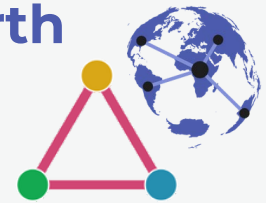
PyPSA *meets* Earth
LAB TRAINING SESSION



# PyPSA Demystified

## Core concepts, best practices and new features

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Director – Energy Solutions | PAS Automation

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pypsa-introduction

# Background

- From South Africa, now based in Edinburgh, Scotland.
- Mechanical engineer with 15 years in the energy sector.
- Turbine plant engineer at Eskom.
- Researcher manager, lecturer at the University of Cape Town.
- Independent consultant developing numerical simulation tools
  - Thermal fluid modelling.
  - Energy systems modelling.
  - Dispatch optimisation for power markets.
  - Co-optimisation of power systems with large shares of hydropower.
  - Deliver training courses to introduce working professionals into the area of energy system modelling.
  - Develop and implement custom workflows using opensource tools.

Founder of:

Innovate for Impact

Director at:

PAS
The Human Reliability Company

Clients:

ICH International Centre for Hydropower

energynautics
solutions for sustainable development

CAAS Chown and Associates

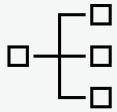
University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

Electricité du Laos

# Objectives of this training

Walk participants through the tools, environment, and dependencies required to model energy systems with PyPSA.

Explain how a PyPSA model is structured and how its core components operate.

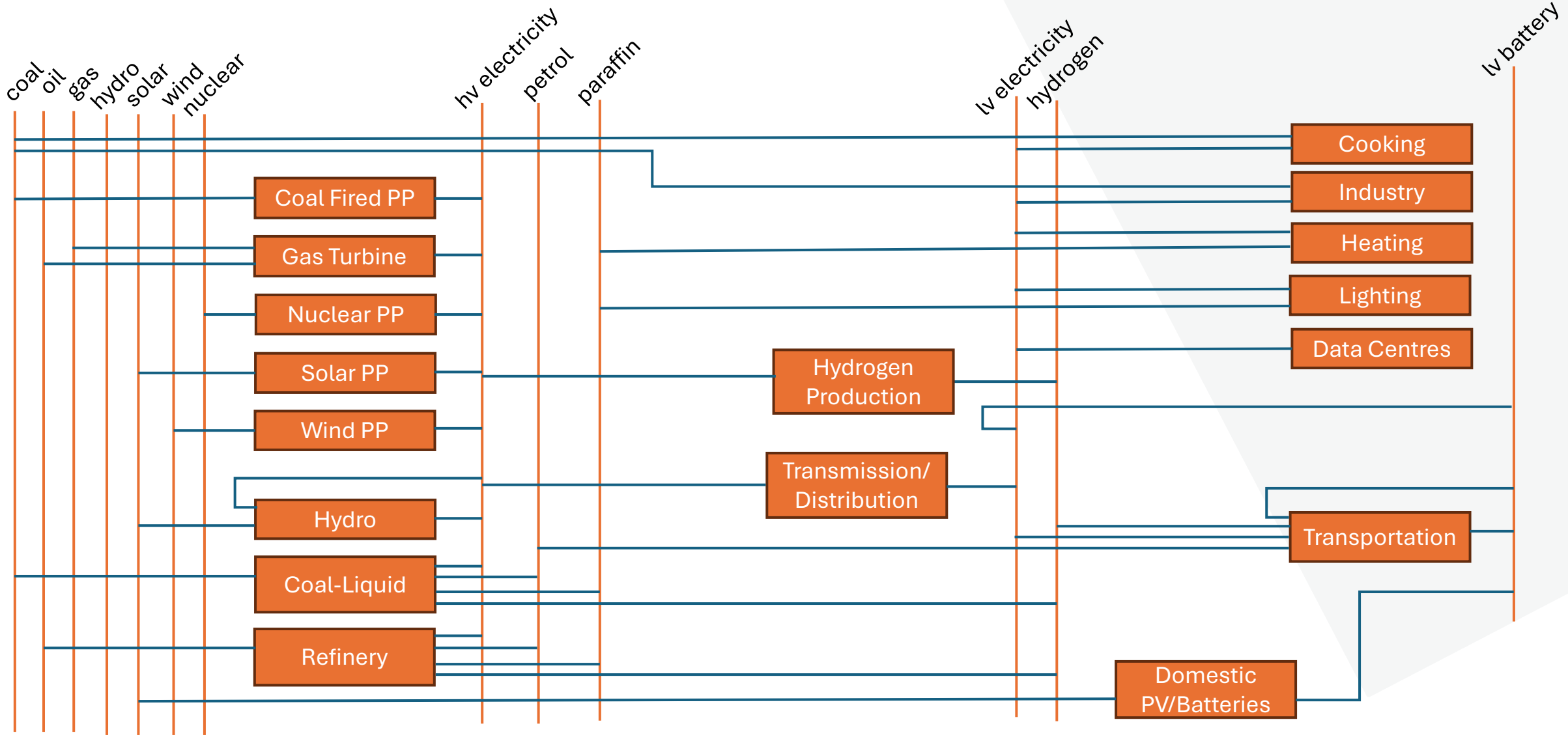


Showcase the latest improvements and newly added capabilities in PyPSA.

