

The University of Edinburgh
Fraunhofer
EMBER COAL TO CLEAN
DLR
Università di Pisa
European Commission JOINT RESEARCH CENTRE
TATA STEEL
Stanford University

What can PyPSA do?

Open
Energy
Transition
from the creators of PyPSA meets Earth

Optimization Problems

Capacity expansion (linear)

- single-horizon
- multi-horizon

Market modelling (linear)

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

Non-linear power flow

- Newton-Raphson

+

Components

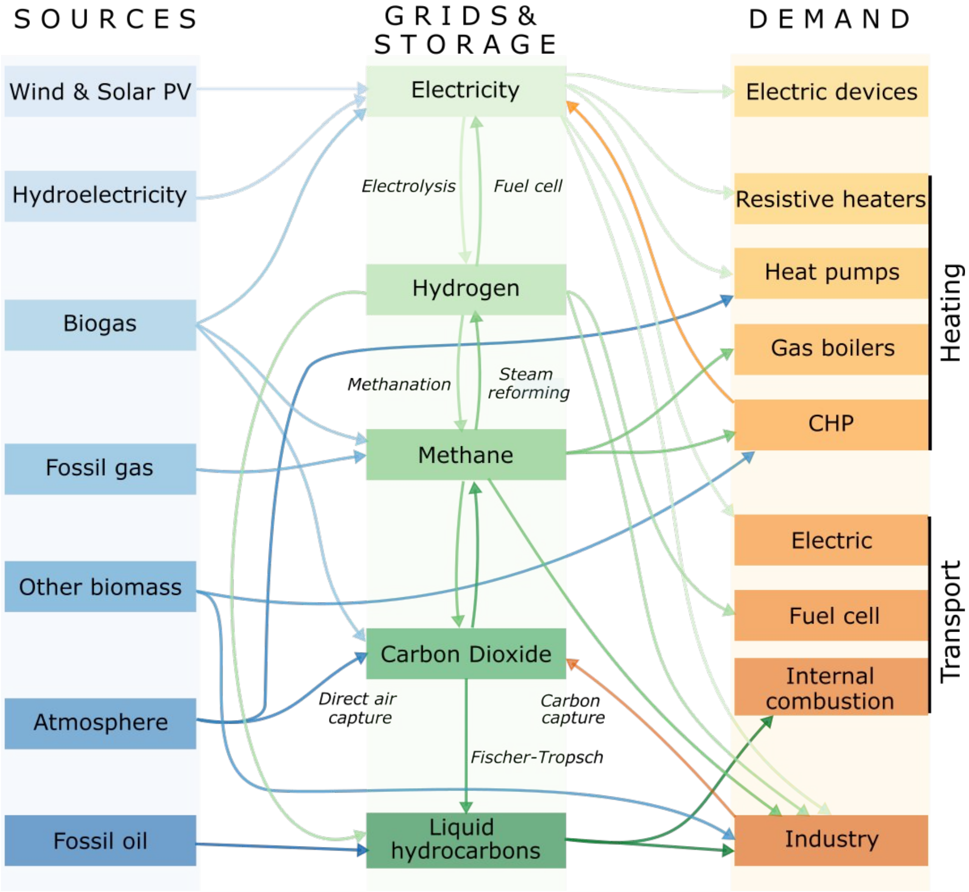
- **Resources**: Generators with unit commitment and hourly time series
- **Transmission**: Meshed AC-DC networks (Transmission)
- **Storage**: Includes efficiency losses and inflow/spillage for hydro
- **Conversion** between energy carriers & materials (PtX, CHP, BEV, DAC, CO2, ...)

Backend:

- all data stored in **pandas**
- interface for all major solvers with **linopy** (created by PyPSA developers)

Decarbonise all Energy Sectors with PyPSA

Open Energy Transition
from the creators of PyPSA meets Earth



Walkthrough

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

Dr. Fabian Neumann
Technische Universität Berlin

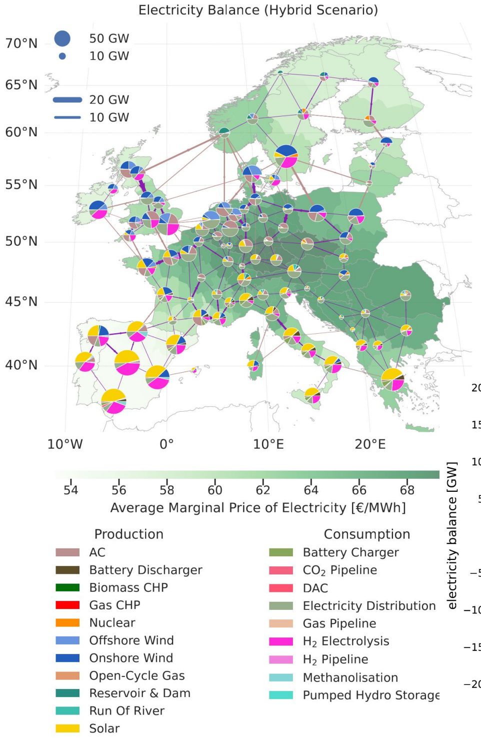
Gurobi Energy Innovation Summit
25 June 2025

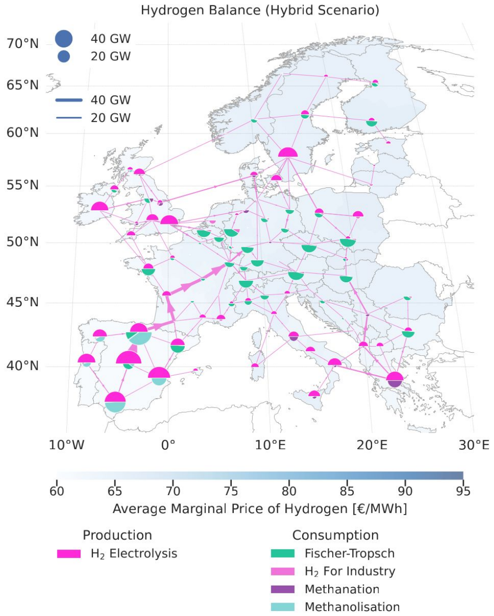
github.com/pypsa/pypsa-eur
pypsa-eur.readthedocs.io

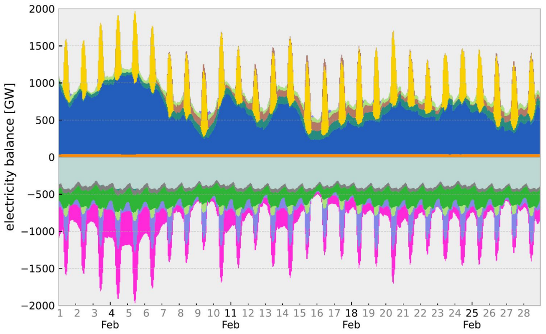
PyPSA-Eur: A sector-coupled open model of the European energy system

Automated workflow to build energy system model of Europe from raw open data:

1. Energy balances
2. Power transmission and gas pipelines
3. Geographical data about power plants, industrial sites, LNG terminals
4. Geographical potentials for the expansion of wind, solar, biomass, hydrogen and CO2 storage
5. Time series for energy demand (electricity, heat, transport, industry)
6. Time series for wind and solar production, hydro-power, heat pumps, etc.
7. Techno-economic assumptions





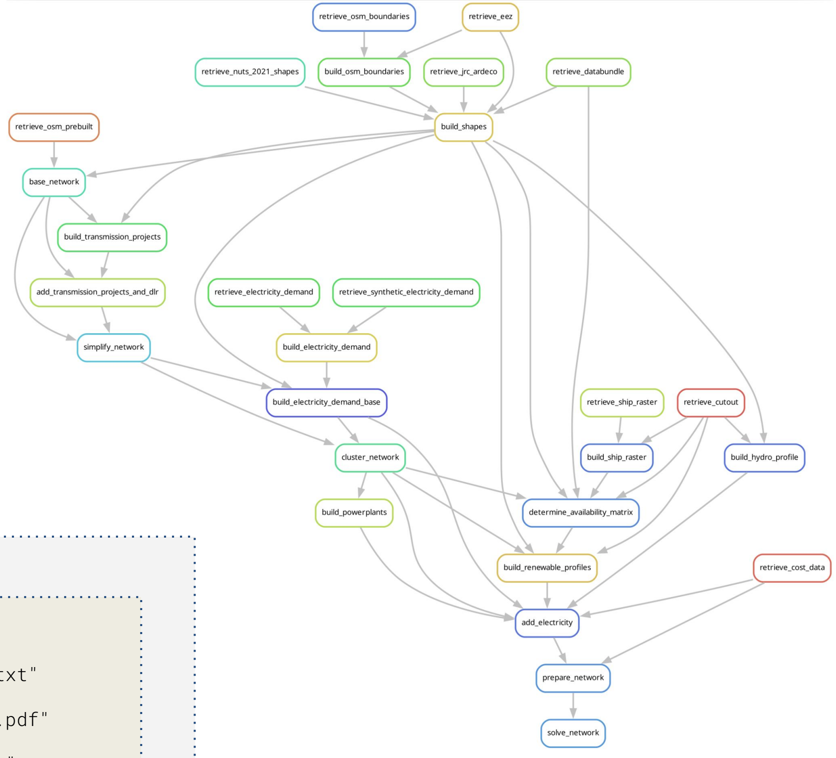


Workflow Management with **Snakemake**

- **Data Dependencies:**

  Raw data is processes step by step.
- **Software Dependencies:**

  Software environments logged for reproducibility.
- **Scenario-Management** and **Cluster-Integration**

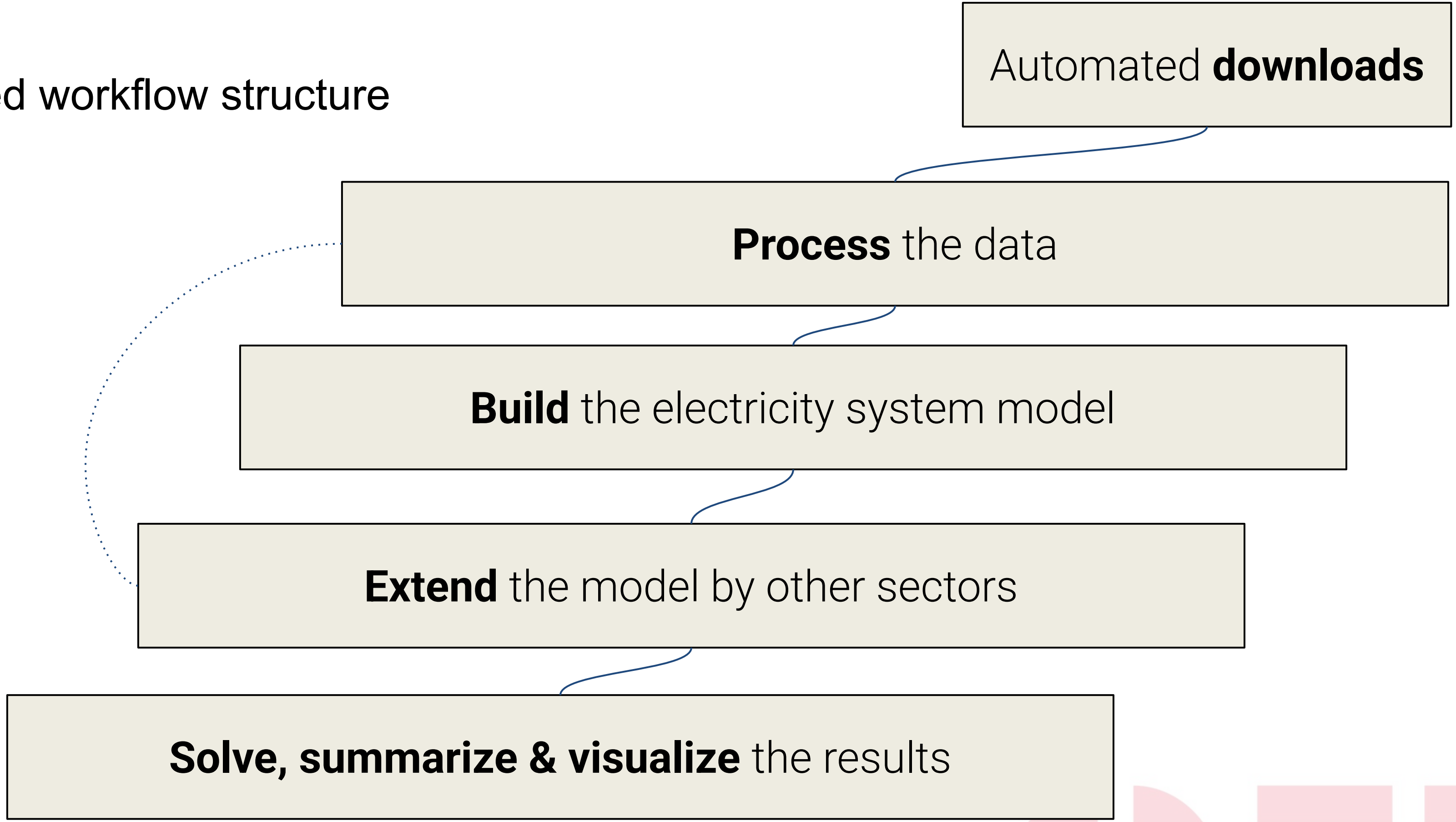


Snakefile

```
rule mytask:
    input:
        "data/{sample}.txt"
    output:
        "result/{sample}.txt"
    script:
        "scripts/mytask.py"
```

```
rule myplot:
    input:
        "result/{sample}.txt"
    output:
        "figures/{sample}.pdf"
    script:
        "scripts/myplot.py"
```

