## Webinar-Series: Open-Source GIS Solutions in Energy Access



## 12.04.2022, Maximilian Parzen

(00)



## WHAT IS PyPSA?



Economic Analysis

#### Purpose:

- A tool that can do both <u>economic</u> <u>analysis</u> and <u>grid analysis (load</u> <u>flow studies)</u>
- Developed for large scale optimization and
- Studies in high spatial resolution

|  |              |         |          |               |            | ond m                      | Leonome I Intrybio  |                 |            |        |               |                              |                 |                            |                         |  |
|--|--------------|---------|----------|---------------|------------|----------------------------|---------------------|-----------------|------------|--------|---------------|------------------------------|-----------------|----------------------------|-------------------------|--|
|  | Software     | Version | Citation | Free Software | Power Flow | Continuation<br>Power Flow | Dynamic<br>Analysis | Transport Model | Linear OPF | SCLOPF | Nonlinear OPF | Multi-Period<br>Optimisation | Unit Commitment | Investment<br>Optimisation | Other Energy<br>Sectors |  |
| Energy system tools Power system tools | MATPOWER     | 6.0     | [6]      | 1             | 1          | 1                          |                     | 1               | 1          |        | 1             |                              |                 |                            |                         |  |
|  | NEPLAN       | 5.5.8   | [2]      |               | 1          |                            | 1                   | 1               | 1          | 1      | 1             |                              |                 |                            | 1                       |  |
|  | pandapower   | 1.4.0   | [9]      | 1             | 1          |                            |                     | 1               | 1          |        | 1             |                              |                 |                            |                         |  |
|  | PowerFactory | 2017    | [1]      |               | 1          |                            | 1                   |                 | 1          | 1      | 1             |                              |                 |                            |                         |  |
|  | PowerWorld   | 19      | [3]      |               | 1          |                            | 1                   | 1               | 1          | 1      | ~             |                              |                 |                            |                         |  |
|  | PSAT         | 2.1.10  | [7]      | 1             | 1          | 1                          | 1                   |                 | 1          |        | 1             | 1                            | 1               |                            |                         |  |
|  | PSS/E        | 33.10   | [4]      |               | 1          |                            | 1                   |                 | 1          | 1      | 1             |                              |                 |                            |                         |  |
|  | PSS/SINCAL   | 13.5    | [5]      | 0.25          | ~          |                            | 1                   |                 | 0.25       |        | -             |                              |                 |                            | 1                       |  |
|  | PYPOWER      | 5.1.2   | [8]      | 1             | ~          |                            |                     | 1               | 1          |        | 1             |                              |                 |                            |                         |  |
|  | PyPSA        | 0.11.0  |          | 1             | 1          |                            |                     | 1               | 1          | 1      |               | 1                            | 1               | 1                          | ~                       |  |
|  | calliope     | 0.5.2   | [11]     | 1             |            |                            |                     | 1               |            |        |               | 1                            |                 | 1                          | 1                       |  |
|  | minpower     | 4.3.10  | [12]     | 1             |            |                            |                     | 1               | 1          |        |               | 1                            | 1               |                            |                         |  |
|  | MOST         | 6.0     | [13]     | 1             | 1          | 1                          |                     | 1               | 1          | 1      | ~             | 1                            | 1               |                            |                         |  |
|  | oemof        | 0.1.4   | [14]     | 1             |            |                            |                     | 1               |            |        |               | 1                            | 1               | 1                          | 1                       |  |
|  | OSeMOSYS     | 2017    | [15]     | 1             |            |                            |                     | 1               | 2.2        | -      |               | 1                            |                 | 1                          | 1                       |  |
|  | PLEXOS       | 7.400   | [16]     |               |            |                            |                     | ~               | 1          | 1      |               | 1                            | 1               | 1                          | ~                       |  |
|  | PowerGAMA    | 1.1     | [17]     | 1             |            |                            |                     | 1               | 1          |        |               | 1                            |                 | 13                         | 10                      |  |
|  | PRIMES       | 2017    | [18]     |               |            |                            |                     | 1               | 1          |        |               | 1                            | 1               | 1                          | 1                       |  |
|  | TIMES        | 2017    | [19]     |               |            |                            |                     | 1               | 1          |        |               | 1                            | 1               | 1                          | -                       |  |
|  | urbs         | 0.7     | [20]     | -             |            |                            |                     | ~               |            |        |               | -                            | 1               | ~                          | ~                       |  |

Grid Analysis

#### THE SPATIAL RESOLUTION IN ENERGY PLANNING STUDIES

## **Classical models.** 1 or slightly more aggregation nodes per county



**PyPSA models.** Up to 1000 nodes per region of interest fetched automatically. (resolution limits are improving continuously)



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## Is PyPSA popular?