Allow attendees to explore and manipulate a working PyPSA network themselves.

Guide users through building, executing, and interpreting a basic PyPSA model from scratch.

# Evolution of South African energy system



# What keeps energy leaders up at night?

What is the optimal location and capacity for new renewable energy installations considering geographic and grid constraints?

What is the optimal mix of renewable energy sources (wind, solar, offshore wind, etc.) to ensure reliable electricity supply?

How can regional energy integration improve overall system resilience?

How sensitive is the energy system to changes in technology costs, policy environments, and global market conditions?

How can battery storage and electric vehicles be strategically integrated to provide grid flexibility?

How can pumped storage and other energy storage technologies complement intermittent renewable generation?

What are the potential benefits and challenges of developing a hydrogen economy?

What policy interventions could accelerate the transition to a more sustainable energy system?

What is the optimal pathway to reduce carbon emissions while ensuring energy security?

What fossil fuel capacity is required to maintain national energy security under increasing renewable penetration?

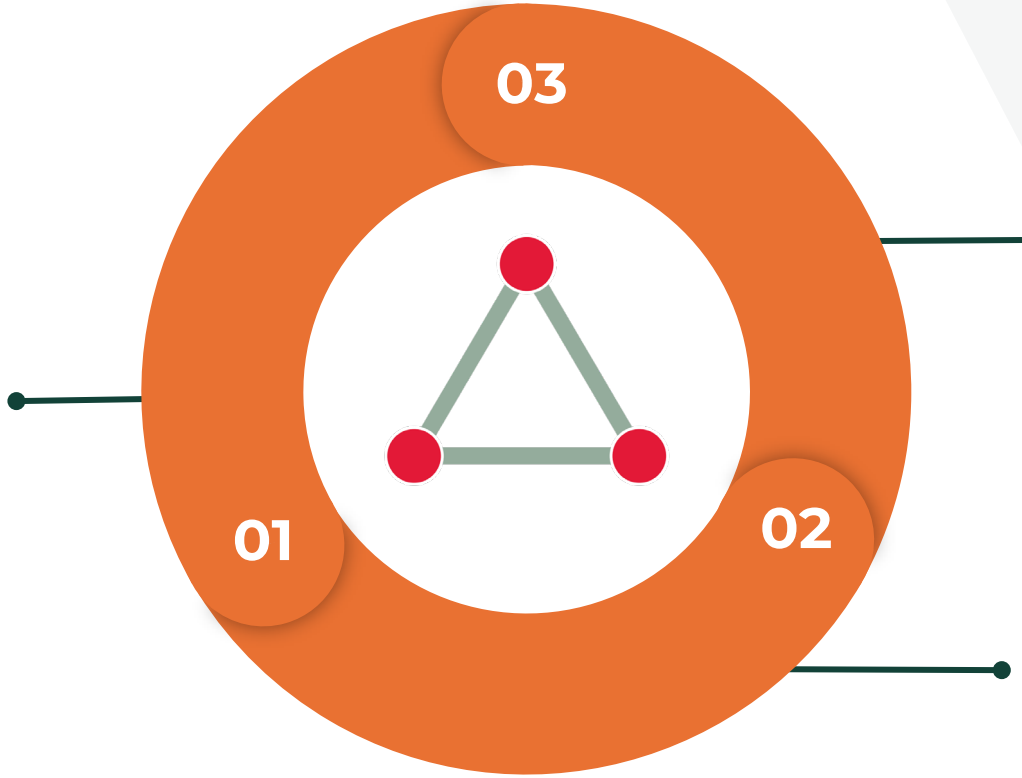
# What kinds of questions related to the energy sector keep you up at night?