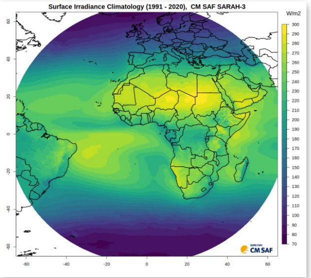
Simplified workflow structure



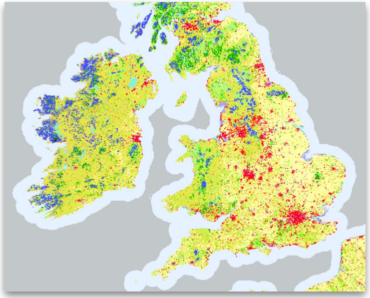
Public data sources

WDPA

SARAH-3

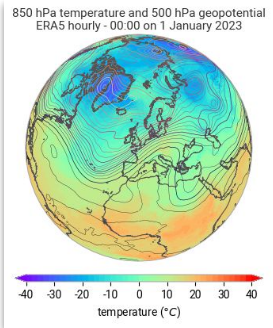


CORINE

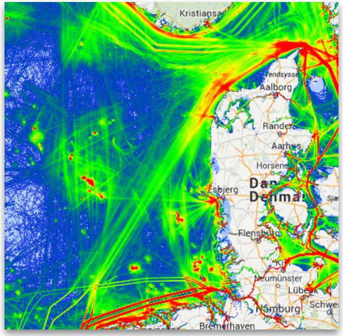


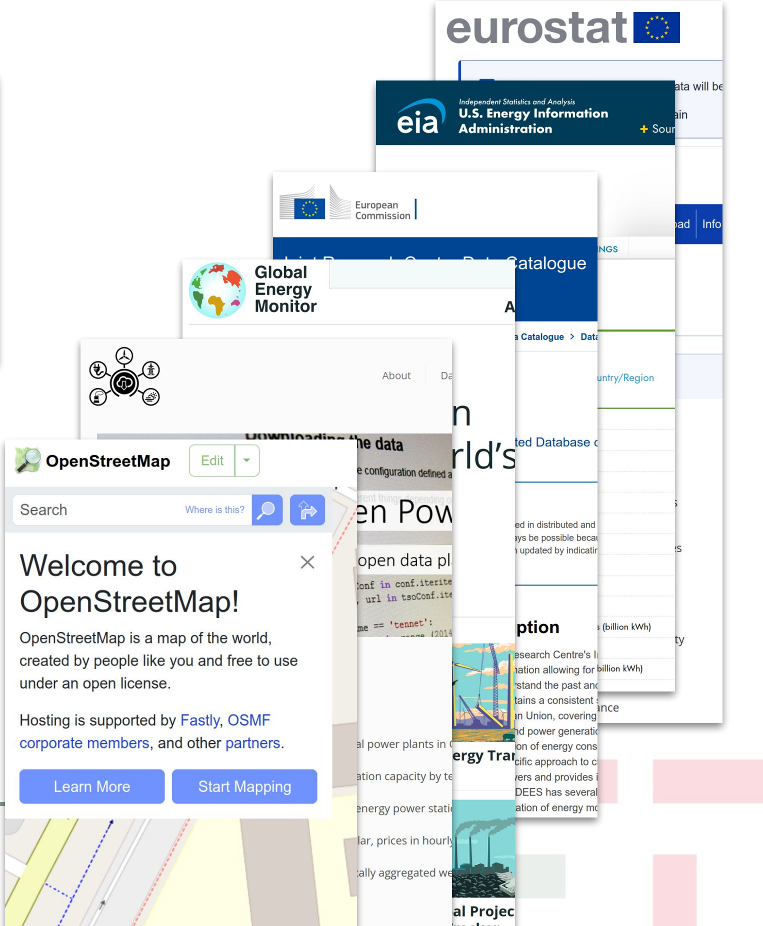
GEBCO

ERA5



World Bank



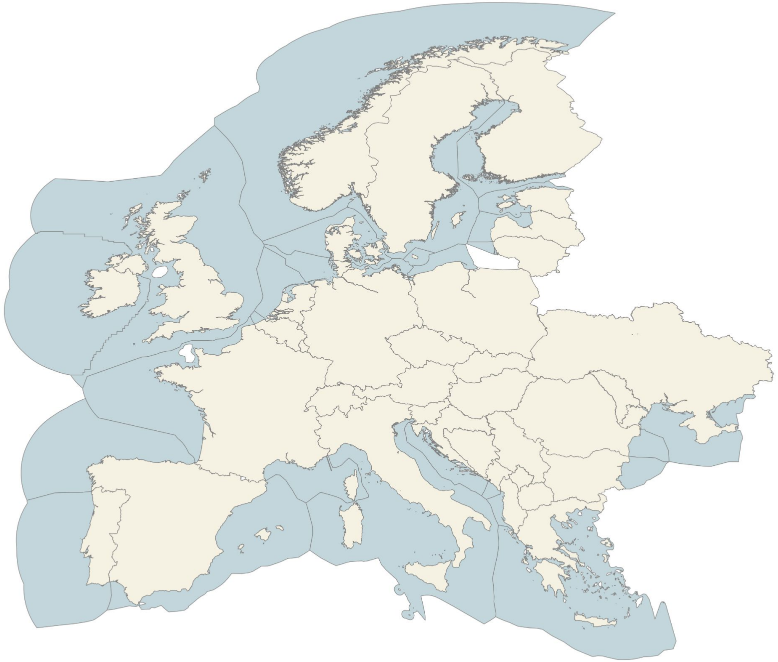


https://pypsa-eur.readthedocs.io/en/latest/data_sources.html

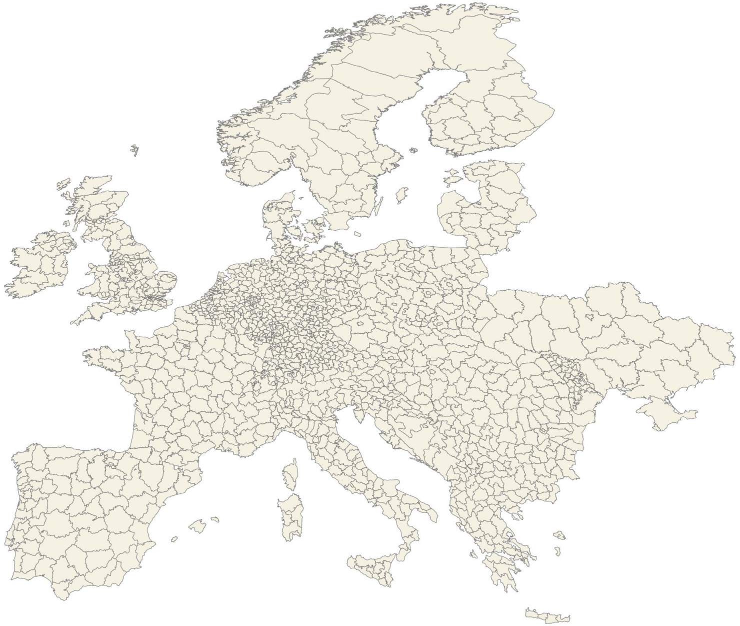
Steps to building PyPSA-Eur

Retrieve onshore & offshore polygons for each country

Country shapes & exclusive economic zones (EEZ)



NUTS administrative regions (NUTS3)



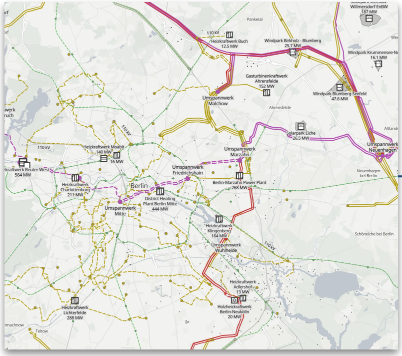
Steps to building PyPSA-Eur

Retrieve onshore & offshore polygons for each country

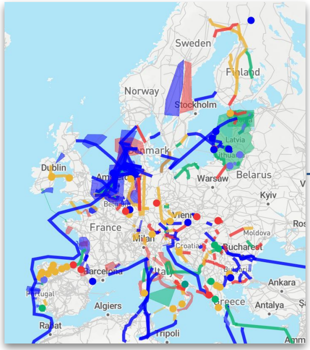
Construct a base high-voltage network with
buses, transformers, AC & DC lines with DLR & TYNDP

Power grid topology

OpenStreetMap data



TYNDP projects



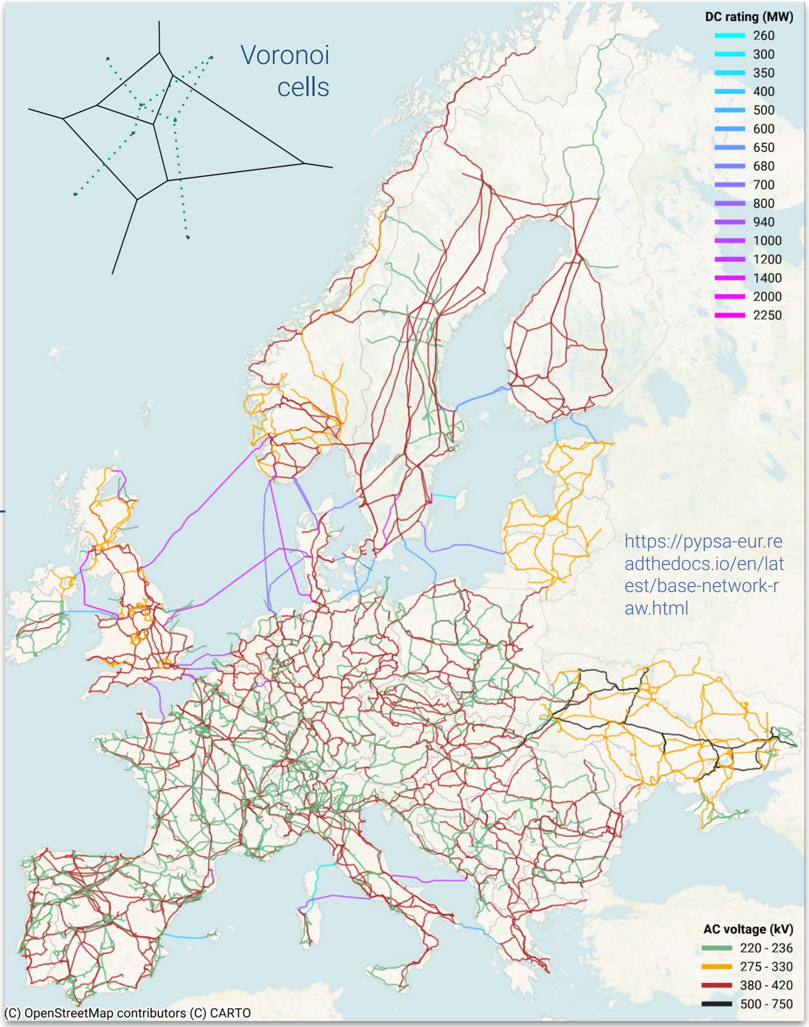
Apply **standard line types** for capacity and parameters.

Calculate **dynamic line rating** potential from weather data.

European network with

- ~5,800 buses
- ~7,300 AC lines (>220 kV)
- 36 HVDC links (+TYNDP)

https://www.nature.com/articles/s41597-025-04550-7



Steps to building PyPSA-Eur

Retrieve onshore & offshore polygons for each country

Construct a base high-voltage network with buses, transformers, AC & DC lines with DLR & TYNDP

Transform all transmission lines to 380kV, remove dead ends & cluster with k-means or hierarchical clustering

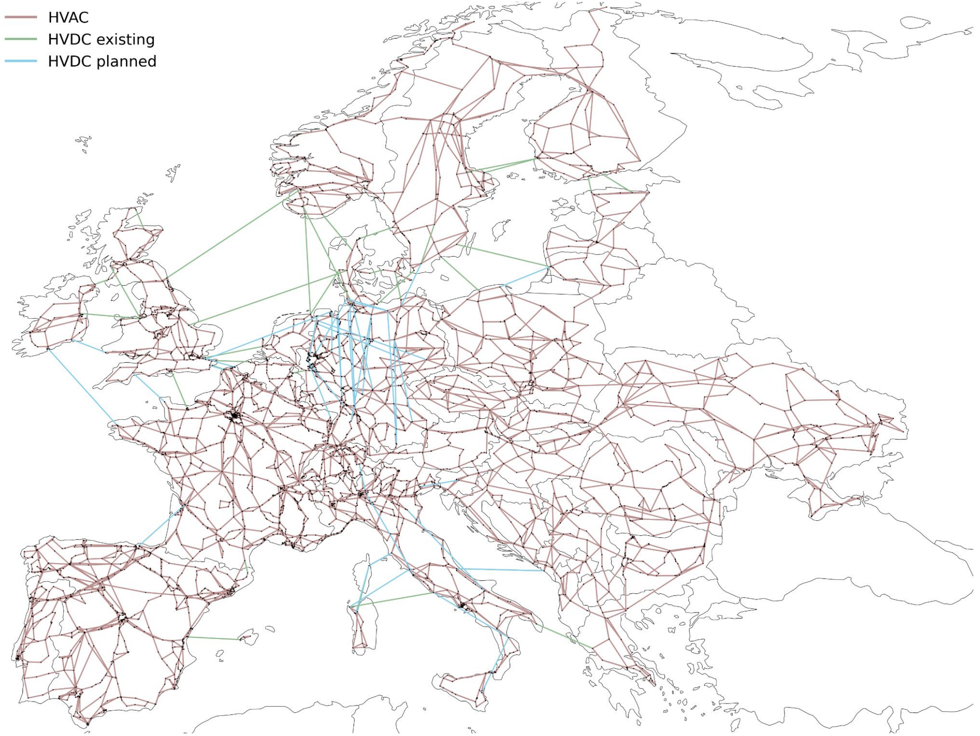
Clustering the electricity network

Need to make the optimization problem less **computationally challenging**…

…if we want to **co-optimize** generation, storage, PtX conversion and transmission infrastructure:

1. Lift all lines to common voltage level of 380 kV.

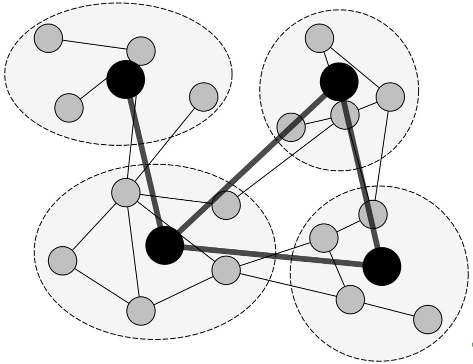
1. Remove dead ends.