#### GitHub stars - indicating the user popularity

# **USE CASES**

# SUPPLY DIVERSI. PLANS

**COAL-EXIT** 

LANS

## ENERGY-TRANSITION PLANS

ergiewende - Energy transition" by <u>florianric</u> is marked with <u>CC BY-SA 2.0</u>.



"House solar PV diesel mini-grids for 32 villages in Mali, selected for funding in the first cycle." by International Renewable Energy Agency (IRENA) is licensed under <u>CC BY-NC-ND 2.0</u>

## PyPSA is a framework. We build tools on top.

# **A**PyPSA



A python software toolbox for simulating and optimising modern power systems.



An open optimisation model of the European transmission system.

Atlite

A Lightweight Python Package

for Calculating Renewable Power

Potentials and Time Series



A sector-coupled open optimisation model of the European energy system.



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







Linear optimization interface for N-D labeled variables.





**PyPSA-Earth** 



A highly flexible sectorcoupled energy system model of the global energy system





A machine learning framework to detect energy assets from satellites



A general framework to create demand timeseries in subnational resolution



meets Earth



- Investment and dispatch optimization for multiple-horizons
- **Powerflow optimization** (e.g. AC powerflow, security constrained LOPF, DCOPF)
- **Data-driven constraint formulation** (e.g. renewable potentials, protected areas, climate-change impacts)
- Machine learning (Object detection with transfer learning, super resolution, Timeseries prediction with DeepML, Bayesian inference for demand prediction..)
- **Graph theory** (for spatial clustering and graph expansion e.g. k-means, steiner-tree, minimum spanning tree,...)
- Statistics (e.g. data-driven disaggregation, demand predictions)
- **Parallel and cloud computing** (dask and xarray)
- Workflow management system (snakemake for reproducibility and ease of use)



#### For Energy Model:

- Powerflow optimization tested against PyPOWER/MATPOWER and pandapower
- Comparison to public accessible stats and reports (e.g. IRENA on existing renewables)
- Comparison to other commercial models (e.g. provide same results as PLEXOS)

#### For Machine Learning:

- Back-testing of historic data
- Validation data from manual validation (e.g. satellite detected images) or existing data (e.g. smart meter data)



# WHAT'S NEXT?



# - 1 MODEL 1 EARTH COMMUNITY -

"Model your province, your country, your continent or the whole planet under one framework"

"Accelerate innovation/time, support quality, make meaningful impact"



#### **OPEN** Global Independent Research Initiative



## SOLVER

## ENERGY SYSTEM MODELS

DATA

USER AND DEVELOPER COMMUNITY

(cc)



### **LET'S OPEN UP THE BLACK BOX**

#### + MAKE THE "OPEN BOX" THE STANDARD







# MAXIMILIAN PARZEN

Co-steering the PyPSA meets Earth initiative

Address: Institute of Energy Systems University of Edinburgh Kings Building EH9 3JL Edinburgh, UK +49 176 70889068









DONATE NOW. WE RAISE 100+k FOR DEVLOPING 10-100x FASTER OPEN-SOURCE SOLVER

#### DETAILED PROPOSAL\*: <u>https://pypsa-meets-</u> <u>africa.github.io/highs.html</u>

\*In collaboration with University of Edinburgh, TU Berlin and Princeton University