**Use the chat feature to post your questions.**

# PyPSA to co-optimise expansion planning and operation

## Resources

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




## Storage

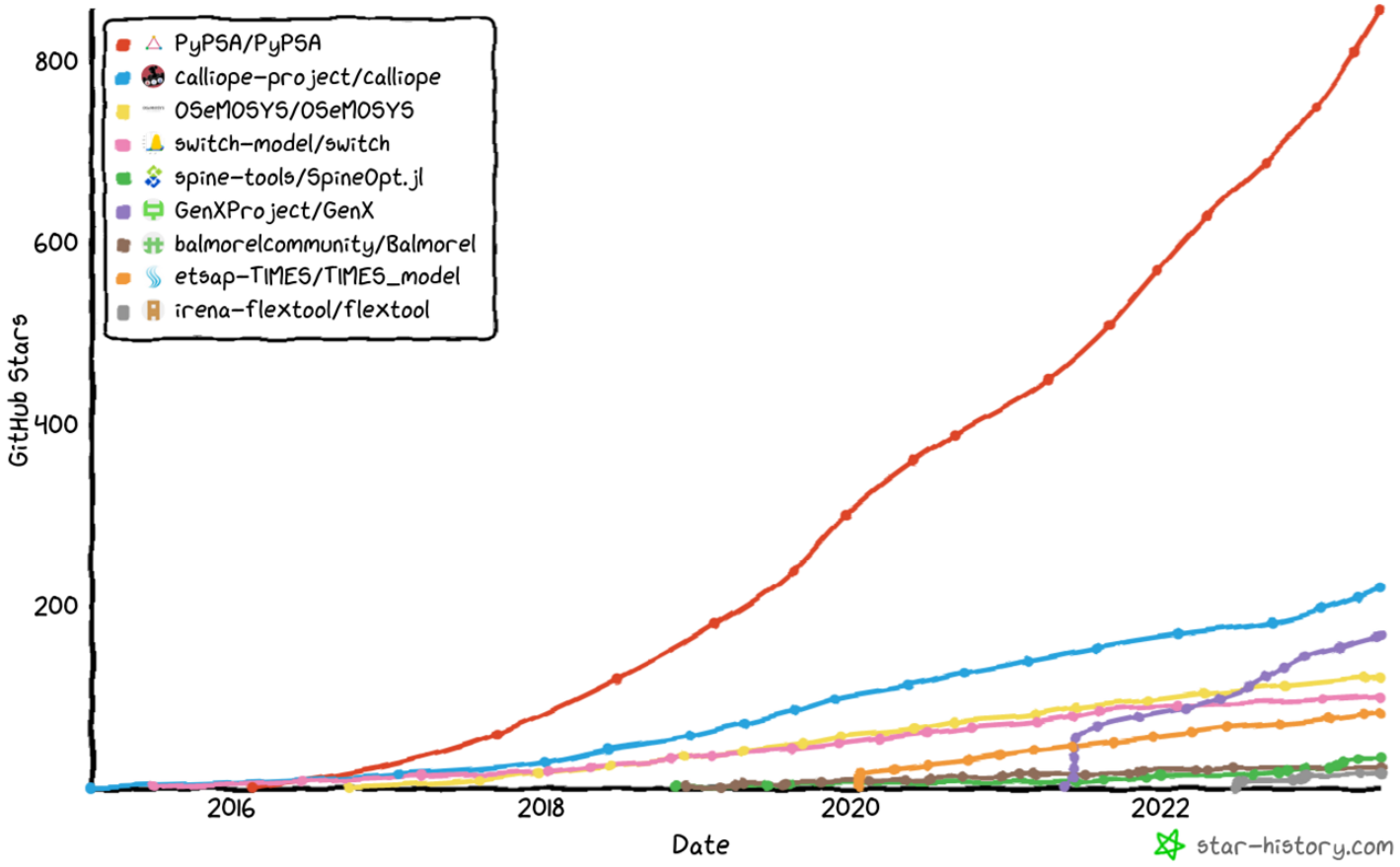
Sourced at available and **profitable sites** where the **connection to the grid** is good where it can help **balance varying supply and demand**

## Transmission

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

*Image credit: Martha Frystaki (OET)*

# Adoption of PyPSA




Major **advantages of PyPSA**:

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

# Packages needed


High-level programming language

Widely used in data science and modelling

Easy to learn, with rich libraries


Platform for version control using Git

Enables collaboration and code sharing

Hosts projects, issues, and documentation


Python distribution with data science tools

Includes Conda for environment management

Useful for reproducible, isolated setups

# IDE Options

Google colab

Runs Python code in the browser — no setup needed

Free access to GPUs/TPUs for basic workloads

Easy to share notebooks via link

**Limited local file access and custom environment control**

Visual Studio Code

Powerful local code editor with rich extensions

Full control over Python environments (e.g., via Conda/venv)

Great for large projects and debugging

**Requires local setup and more resources**

**And many more ...**

# Python Toolboxes


Data wrangling toolkit


Numerical array operations


Static data visualization

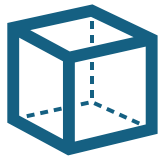

Workflow automation engine

Libraries maintained in the PyPSA ecosystem



atlite

### Network Object



Network framework containing integrated tools for optimisation, power flow modelling, data management, statistical analysis, and visual network representation.

### Input/output


Handles CSV, netCDF, Excel, and HDF5 file formats, enabling network creation within Python scripts and seamless file operations across local and cloud-based storage systems.

### API

Simple yet powerful API interface with clear, user-friendly commands that maximise flexibility while maintaining ease of use and accessibility.

### Components

Energy system components feature structured attributes with specified data types, default values, and detailed descriptions.

### Mapping and Plotting

Interactive and static plotting capabilities with full customisation options. Users can generate various charts and maps for any network metric.