Clustering the electricity network

Transformed **to 380 kV**

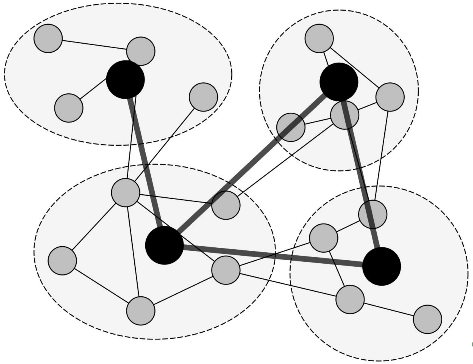
Clustered to **512 regions**

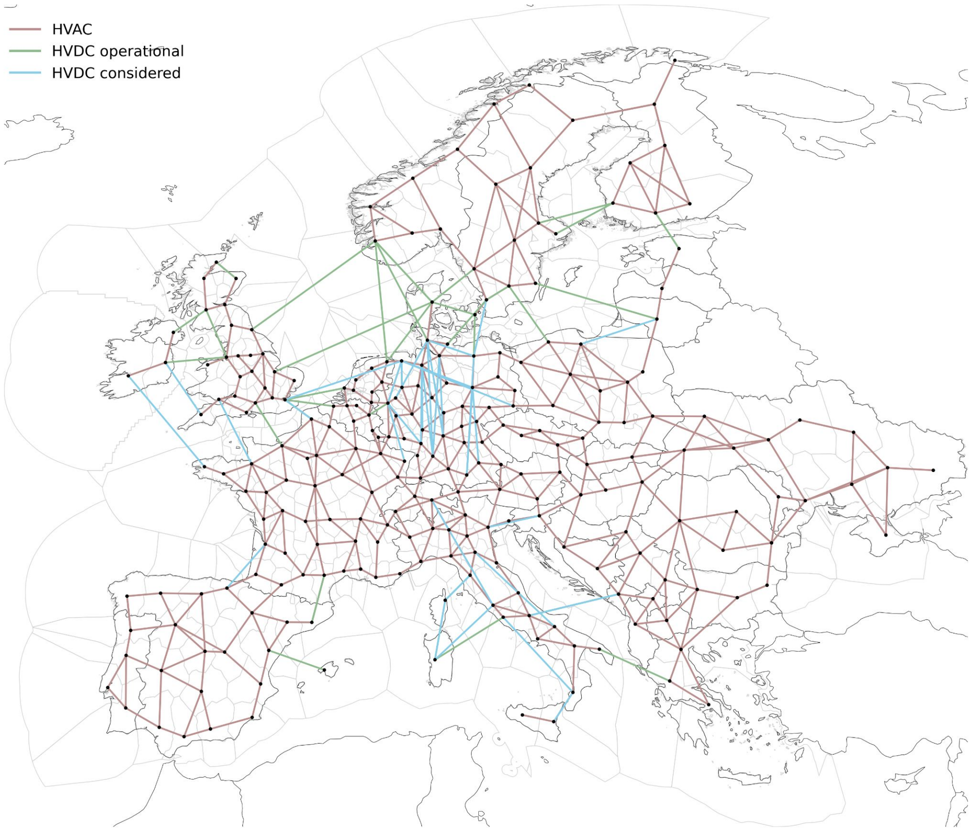


Clustering the electricity network

Transformed
to 380 kV

Clustered to
256 regions

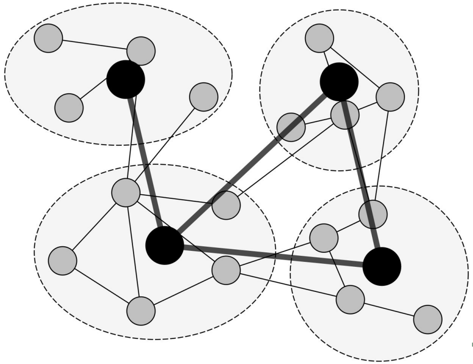




Clustering the electricity network

Transformed
to 380 kV

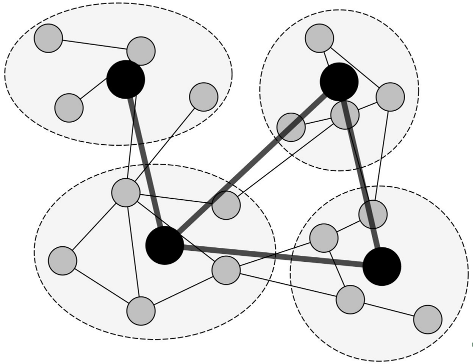
Clustered to
128 regions



Clustering the electricity network

Transformed **to 380 kV**

Clustered to **64 regions**



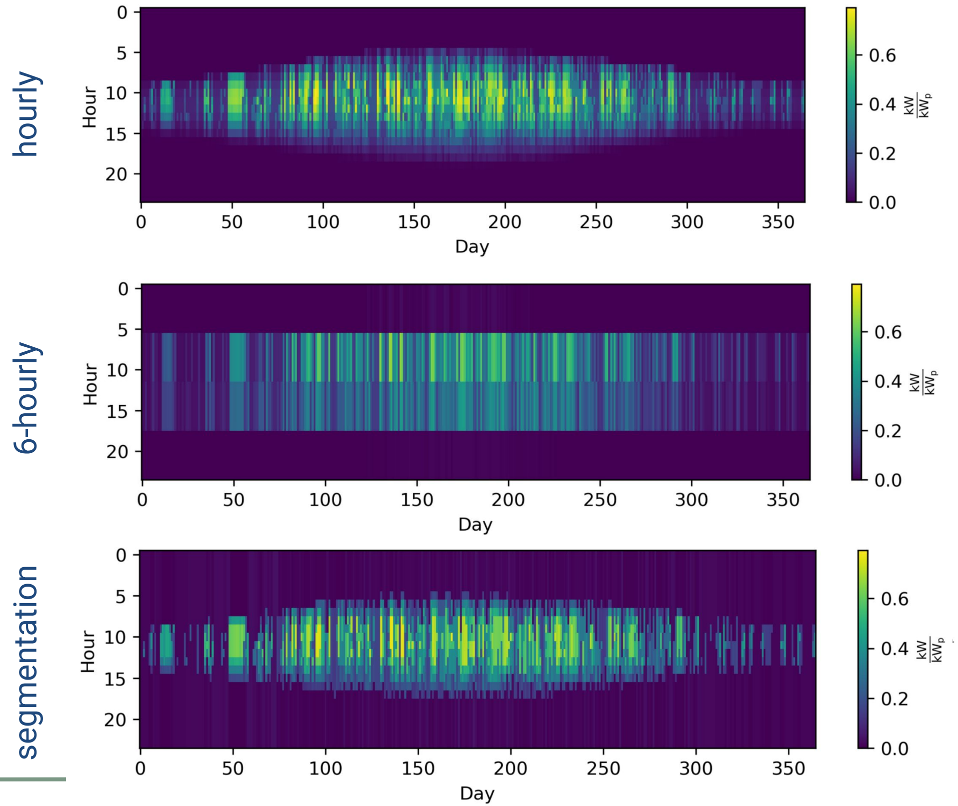
Temporal aggregation

Multiple options:

1. **averaging** of every Nth hour

2. **sampling** every Nth hour (e.g. 3-hourly)

3. Non-equidistant **segmentation** with pre-defined number of segments using the `tsam` Python library from **FZ Jülich**



Introduction

tsam - time series aggregation module

 https://tsam.readthedocs.io/en/latest/newsDoc.html

Steps to building PyPSA-Eur electricity system

Retrieve onshore & offshore polygons for each country

Construct a base high-voltage network with
buses, transformers, AC & DC lines with DLR & TYNDP

Transform all transmission lines to 380kV, remove
dead ends & cluster with k-means or hierarchical clustering

Determine eligible areas for utility-scale PV
& onshore/offshore wind park development

Build renewable capacity factor profiles for
each clustered region based on land availability

atlite: Convert weather data to energy systems data

pypi v0.3.0 | conda-forge v0.3.0 | Tests passing | codecov 72% | docs passing | license MIT
REUSE compliant | JOSS 10.21105/joss.03294 | chat 52 online | stackoverflow pypsa questions 44

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

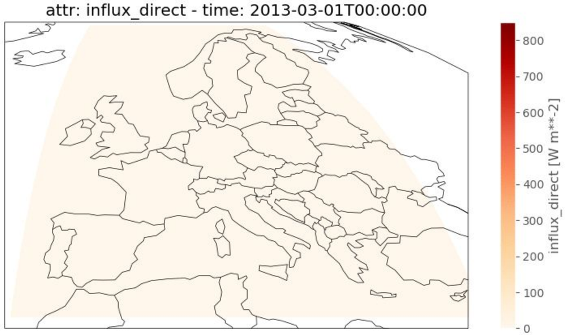
It can also perform **land eligibility analyses**.

- solar photovoltaics
- solar thermal collectors
- wind turbines
- hydro run-off, reservoir, dams
- heat pump COPs
- dynamic line rating (DLR)
- heating and cooling demand (HDD/CDD)

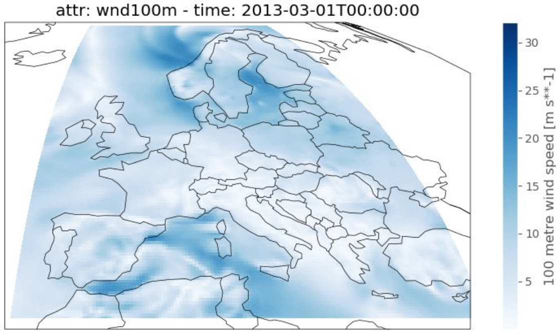
Time series for renewables

The weather years **1996**, **2010**, **2012**, **2013**, **2019, 2020, 2023** and **2024** are currently available as “plug-and-play”.

Historical meteorological weather data from ERA5 and SARAH-3
(up to 84 years, 30x30 km)

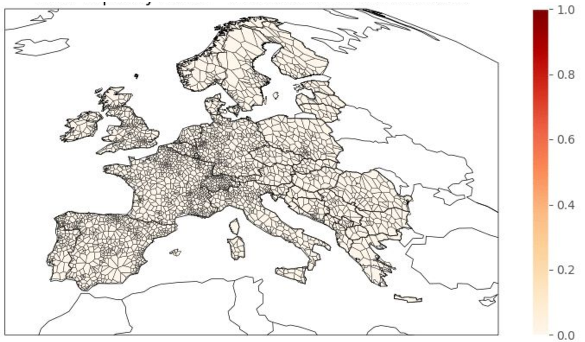


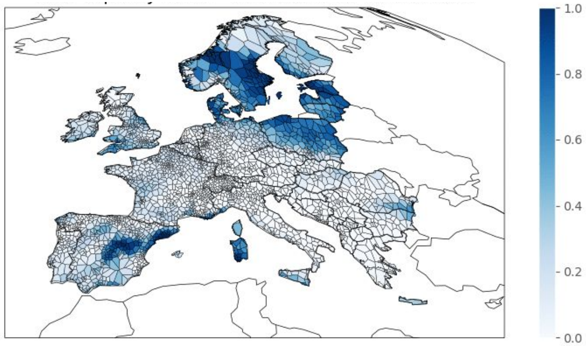
Solar panel models
- orientation
- material



Wind turbine models
- power curve
- surface roughness

Wind and solar capacity factors





Land availability for renewables

Example:
Onshore wind
in one clustered
region

- CORINE / LUISA land cover
  - eligible land types
  - distance requirements
- NATURA / WDPA natural protection areas
- GEBCO bathymetry data
- Shipping lanes
- Distance to shore

Steps to building PyPSA-Eur

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Build renewable capacity factor profiles for each clustered region based on land availability

Prepare existing renewables and fossil power plants

Welcome to powerplantmatching's documentation!

pypi v0.7.0 | conda-forge v0.7.0 | python >=3.9 | Tests failing | docs passing | pre-commit.ci passed | Ruff

license GPLV3+ | DOI 10.5281/zenodo.3358985 | stackoverflow pypsa questions 44

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

```
import powerplantmatching as pm
df = pm.powerplants(from_url=True)
df.query(“DateIn > 2000”)
```

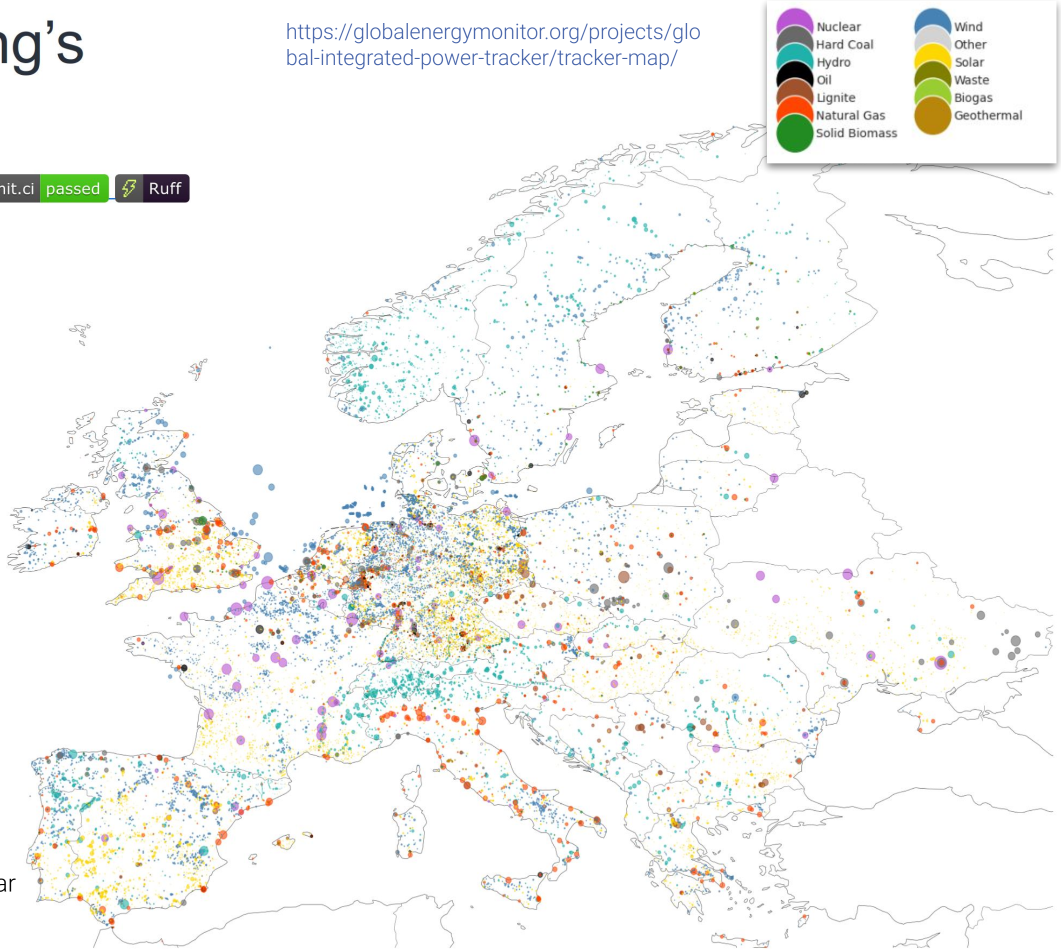
Sources

- Global Energy Monitor (GEM)
- Open Power System Data (OPSD)
- Global Energy Observatory
- World Resources Institute
- Marktstammdatenregister (MaStR)
- CARMA
- ENTSO-E, BNetzA, UBA, IRENA
- JRC for hydro power plants

Attributes

- name
- fuel type
- technology
- country
- capacity
- commissioning year
- retirement year
- coordinates

https://globalenergymonitor.org/projects/global-integrated-power-tracker/tracker-map/



github.com/pypsa/powerplantmatching

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Prepare existing renewables and fossil power plants

Add generation, storage and demand to the network with techno-economic assumptions on costs and efficiencies, …

Database of techno-economic assumptions

compiles **techno-economic assumptions** on energy system components

- investment costs, FOM/VOM costs, efficiencies, lifetimes
- for given years, e.g. 2020, 2030, 2040, 2050
- from mixed sources, but prioritising **Danish Energy Agency** where available (and sensible)