#### **OPEN ENERGY SYSTEM PLANNING**





ACCESSIBLE, ROBUST, TRANSPARENT ENERGY SYSTEM ANALYSIS

> #SUPPORT #HIGHS TO INCREASE ACCESSIBILITY

#### **OPEN** Global Independent Research Initiative



creating open

Data

workflow

data

edicting<sup>-</sup>

data

High

resolution

\_Collaborative

#### USER AND DEVELOPER COMMUNITY Training

Open

alogue

Empower

**High resolution ENERGY** SYSTEM MODELS Problem

formulator

Modular

Help sustaining

#### SOLVER

Support

developers

Initiate new Reveal bottlenecks paths

19

## **USE EXISTING DATA TO PLAN THE FUTURE**

#### DEMAND

#### SUPPLY

#### **NETWORK**





GLOBAL DATA BY DEFAULT

P

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21

#### WHAT IF YOU ARE MISSING DATA?



# INFRASTRUCTURE DETECTION

# DEMAND PREDICTION

M



1. Country-Level Demand Forecasting via Bayesian Deep Learning and Others



2. Downscaling via Economics-Informed Probabilistic Models and Others



3. Building-Level Demand Forecasting via Bayesian Deep Learning and Others







Sources: Lee et al., "How probabilistic electricity demand forecasts can expedite universal access to clean and reliable electricity," *Energy for Economic Growth*, 2021.; Lee et al., "Probabilistic forecasts of country-level electricity demand in Africa," 2022 (not yet public). – Soon to be open-sourced, please contact authors: Sirko et al. Continental-scale building detection from high resolution satellite imagery. arXiv:2107.12283, 2021.; Haklay, M. and Weber, P., 2008. Openstreetmap: User-generated street maps. IEEE Pervasive computing, 7(4), pp.12-18.

# HYDROGEN AND GIS

#### **EXAMPLE OUTPUT:** INVESTMENTS FOR 2050 NET ZERO SCENARIOS



Fabian Neumann and Tom Brown. PyPSA: Free Sofware for Investment Planning in Sector-Coupled Energy Systems https://www.neumann.fyi/files/pesgm2020.pdf

#### **EXAMPLE OUTPUT:** INVESTMENTS + OPERATION FOR 2050 NET ZERO SCENARIOS



Elisabeth Zeyen, Prof. Marta Victoria, Dr. Tom Brown

https://www.pac-scenarios.eu/fileadmin/user\_upload/KIT\_Aarhus\_University\_PAC\_scenarios\_with\_PyPSA-Eur-Sec\_I5oct20.pdf

#### **EXAMPLE OUTPUT:** INVESTMENTS + OPERATION FOR 2050 NET ZERO SCENARIOS

#### Installable Potential and Land Eligibility



Fabian Neumann and Tom Brown. PyPSA: Free Sofware for Investment Planning in Sector-Coupled Energy Systems https://www.neumann.fyi/files/pesgm2020.pdf

# **5 ACTIVE TEAMS**



# **Open Community!**

|                          |      |                      |   | general - Discord  |  |                         |             |              |   |          |                |      | a 😒 |
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| PyPSA-Earth              | ~ [  | general              | The purpose of this channel is                                  | s to provide guidance on how to use th                                   | ne PyPSA-Earth discord server.                                       | <i>‡</i> #              | %           | ۶            | 2 |          | Q              |      | 0   |
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| CO-WORKING SPACE         | +    | system               | planning tools for our planet                                   | t. If you are wondering why it is Py                                     | PSA-Earth and not PyPSA-meet   | ts-Africa,              | than        | 5 <i>7</i> - |   | •        | Yolwo          |      |     |
| MARIE-CURIE              |      | you pro<br>global i  | bably just found out that we<br>issue. Together with people a   | e are not only aim to empower Afri<br>around the world we are building o | ica. The problem of poor energy<br>open source tools that are scalat | planning<br>ole, detail | isa<br>edan | id.          |   | ONLI     | NE — 12        |      |     |
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| EDISON                   |      | Be care              | eful. Some content ins better                                   | suited at other places:  |  |                         |             |              |   |          | eyorat         |      |     |
| ্রী The PyPSA-Earth Stag | ge   | - Ask <i>u</i><br>it | sability questions please on:                                   | https://stackoverflow.com/quesi  | tions/ask and share in #deleted                                      | -channel                | a link      | : to         |   |          | fahiankatma    |      |     |
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| # papers                 |      |                      |   |  |  |                         |             |              |   |          | 1 ony 1 00, 21 |      |     |