### Statistics Library

Summarises and visualises key data and results through postprocessing, streamlining data analysis and presentation for user accessibility.

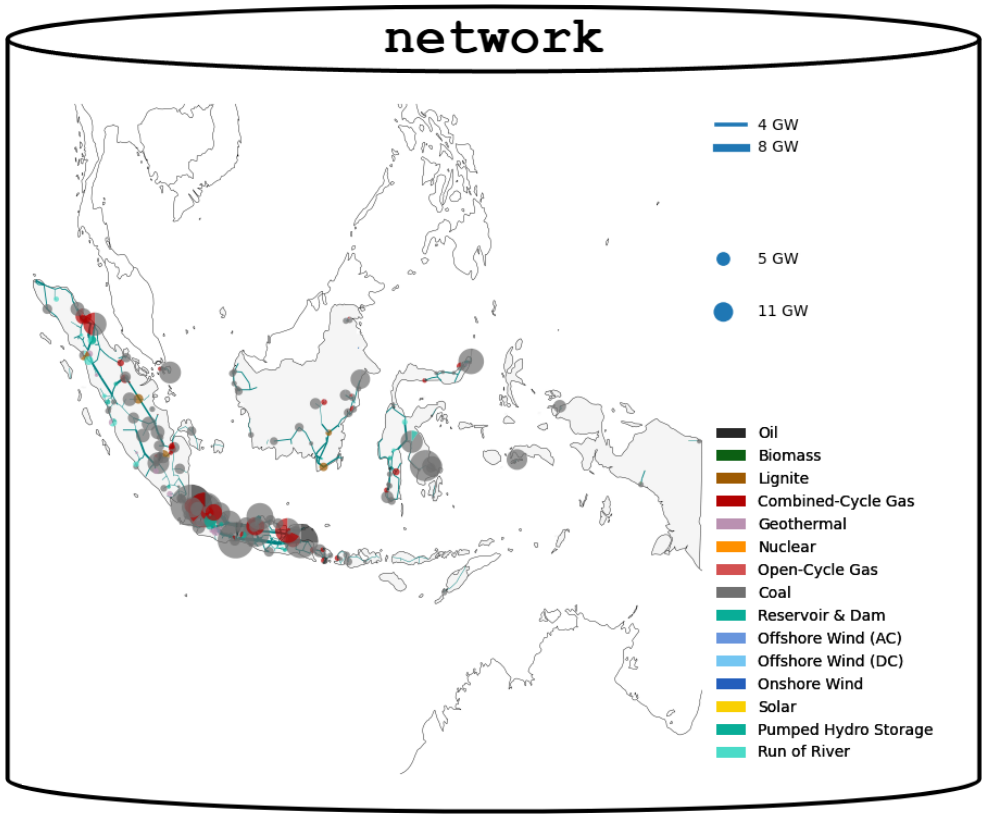
### Solving

The solver handles Economic Dispatch, optimal power flow variants, Capacity Expansion Planning, Stochastic Optimization, and alternative scenario generation.

### Options

Full customisation capabilities allow users to configure all aspects of the model, ensuring the framework can be tailored to any specific application or need.