Preview Code Blame 1097 lines (1097 loc) · 213 KB Raw

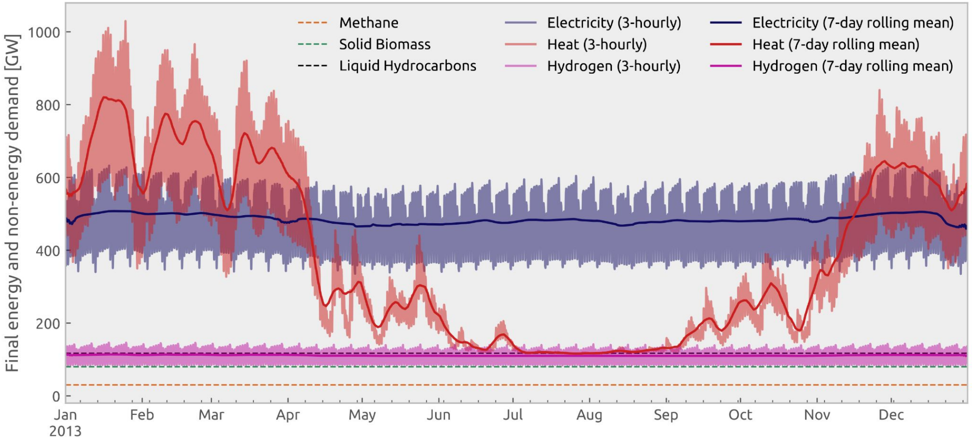
fischer-tropsch

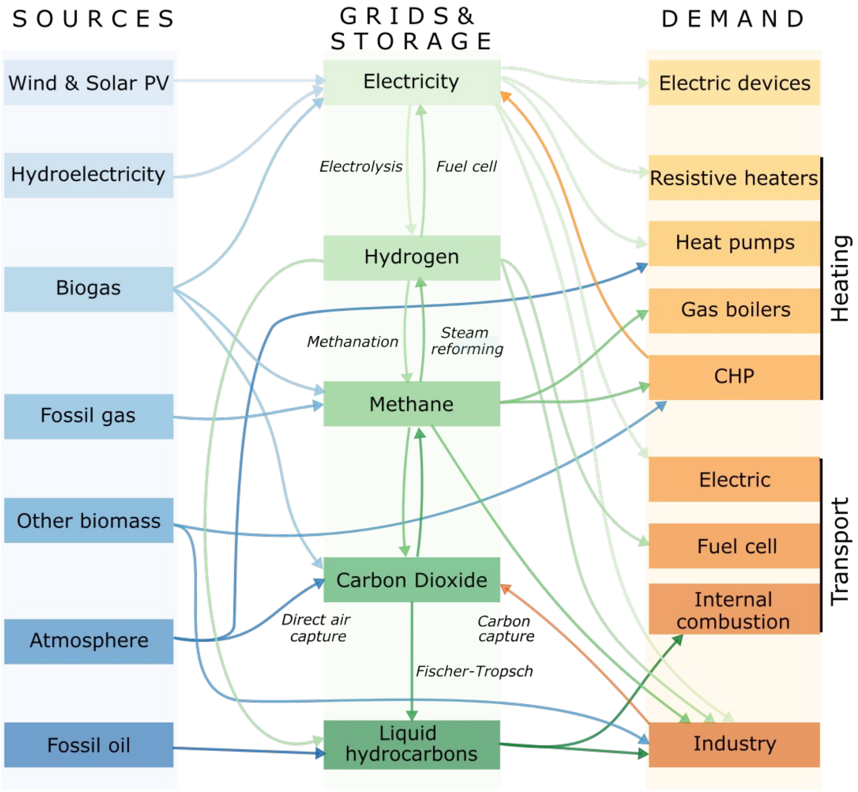
1	technology	parameter	value	unit	source	fu
217	Fischer-Tropsch	FOM	3.0	%/year	Agora Energiewende (2018): The Future Cost of Electricity-Based Synthetic Fuels (https://www.agora-energiewende.de/en/publications/the-future-cost-of-electricity-based-synthetic-fuels-1/), section 6.3.2.1.	
218	Fischer-Tropsch	VOM	4.4663	EUR/MWh_FT	Danish Energy Agency, data_sheets_for_renewable_fuels.xlsx	1(
219	Fischer-Tropsch	capture rate	0.9	per unit	Assumption based on doi:10.1016/j.biombioe.2015.01.006	
220	Fischer-Tropsch	carbondioxide-input	0.326	t_CO2/MWh_FT	DEA (2022): Technology Data for Renewable Fuels (https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-renewable-fuels), Hydrogen to Jet Fuel, Table 10 / pg. 267.	Ir
221	Fischer-Tropsch	efficiency	0.799	per unit	Agora Energiewende (2018): The Future Cost of Electricity-Based Synthetic Fuels (https://www.agora-energiewende.de/en/publications/the-future-cost-of-electricity-based-synthetic-fuels-1/), section 6.3.2.2.	
222	Fischer-Tropsch	electricity-input	0.007	MWh_el/MWh_FT	DEA (2022): Technology Data for Renewable Fuels (https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-renewable-fuels), Hydrogen to Jet Fuel, Table 10 / pg. 267.	0.
223	Fischer-Tropsch	hydrogen-input	1.421	MWh_H2/MWh_FT	DEA (2022): Technology Data for Renewable Fuels (https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-renewable-fuels), Hydrogen to Jet Fuel, Table 10 / pg. 267.	0.
224	Fischer-Tropsch	investment	703726.4462	EUR/MW_FT	Agora Energiewende (2018): The Future Cost of Electricity-Based Synthetic Fuels (https://www.agora-energiewende.de/en/publications/the-future-cost-of-electricity-based-synthetic-fuels-1/), table 8: "Reference scenario".	W
225	Fischer-Tropsch	lifetime	20.0	years	Danish Energy Agency, Technology Data for Renewable Fuels (04/2022), Data sheet "Methanol to Power".	
956	methanation	lifetime	20.0	years	Guesstimate.	B

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

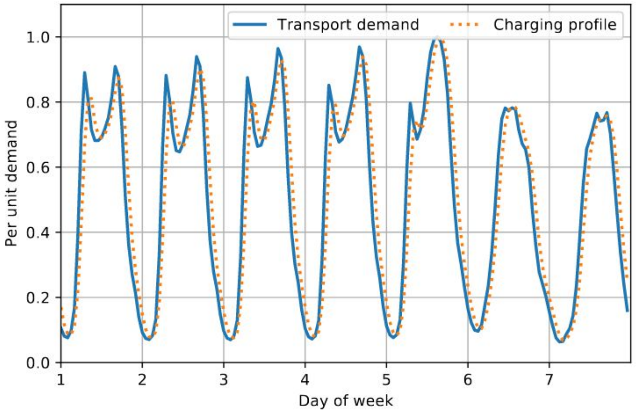
Coupling with other sectors

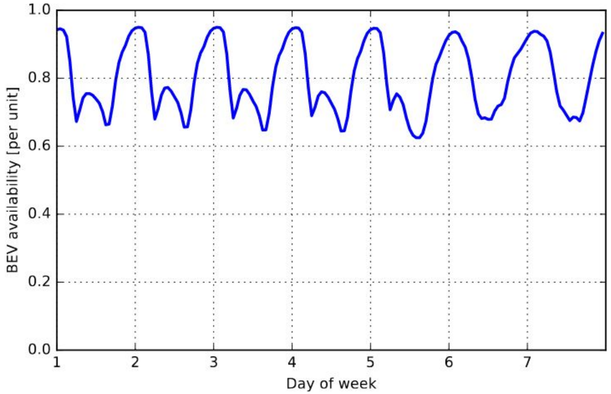
- transport sector (EVs, shipping, aviation)
- heating sector (district heating, individual)
- industry sector (steel, chemicals, ammonia, …)
- carbon management (CCUTS) + biomass
- hydrogen, CO_2 and gas networks





Transport - Electrification of land transport





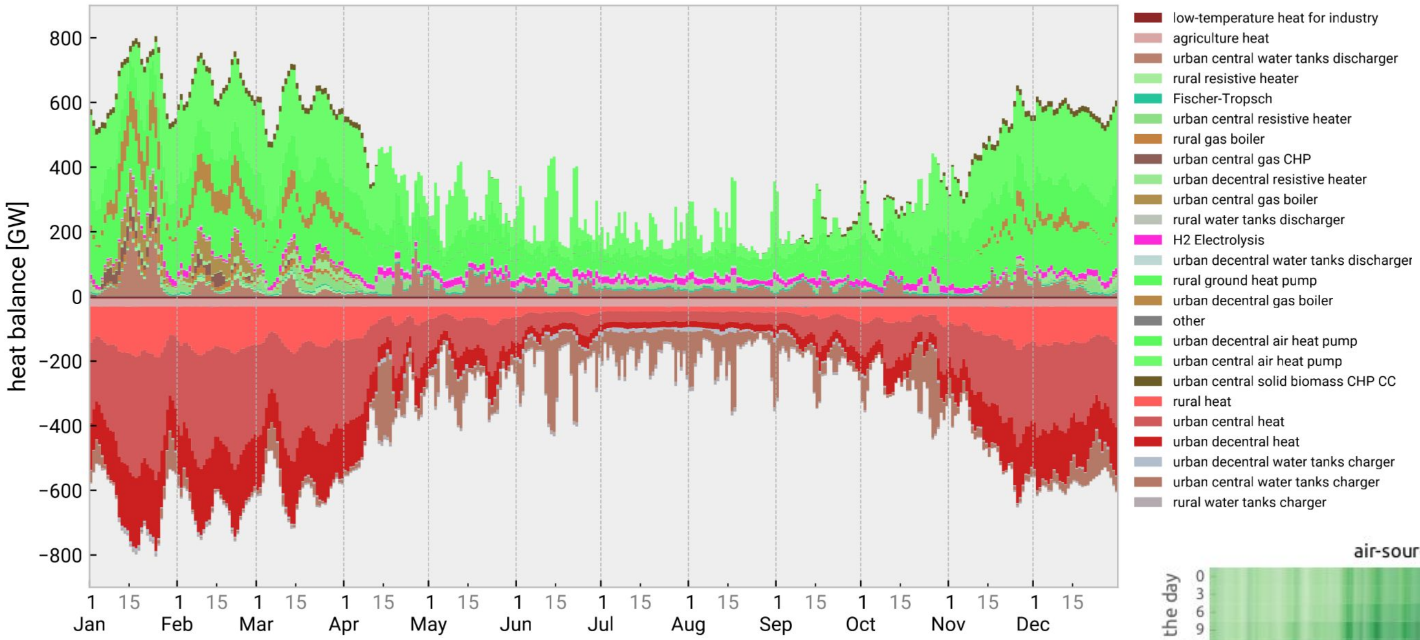
Road and rail are **largely electrified**, ICE only during pathway to net-zero

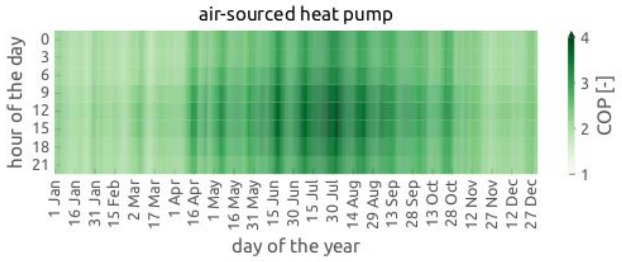
Time series from traffic counting

A configurable share of electric vehicles participates in demand-side management (**DSM**) or vehicle-to-grid (**V2G**)

Electric vehicles have **time-varying availability** for charging depending on driving profiles

Heating - Time series of supply and demand





Heating - Techs for individual & district heating

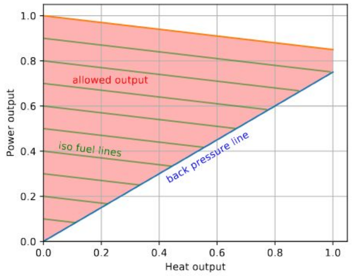
Decentral individual heating
can be supplied by:

- air- or ground-sourced heat pumps
- resistive heaters
- gas / oil / biomass / hydrogen boilers
- solar thermal
- small water tanks

District heating systems
can be supplied in urban areas by:

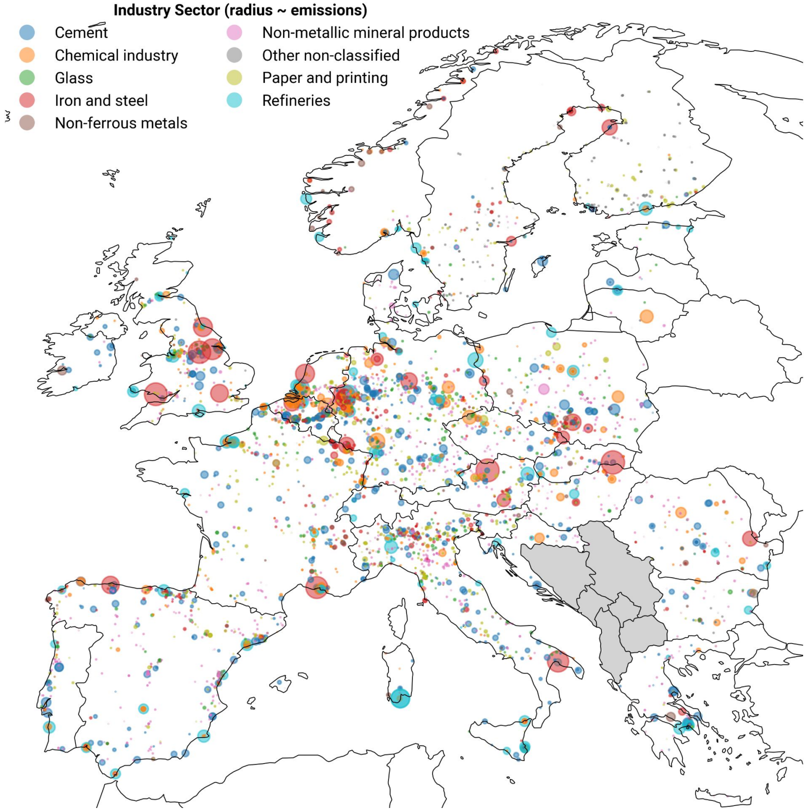
- air-sourced heat pumps + other
- resistive heaters
- gas / hydrogen / biomass / waste CHP
- gas / oil / biomass / hydrogen boilers
- solar thermal
- long-duration hot water storage
- waste heat from industrial processes

CHP feasible dispatch:



Building renovations can be co-optimized to reduce space heating demand.

Industry - Regionalisation based on Hotmaps



https://gitlab.com/hotmaps/industrial_sites/industrial_sites_Industrial_Database

Iron & Steel	Phase-out integrated steelworks; increased recycling; rest from H_2-DRI + EAF
Aluminium	Methane for high-enthalpy heat; increased recycling
Cement	Solid biomass; capture of CO_2 emissions
Ceramics	Electrification
Ammonia	Gray, blue, green hydrogen
Plastics	Synthetic naphtha; MtO/MtA, increased recycling
Other industry	Electrification; process heat from biomass
Shipping	Methanol, (oil), (liquid hydrogen), (LNG)
Aviation	Kerosene from Fischer-Tropsch or methanol

Infrastructure - Gas network with H_2 retrofitting

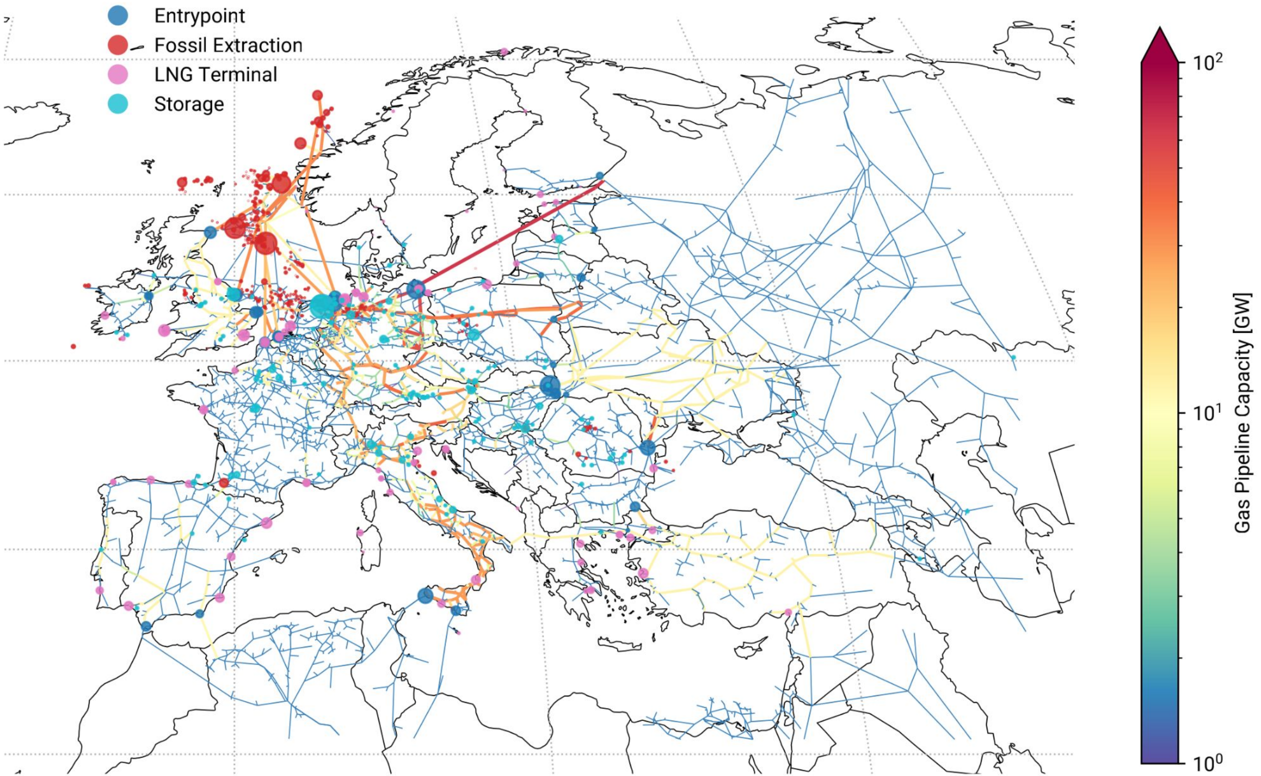
Compiled from open **SciGRID_gas** dataset.

Fossil gas enters at **LNG terminals** or **gas fields**.

Gas flow **physics** and **valve control** neglected 👉 transport model.

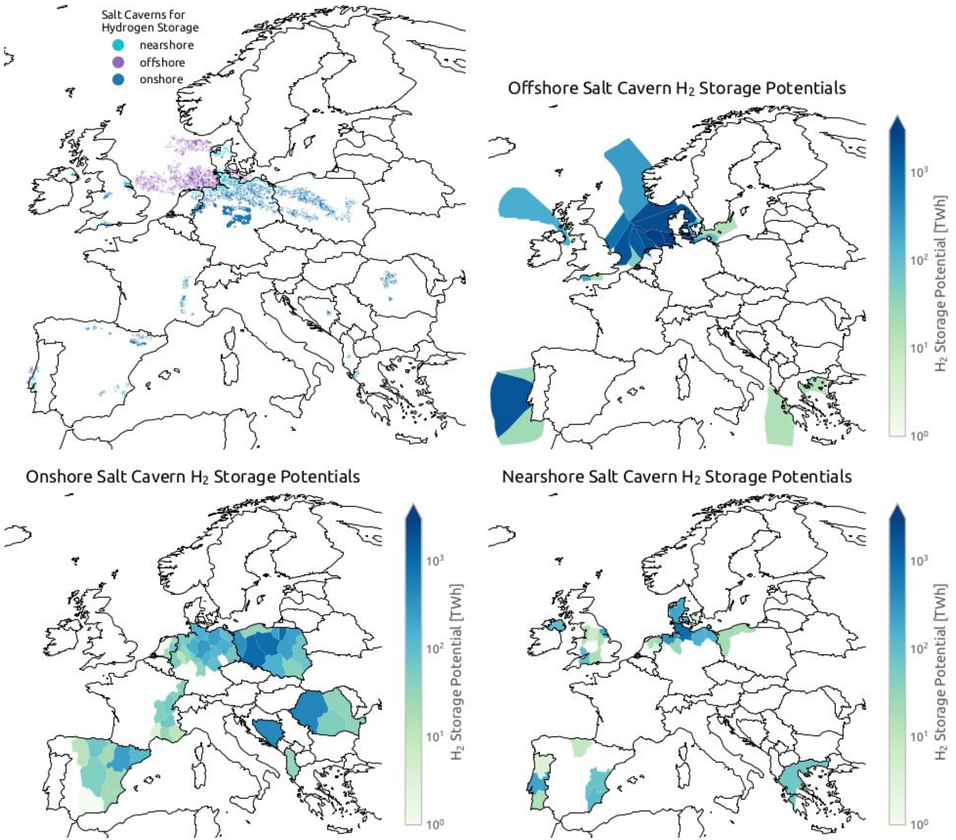
Electricity demand for **compression** and **leakage** configurable.

Pipelines can be **retrofitted** to H_2 with costs from EHB.



https://zenodo.org/records/4767098

Infrastructure - Hydrogen storage potentials

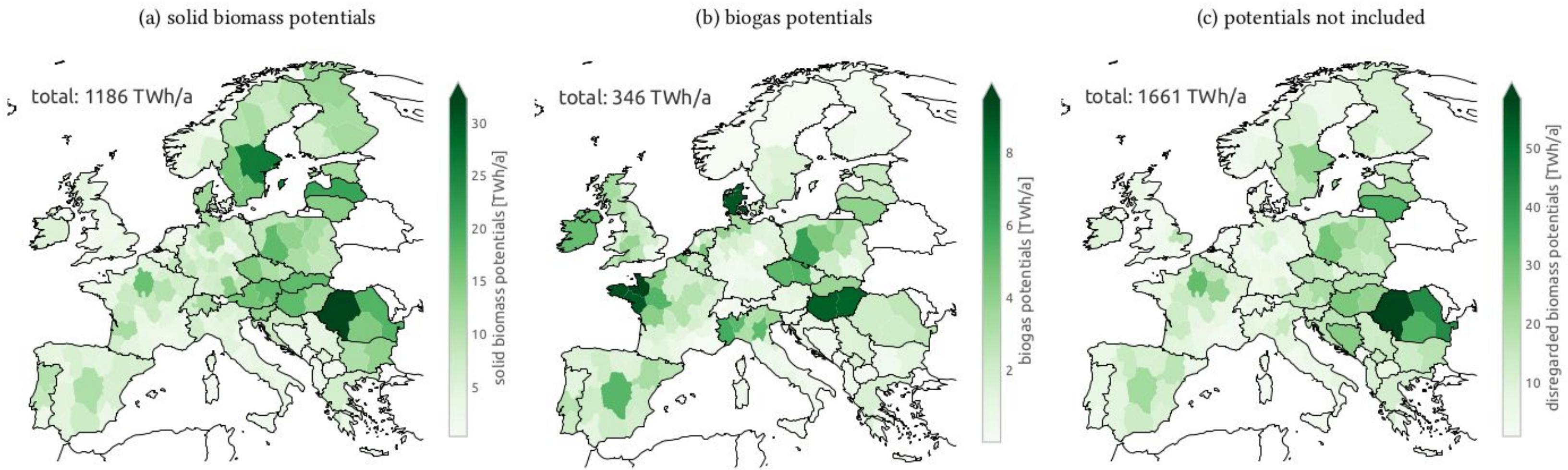


The regional distribution of **geological potential** to store hydrogen in **salt caverns** is considered.

The user can **configure** if onshore and/or offshore potentials can be used.

Dilara Gulcin Caglayan, Nikolaus Weber, Heidi U. Heinrichs, Jochen Linßen, Martin Robinius, Peter A. Kukla, Detlef Stolten, *Technical potential of salt caverns for hydrogen storage in Europe*, **International Journal of Hydrogen Energy**, Volume 45, Issue 11, 2020, 6793-6805, https://doi.org/10.1016/j.ijhydene.2019.12.161

Infrastructure - Biomass potentials



Biomass potentials are split between **solid biomass** and **biogas** (which can be, for instance, upgraded).

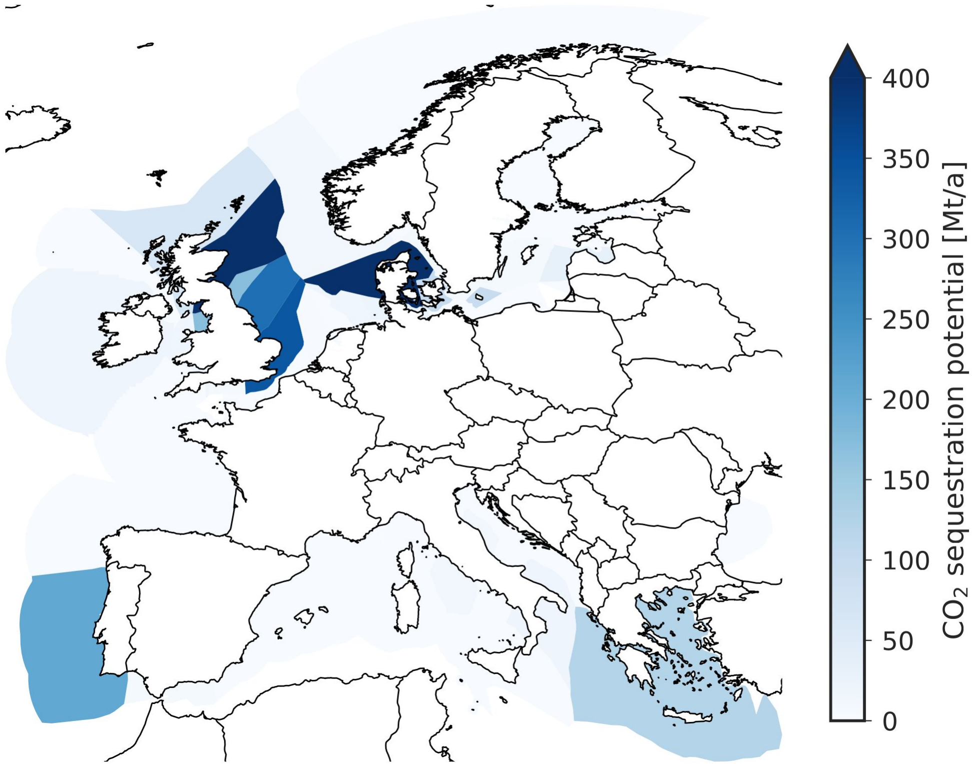
The user can configure low/medium/high potentials and what categories of biomass to consider (e.g. forest residues).

The default configuration only considers **residual biomass**, no energy crops according to JRC ENSPRESO.

https://data.jrc.ec.europa.eu/dataset/74ed5a04-7d74-4807-9eab-b94774309d9f

Infrastructure - Carbon sequestration potentials

Example: Offshore carbon sequestration potentials



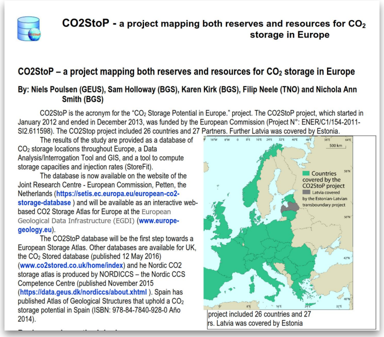
The user can **configure**

- onshore/offshore sequestration,
- gas fields/oil fields/aquifer, and
- low/medium/high potentials,

as well as a **total limit** on the annual sequestration, e.g. 250 Mt per year.

Data source:

https://energy.ec.europa.eu/publications/assessment-co2-storage-potential-europe-co2stop_en



CO2StoP - a project mapping both reserves and resources for CO_2 storage in Europe

CO2StoP – a project mapping both reserves and resources for CO_2 storage in Europe

By: Niels Poulsen (GEUS), Sam Holloway (BGS), Karen Kirk (BGS), Filip Neele (TNO) and Nichola Ann Smith (BGS)

CO2StoP is the acronym for the "CO_2 Storage Potential in Europe." project. The CO2StoP project, which started in January 2012 and ended in December 2013, was funded by the European Commission (Project N°: ENER/C1/154-2011-SI2.611598). The CO2Stop project included 26 countries and 27 Partners. Further Latvia was covered by Estonia.