# PyPSA Model Structure



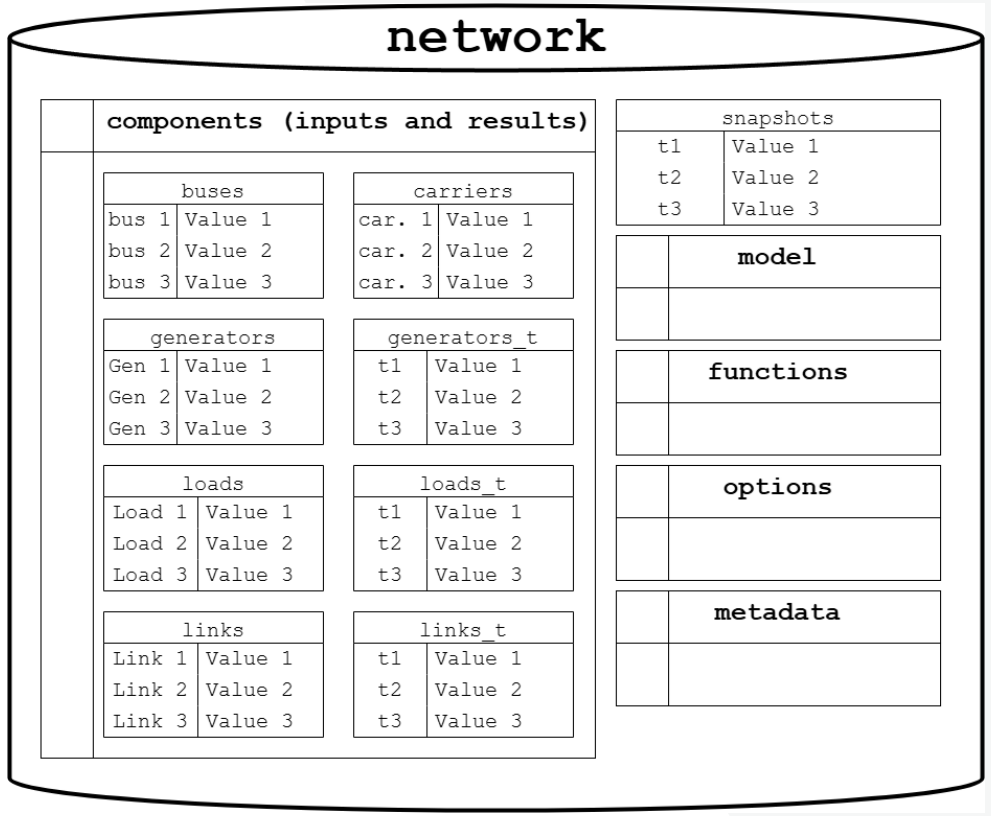
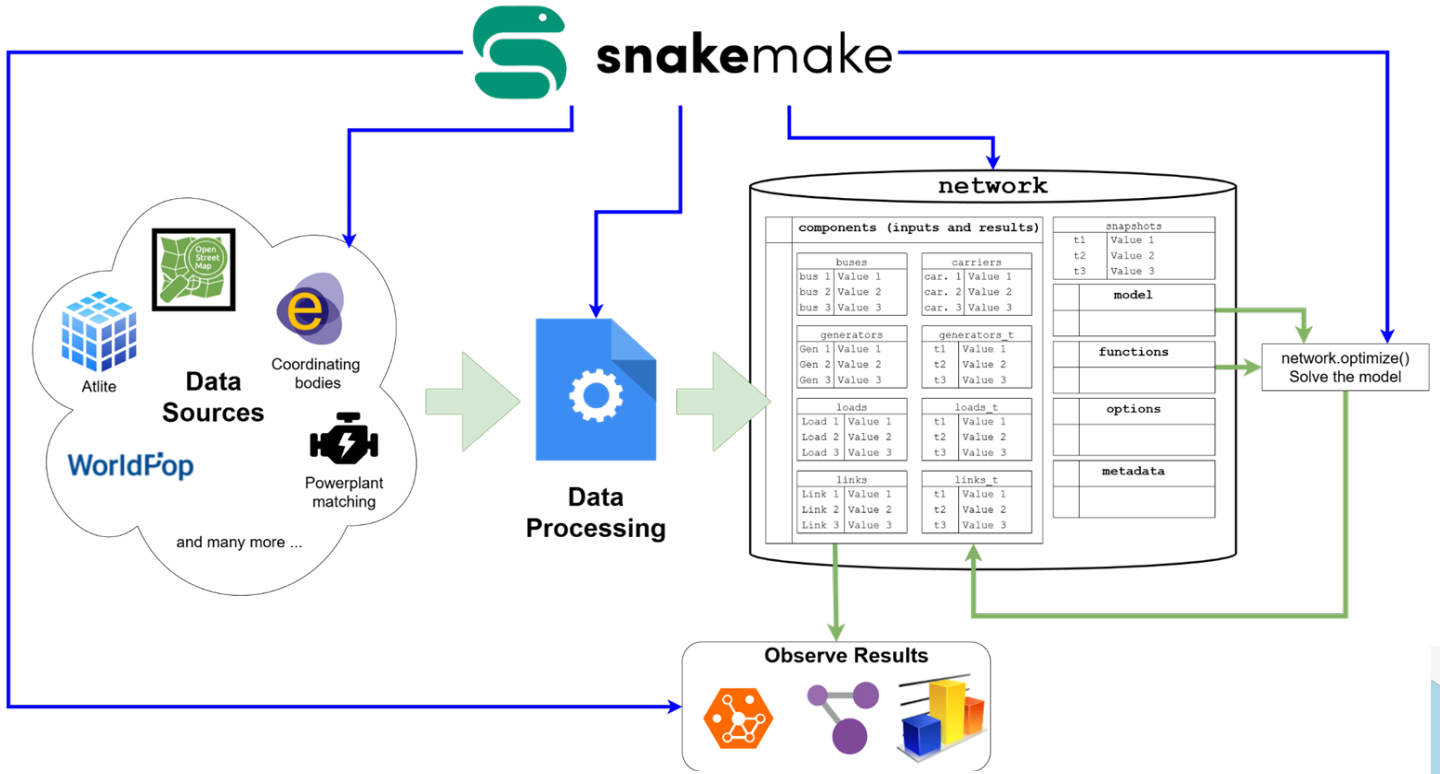