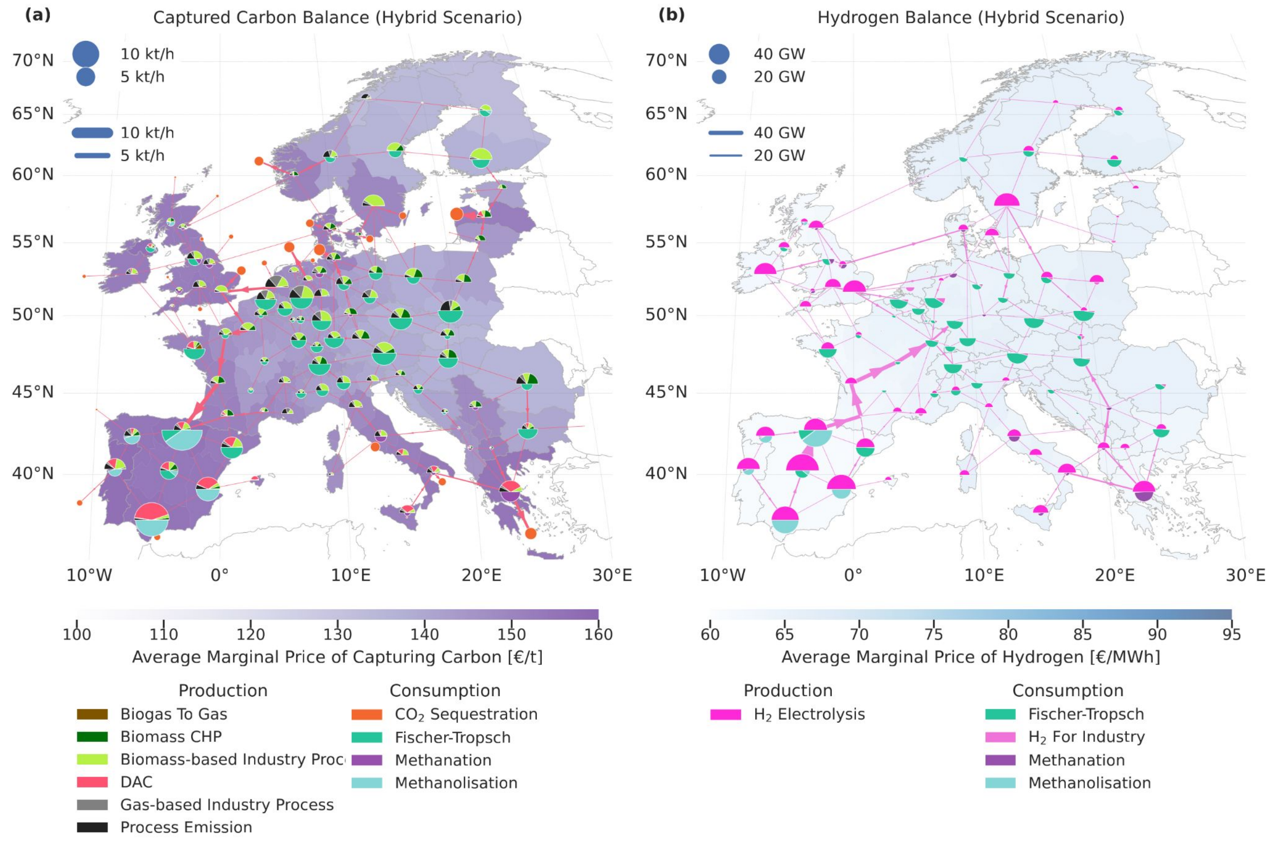
The results of the study are provided as a database of CO_2 storage locations throughout Europe, a Data Analysis/Interrogation Tool and GIS, and a tool to compute storage capacities and injection rates (StoreFit).

The database is now available on the website of the Joint Research Centre - European Commission, Petten, the Netherlands (https://setis.ec.europa.eu/european-co2-storage-database) and will be available as an interactive web-based CO2 Storage Atlas for Europe at the European Geological Data Infrastructure (EGDI) (www.europe-geology.eu).

The CO2StoP database will be the first step towards a European Storage Atlas. Other databases are available for UK, the CO_2 Stored database (published 12 May 2016) (www.co2stored.co.uk/home/index) and he Nordic CO2 storage atlas is produced by NORDICCS – the Nordic CCS Competence Centre (published November 2015 (https://data.geus.dk/nordiccs/about.xhtml). Spain has published Atlas of Geological Structures that uphold a CO_2 storage potential in Spain (ISBN: 978-84-7840-928-0 Año 2014).

project included 26 countries and 27
rs. Latvia was covered by Estonia

Infrastructure - Carbon management



Built-in carbon flows:

- **Capture:** DAC, process emissions, fossil / biomass CHP
- **Transport:** CO_2 pipelines
- **Storage:** intermediate storage and long-term geological sequestration
- **Utilization:** for synthetic carbonaceous fuels

Live Demo

Initiate the building process:

```
$ snakemake all --configfile config/test/config.overnight.yaml
```

This will create a file

```
$ cd …/pypsa-eur/results/test-sector-overnight/networks/base_s_60___2050.nc
```

Which can be explored in a Jupyter notebook:

```
$ jupyter notebook
```

PyPSA Modelling Track

Creating your own scenarios with PyPSA

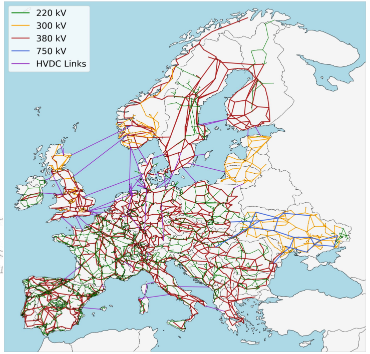
Priyesh Gosai

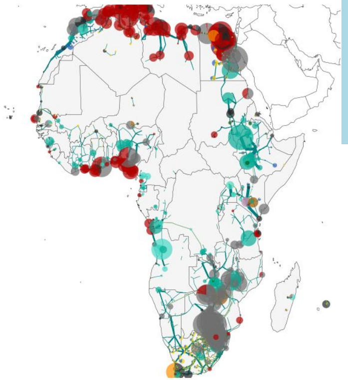
Energy Innovation Summit 2025

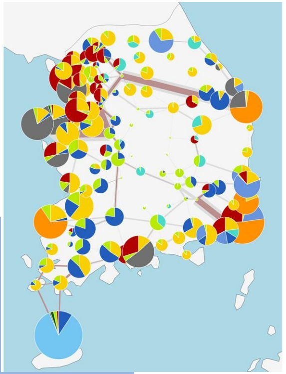
24.06.2025

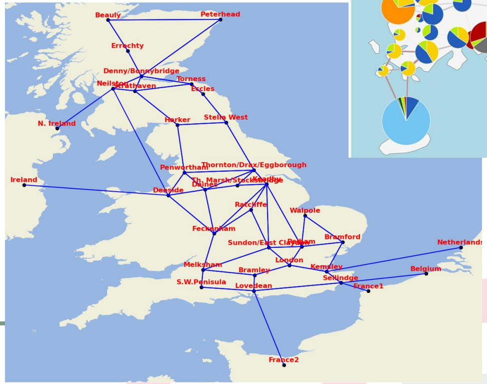
PyPSA-X

- PyPSA-X is seeing increasing adoption worldwide.
- Users are building models to address a wide range of energy system challenges.
- A coordinated effort is driven through PyPSA-Meets-Earth and PyPSA-Eur.
- Local projects are customizing PyPSA-X to meet region-specific needs.
- The community is driving open, transparent, and collaborative development.
- A global ecosystem of interoperable PyPSA-X models is taking shape.

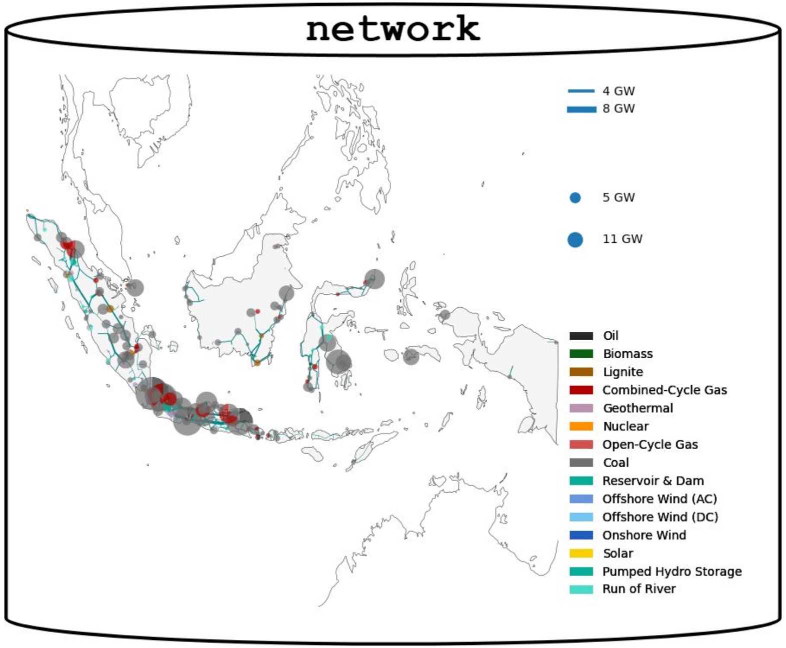




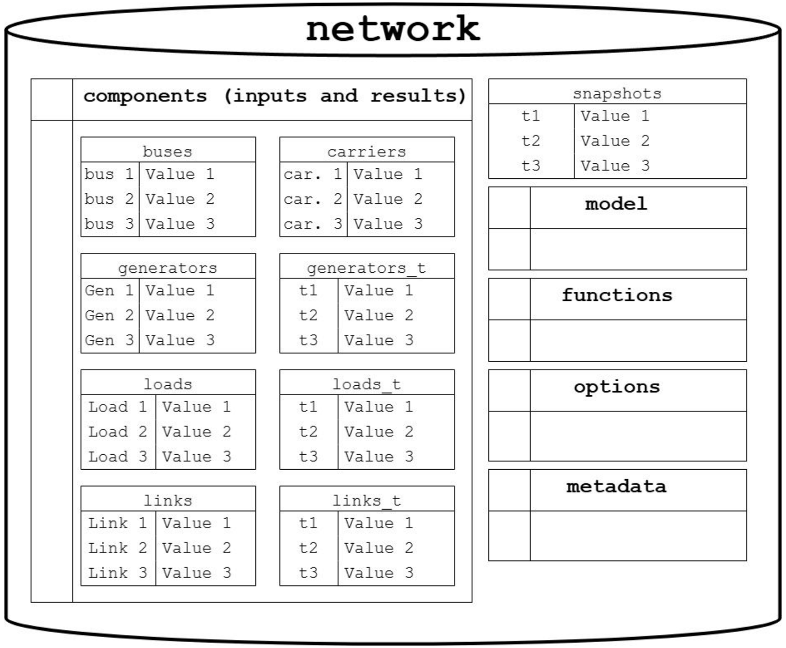




What is a PyPSA Network

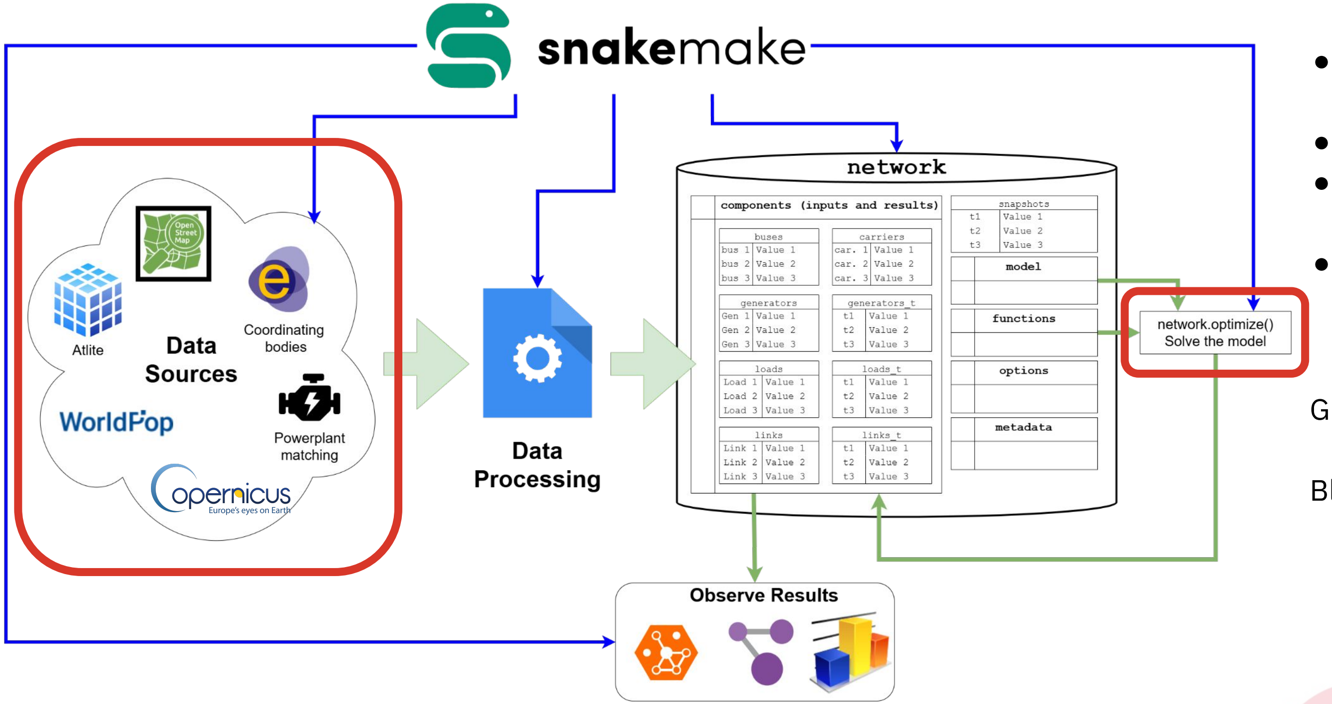


Visual representation



Data structure

PyPSA Workflow



The modeling workflow follows a clear sequence:

- **Data collection and import** into the model,
- **Constraint formulation and application**,
- **Solving** the model, and
- **Reviewing and analyzing** the results.
- Snakemake **orchestrates** the processes

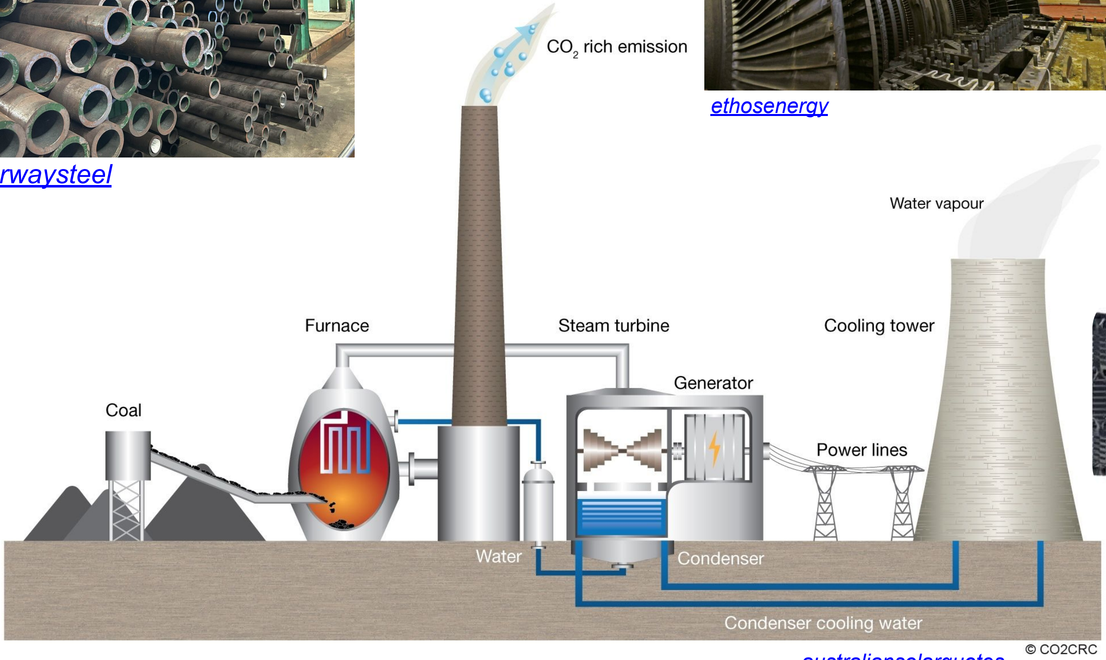
Green arrows - Process flow

Blue arrows - Coordination

Coal fired power plants

centerwaystee l

ethosenergy



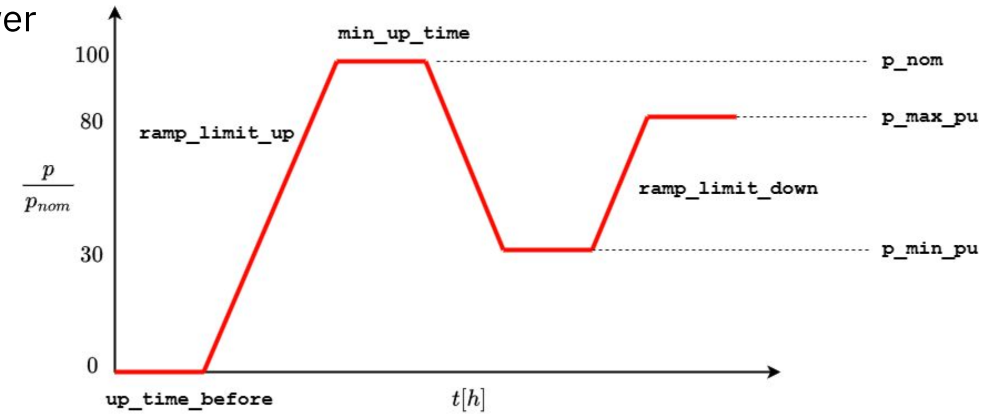
australiansolarquotes

vistechcooling

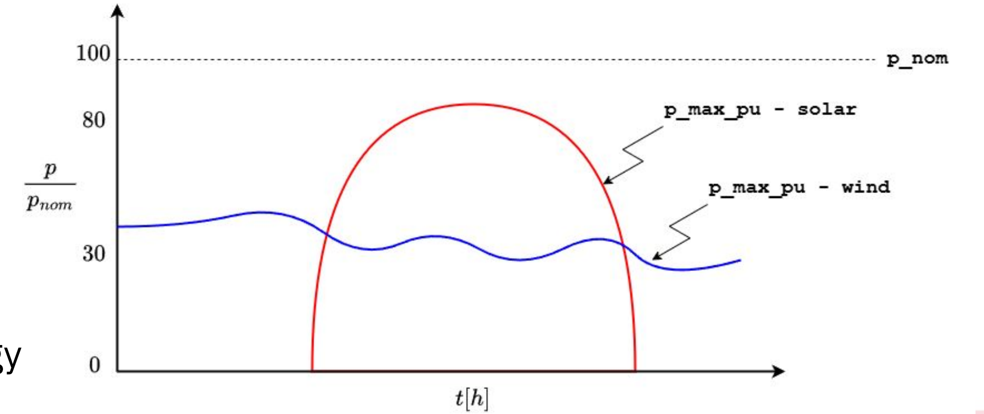
Considerations

- CAPEX
- Fuel and operational cost
- Long startup times
- Slow ramp rates
- Limits to maximum output

Thermal/Coal power plants



Generator Attributes



Renewable energy plants

Demo

The coding activity will take place in **Google Colab**. Please follow these steps:

1. Open your browser and go to https://colab.research.google.com/.
2. In the Colab interface, click on **GitHub** in the left-hand menu.
3. In the search bar, type: `open-energy-transition`
4. Select the repository: `EIS-2025`

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bsky.app/profile/oetenergy.bsky.social

PyPSA Modelling Track

Climate Data

Dr. Ekaterina Fedotova

Energy Innovation Summit 2025

24.06.2025

CLIMATE DATASETS

Actual weather & climate

1. **Observations**
   - Meteorologic stations
   - Inputs of local monitoring
   - Remote sensing

2. **Observations + computations**
   - Gridded observations data
   - Reanalyses

3. **Weather forecasts**

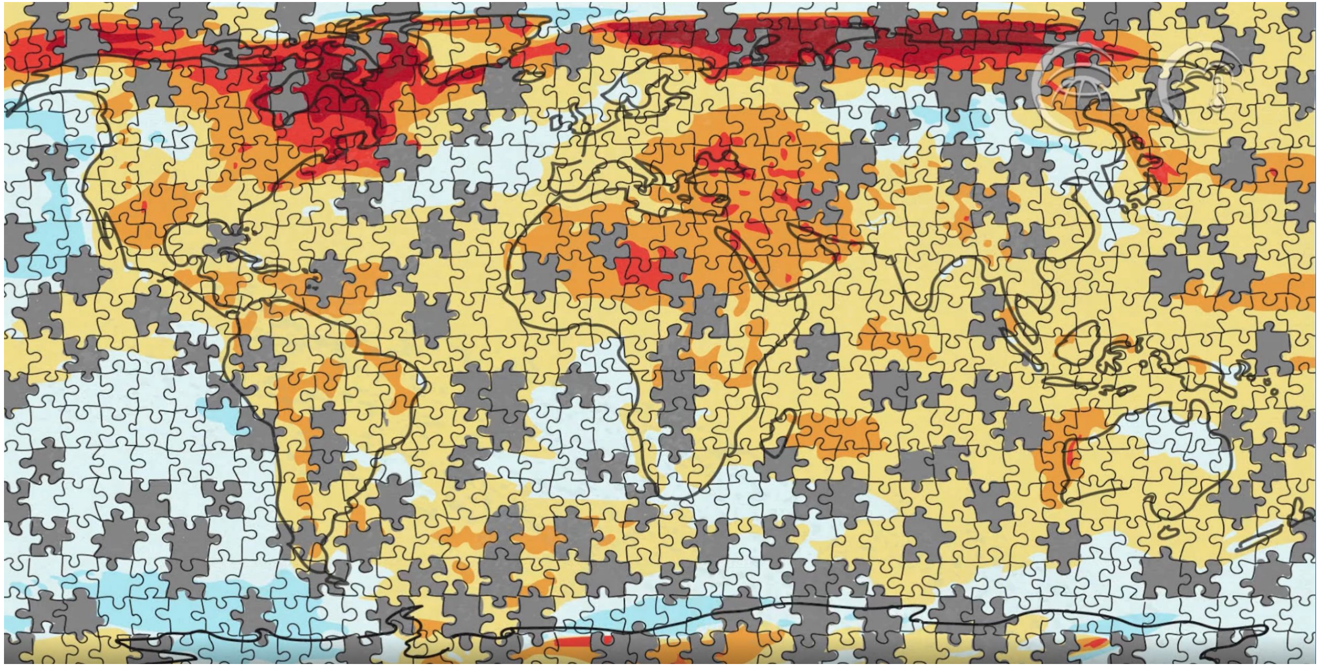
Future climate

4. **Climate models**
   - global runs
   - regional downscaling

REANALYSIS

Open Energy Transition
from the creators of PyPSA meets Earth

Idea: use balance equations to fill the gaps between observation points



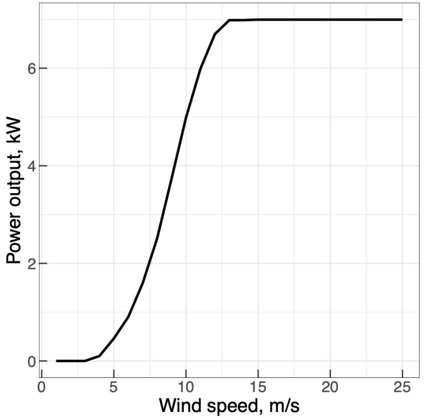
Source: Reanalysis explained by Hannah Bloomfield

CLIMATE DATA WORKFLOW

Open Energy Transition
from the creators of PyPSA meets Earth

Climate inputs

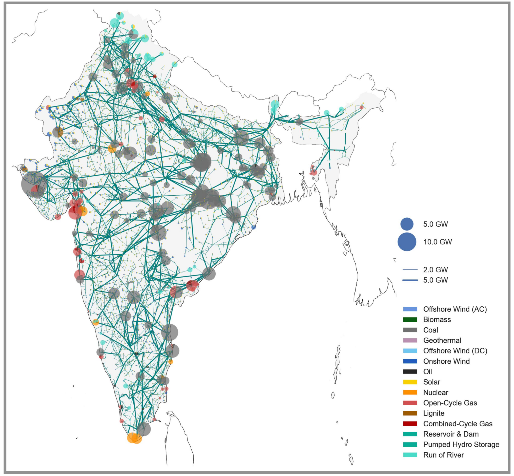
Sensitivity model



+

Land usage

Energy system model

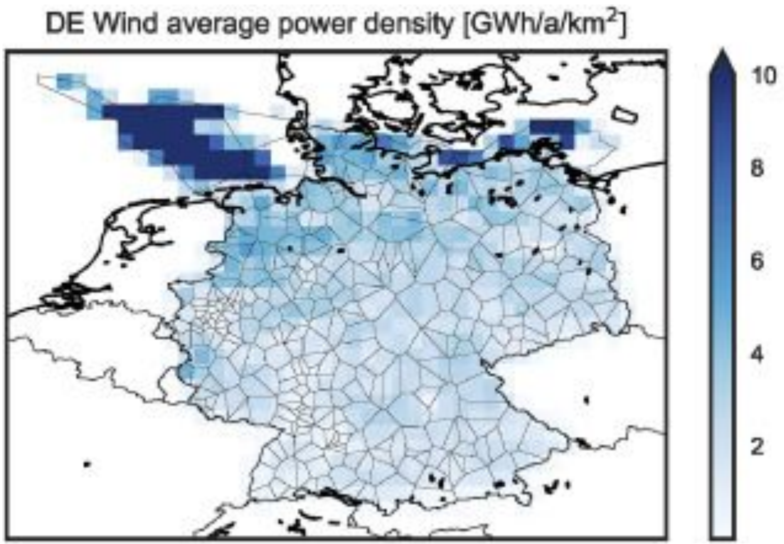


CLIMATE INPUTS: TRANSFORMATION

Open Energy Transition
from the creators of PyPSA meets Earth

atlite

- Automated processing (currently ERA5 & SARRAH data)
- Transform weather parameters into energy-relevant ones
- A cutout as a climate data container
- nc format + xarray methods

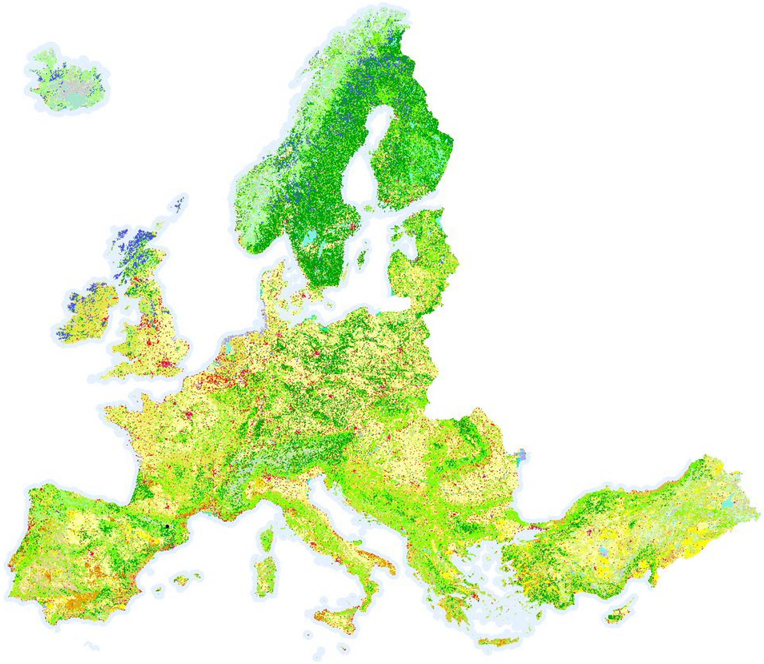


Source: J. Hoersch et al (2018) PyPSA-Eur: An open optimisation model of the European transmission system

CLIMATE INPUTS: INTEGRATION

Open Energy Transition
from the creators of PyPSA meets Earth

- Land-usage
- Sea depth
- Nature reserves



CLIMATE INPUTS: CHALLENGES

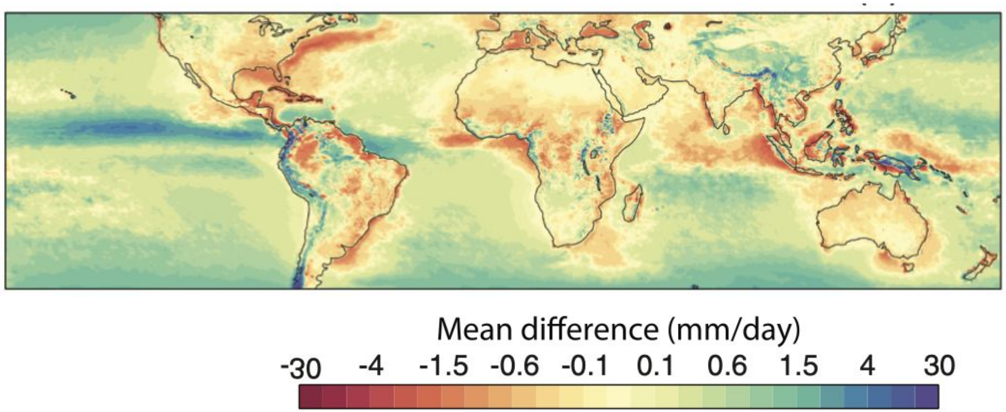
Open Energy Transition
from the creators of PyPSA meets Earth

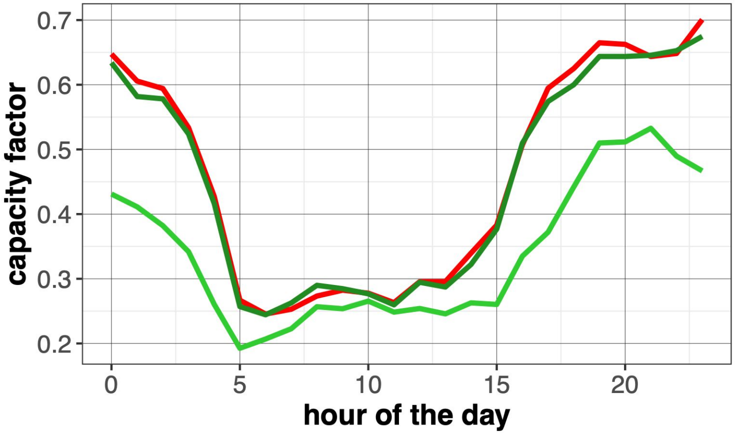
- Bias correction / downscaling
- Advancing of runoff modelling
- Climate change effects
- Year-to-year variability