*Image credit: Arizeo Salac (Univ. of Pisa)*

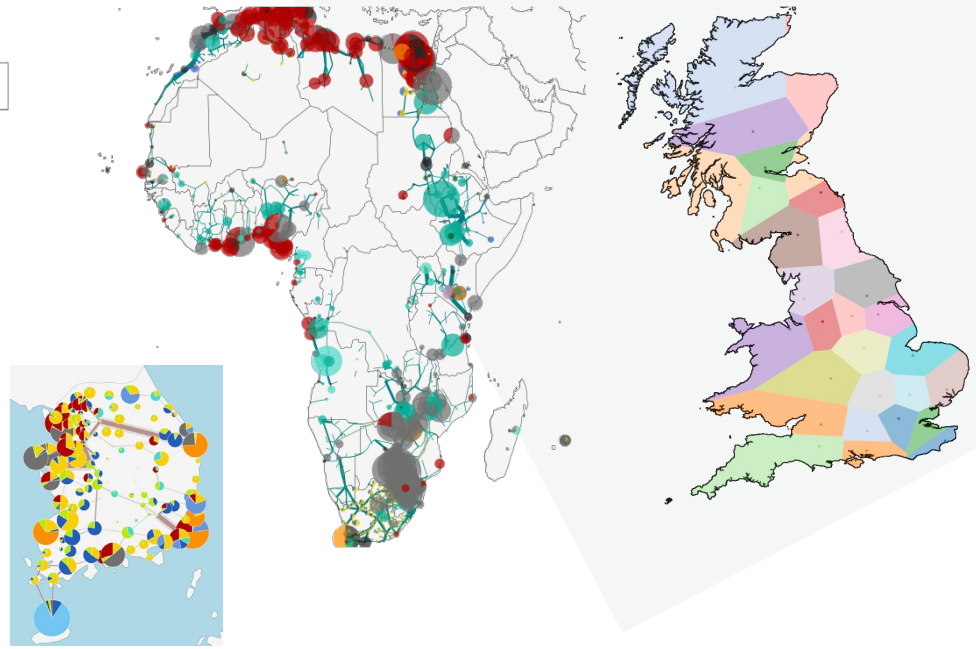
# Typical PyPSA Workflow




Green arrows - Process flow
Blue arrows - Coordination

The modelling workflow:

- **Data collection and import** into the model.
- **Constraint formulation and application using Linopy.**
- **Solve** the model using HiGHS or other solvers.
- **Review and analyse** the results.
- Snakemake **orchestrates** the processes



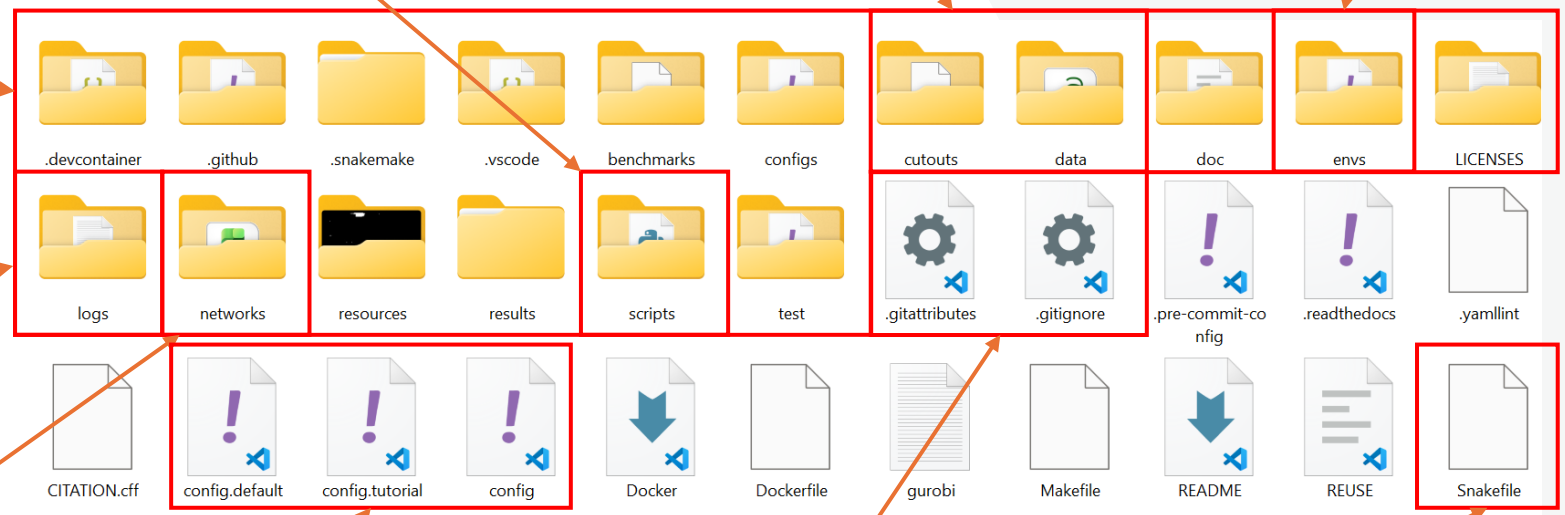
# Organising a pypsa-project

Environments for different systems.