BIAS CORRECTION

Advantage: reanalyses are capturing the overall picture well

Pitfalls: all reanalyse datasets contain intrinsic errors



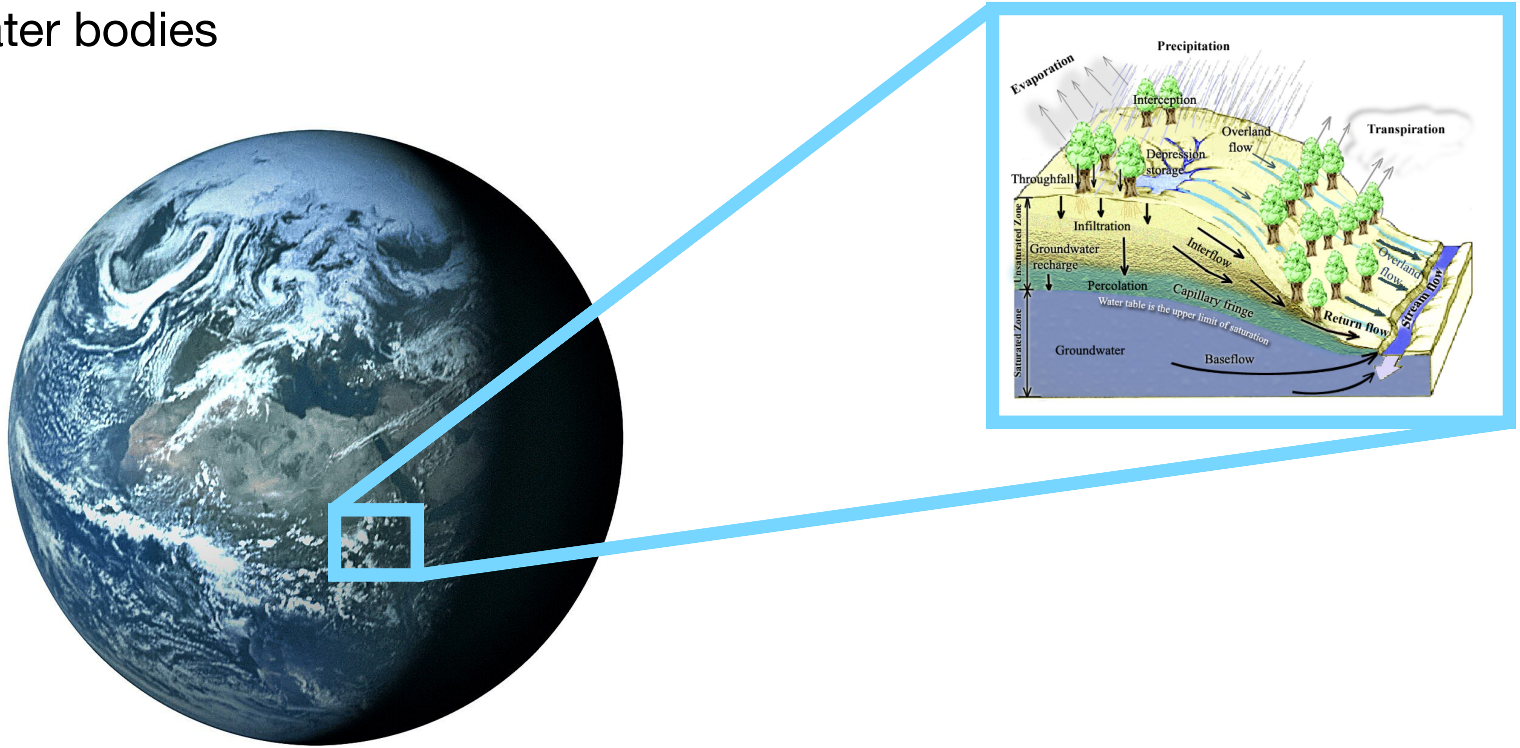


Source: Hersbach et al. 2020

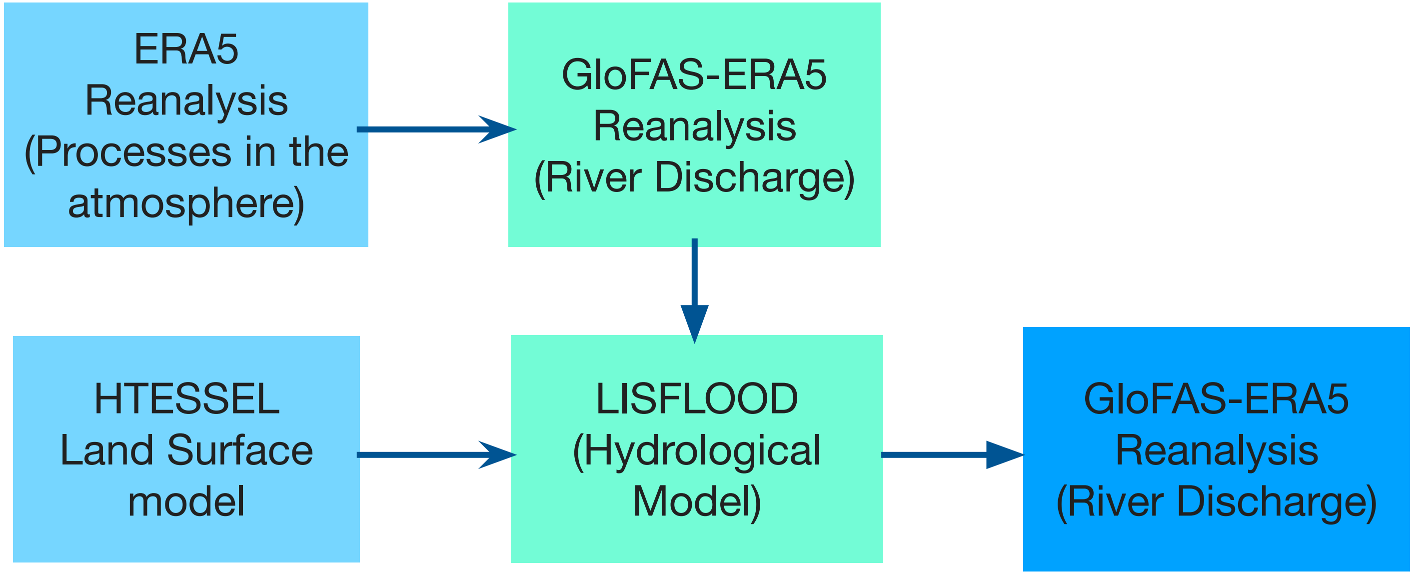
Source: Shestakova et al. 2024

ADVANCING OF RUNOFF MODELLING

Simulates transport of water between the atmosphere and water bodies

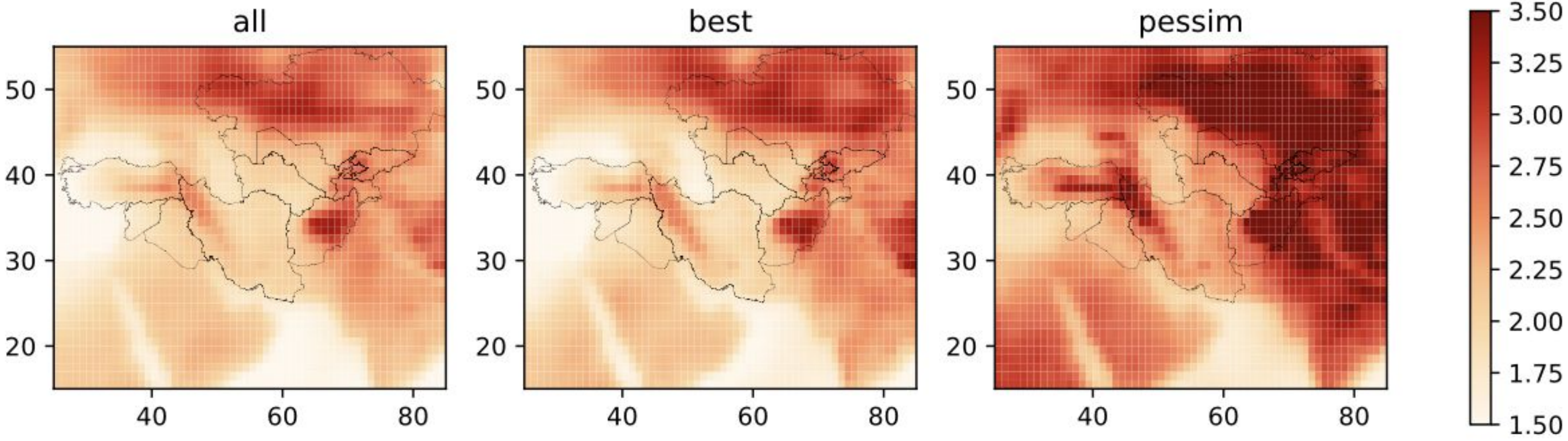


ADVANCING OF RUNOFF MODELLING



CLIMATE CHANGE EFFECTS

- CMIP5 & CMIP6 datasets
- Ensemble approach
- Robustness analysis



YEAR-TO-YEAR VARIABILITY

Synergies between the energy and climate

YEAR-TO-YEAR VARIABILITY

- Analogues approach (wet years vs dry years)
- Running multi-annual simulations
- Typical years
- Subsampling

Open Energy Benchmark: Hands-on Workshop

openenergybenchmark.org

Wed Jun 25, 2025

Daniele Lerede, PhD
Open Energy Transition

SUPPORTED BY
Breakthrough Energy

Agenda

- **Website dashboards**
- **Status of current benchmark collection**
- **Why and How to contribute?**

Introduction to the Open Energy Benchmark platform

- The platform consists of **open-source**, **community-contributed benchmarks** from leading **energy modelling** frameworks.
- **Multiple versions of leading solvers** are run on multiple hardware configurations, to gather **insights** on how **performance** varies with **benchmark size, computational resources, and solver developments.**

Who do we want to make happy?

- Energy System **Modellers**, who need to decide which solver works best for them
- **Solver Developers**, who need realistic, well-maintained optimization benchmarks
- **Funders**, interested in speeding up energy modelling, who need reliable metrics to evaluate solver performance over time

Dashboards on the Open Energy Benchmark platform

- **Main results:** Shifted geometric mean (SGM) of **memory usage** and **runtime**, and **rate of solved benchmarks** presented in 2 configurations
  - **Short:** smaller benchmarks (n. vars < 1e6), timeout 1 hour, ran on machine with 7 GB memory and 2 vCPUs
  - **Long:** larger benchmarks (n. vars > 1e6), timeout 10 hours, ran on machine with 62 GB and 8 vCPUs

- **Benchmark set:** Features of the full benchmark set can be accessed, also with **full detail on the results** on each of them

🔎 In each dashboard, users can filter the benchmark set to specific problems of interest and graphs/tables in each dashboard will automatically re-generate to show them.

Dashboards on the Open Energy Benchmark platform

- Solvers: Users can **select a base solver for comparison** and **explore its performances** (relative to the other solvers) on the selected set of benchmarks
- Compare solvers: 1:1 solver comparison (also useful for solver developers who want to compare two versions of their solver to see on which benchmarks the performance improved or degraded)
- Performance history: Tracks **solver performances over time.**
- Full results: Full benchmark results for download.

🔎 In each dashboard, users can filter the benchmark set to specific problems of interest and graphs/tables in each dashboard will automatically re-generate to show them.

Status of current benchmark collection

✅ We **cover most of the main application fields** for modelling frameworks on the platform (including Realistic benchmarks)

🚨 Still some **gaps** need to be addressed:

- **Resource adequacy** problems
- **Production cost models**
- **Multi period** benchmarks
- **Additional modelling platforms**

	DCOPF	GenX	PowerModels	PyPSA	Sienna	TEMOA	TIMES	Tulipa
Problem Class								
LP	✅	✅	✅	✅	❌	✅	✅	❌
MILP	✅	✅	✅	✅	✅	❌	❌	✅
Application								
DC optimal power flow	❌	✅	❌	❌	❌	N.A.	N.A.	❌
Resource adequacy	✅	❌	❌	❌	❌	❌	❌	❌
Infrastructure & Capacity Expansion	N.A.	✅	✅	✅	✅	✅	✅	✅
Operational	❌	❌	N.A.	✅	❌	N.A.	N.A.	❌
Steady-state optimal power flow	N.A.	❌	✅	❌	N.A.	N.A.	N.A.	N.A.
Production cost modelling	❌	❌	N.A.	❌	❌	❌	❌	❌
Time Horizon								
Single Period	✅	✅	✅	✅	✅	❌	✅	✅
Multi Period	❌	✅	❌	❌	❌	✅	✅	❌
MILP Features								
None	✅	✅	❌	✅	❌	✅	✅	❌
Unit commitment	✅	✅	✅	✅	✅	❌	❌	✅
Piecewise fuel usage	❌	✅	❌	❌	❌	❌	❌	❌
Transmission switching	❌	❌	✅	❌	❌	❌	❌	❌
Modularity	❌	❌	❌	✅	❌	❌	❌	✅
Realistic								
Realistic	✅	✅	✅	✅	❌	✅	✅	✅
Other	❌	✅	✅	✅	✅	✅	✅	❌

Public contributions

CALL TO ACTION:

📣 Can you produce any benchmark to expand the current set? **2 ways to contribute:**

- ❤️ **Familiar with Github?** Contribute at https://github.com/open-energy-transition/solver-benchmark opening a PR to submit new benchmarks or an issue for feedback or suggestions!
- 😱 **Github hater?** Please use the **contact form** on the website landing page

Why contribute?

✅ **Pick the best solver for your real-life use cases**

🚀 **Drive solver development where it matters most**
Help focus solver development efforts on the energy modelling problems you care about.

📈 **Track progress on solvers**
Understand current limits of open-source solvers and their improvements over time.

🔍 **Understand solver behavior deeply**
Discover how different model features affect performance.

🤝 **Join a fast-growing, exciting and impactful open-source community!**

How to contribute?

What you/we need to contribute

- Your benchmark(s) in **.mps** (or .lp) **format***, uploaded to any online sharing service
- A summary of the features of the benchmark. The template is available at **https://github.com/open-energy-transition/solver-benchmark/blob/main/benchmarks/_template_metadata.yaml**
- Open a pull request (PR) to upload the metadata and share the link to the benchmark .mps file or reach out to us to get support through all the required steps.
- Your **contribution will be reviewed** and hopefully added to the platform! 🎉
- If you have any doubts, you can also refer to the **README on the Github repo**

* .lp / .mps formats and our metadata template are intended to preserve data confidentiality

Running benchmarks

If you're interested in **running your own benchmarks** and assessing solver performances autonomously, please follow the instructions in the **Running Benchmarks** section of the project's README:

github.com/open-energy-transition/solver-benchmark

README AGPL-3.0 license

Running Benchmarks

The benchmark runner script creates conda environments containing the solvers and other necessary pre-requisites, so a virtual environment is not necessary.

```
./runner/benchmark_all.sh ./results/metadata.yaml
```

The script will save the measured runtime and memory consumption into a CSV file in `results/` that the website will then read and display. The script has options, e.g. to run only particular years, that you can see with the `-h` flag:

THANK YOU!

For the attention and the contributions

openenergybenchmark.org

Reach out to us for feedback, suggestions and contributions:

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Gurobi Performance on OET Benchmarks

Matthias Miltenberger

Link