Store input data and cutout data.

Use folders to keep your model organised so you can find, reuse, and maintain your code.

Keep scripts in a single folder.




Store data from modelling logs.

All result networks.

Config files that define the main inputs for the model.

Files for Github.

File telling Snakemake what steps to run, in what order, and what each step depends on.

# Formulation of constraints



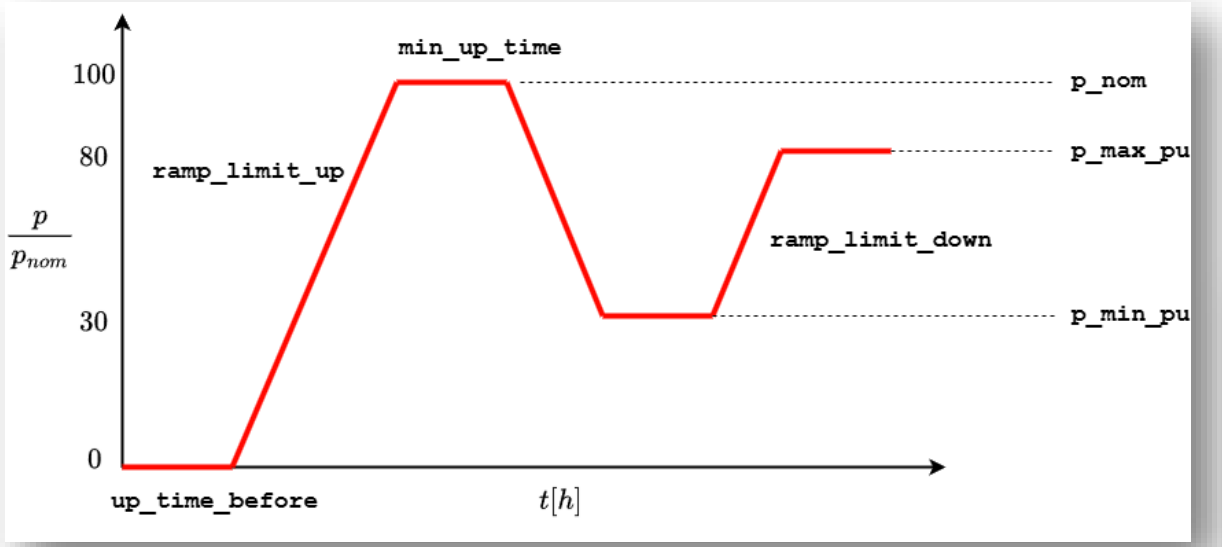


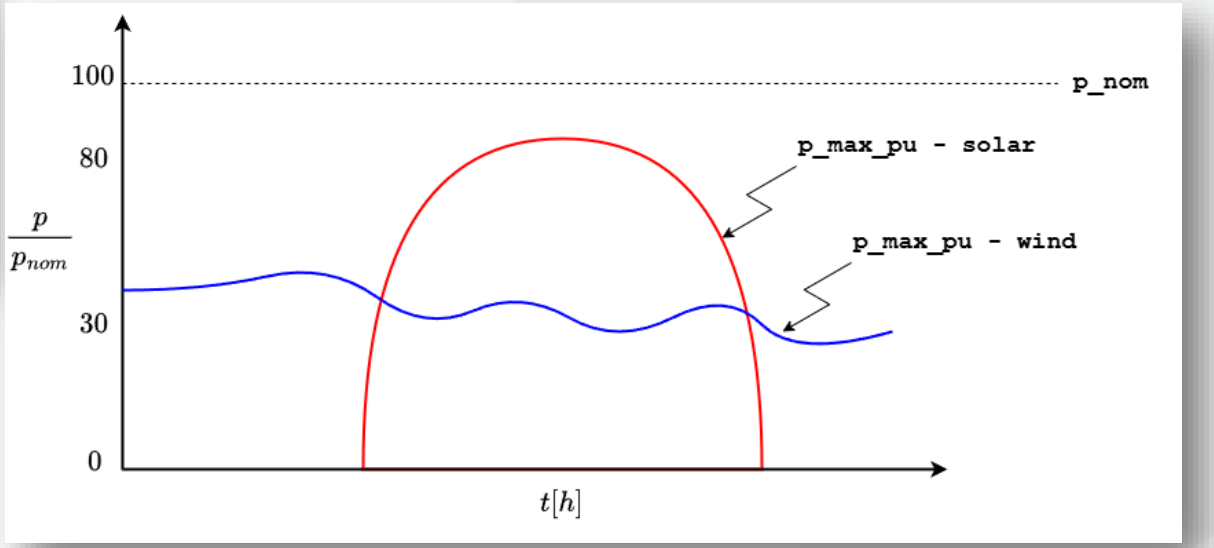

**Considerations**

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

centerwaysteel
australiansolarquotes
ethosenergy
vistechcooling

# Formulation of constraints

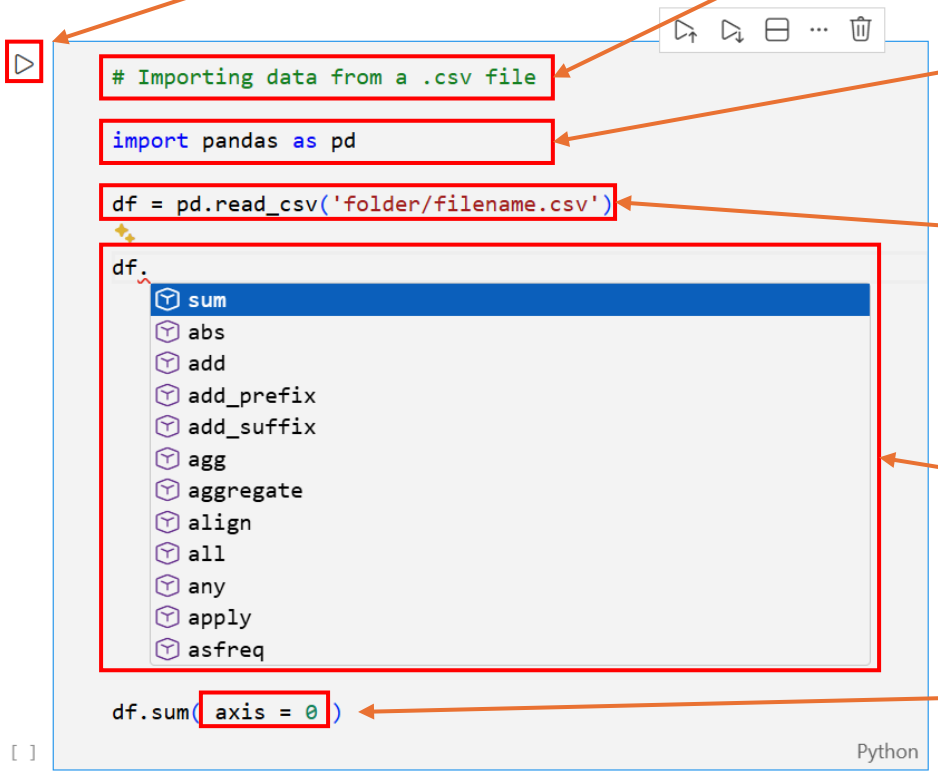



marginal_cost
[currency/MWh]

capital_cost
[currency/MW]
*Additional capacity*

# Components of a Python Script




- Clicking on the triangle will execute the cell in Python.
- Comments start with # and help explain code;
  Python ignores everything after the # on that line.
- Pandas is a library designed for handling and analyzing large datasets efficiently.
- Import brings in external packages; use "as" to abbreviate the package name for easier reference
- Assign data to a variable named "df," short for dataframe.
- "pd" prefix tells Python to use the function from the Pandas library.
- The read_csv function opens a CSV file and converts it into a dataframe you can work with.
- After creating df, you access its methods by typing df. (dot) followed by the method name.
- sum() adds up values in the dataframe; axis=0 specifies it sums down each column.

# Accessing the PyPSA API

## Old component API

**Expected deprecation in V2.0.0**

```python
import pypsa


network = pypsa.Network('basic_network.xlsx')
```

Import a pypsa network and create an object in the variable network.

```python
network.generators
```

Access all the static generator data as a dataframe.

```python
network.generators_t.p_max_pu
```

Access all the dynamic generator data as a dataframe.

```python
network.optimize()
```

Optimize the model.

```python
network.generators_t.p
```

Access results data as a dataframe.

Python

## New component API

**>V 1.0.0**

```python
import pypsa
pypsa.options.api.new_components_api = True

network = pypsa.Network('basic_network.xlsx')
```

Enable the new components api

```python
network.generators.static
```

```python
network.generators.dynamic.p_max_pu
```

```python
network.optimize()
```

```python
network.generators.dynamic.p
```

Python

# Dataframe handling

## Old component API
**Expected deprecation in V2.0.0**

```python
import pypsa

network = pypsa.Network('basic_network.xlsx')

network.generators

network.generators_t.p_max_pu

network.optimize()

network.generators_t.p
```

Python

All data is stored as pandas DataFrames.

Apply the full range of DataFrame operations—like sum(), resample(), and loc[]

It is recommended that users familiarise themselves with Pandas.


## New component API
**>V 1.0.0**

```python
import pypsa
pypsa.options.api.new_components_api = True

network = pypsa.Network('basic_network.xlsx')

network.generators.static

network.generators.dynamic.p_max_pu

network.optimize()

network.generators.dynamic.p
```

Python

# Activity

```
import pypsa

network = pypsa.Network()

network.component.
```

Kahoot!

Python

# Coding Exercise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**https://priyeshgosai.github.io/pypsa-meets-earth-lab-2025/intro.html**