Guest lecture @ ICTP Summer School

"PyPSA Database & Remote Sensing"

02.06.2022, Maximilian Parzen

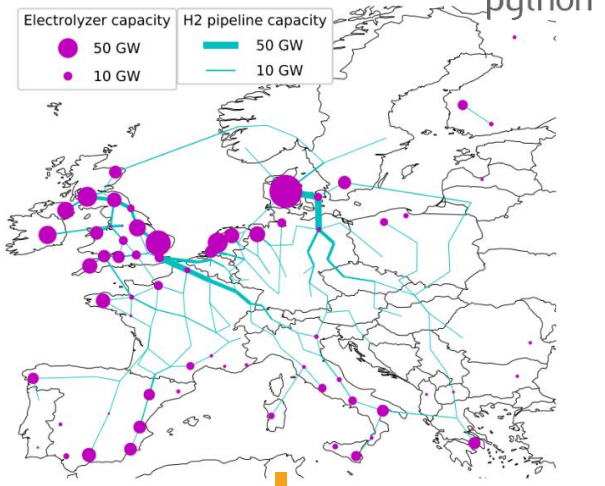
CC

WHO IS MAX?

Bored PhD student
Winter 20/21

Used it & loved it

PyPSA-Eur

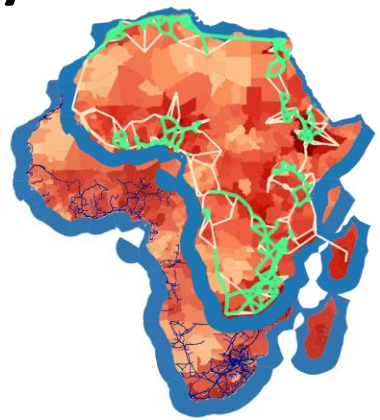


Created an initiative

PyPSA meets Africa

Built a model. Release Q4 2021

PyPSA-Africa & Co.

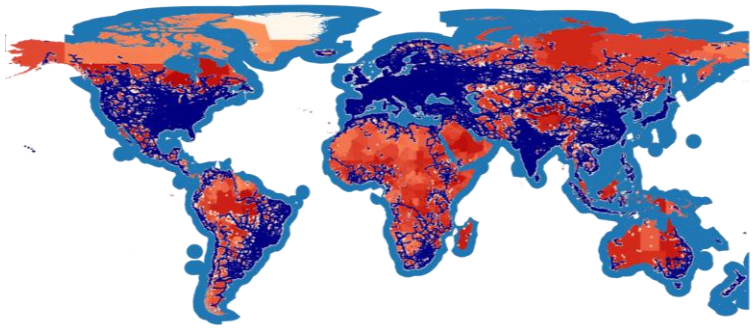


Extended the initiative

PyPSA meets Earth

Started activities on global scale

PyPSA-Earth & Co.



PyPSA
meets Earth
“PyPSA meets Earth's vision is to create together the most compelling open data and open source planning tool to accelerate the world’s sustainable energy transition.”
CC

PyPSA is a framework. We build tools on top.

MODEL = Data+Framework

PyPSA

PyPSA meets Earth

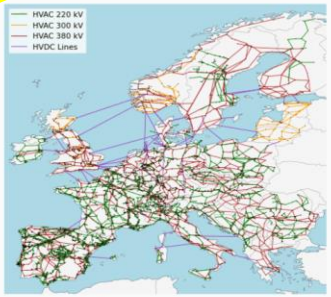
FRAMEWORK

PyPSA

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

MODEL

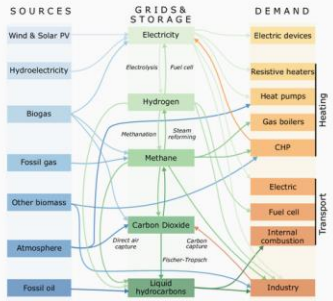
PyPSA-Eur



An open optimisation model of the European transmission system.

MODEL

PyPSA-Eur-Sec



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

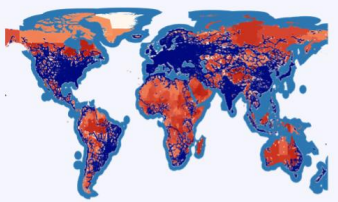
MODEL

PyPSA-Africa

An open optimization model of the African transmission system

MODEL

PyPSA-Earth



A highly flexible **sector-coupled** energy system model of the global energy system

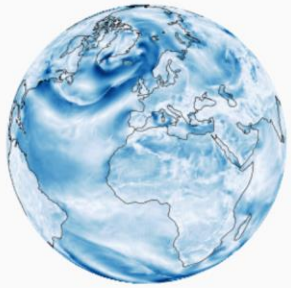
DATA

Powerplantmatching

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

DATA

Atlite



A Lightweight Python Package for Calculating Renewable Power Potentials and Time Series

BETTER PYOMO

Linopy

Linear optimization interface for N-D labeled variables.

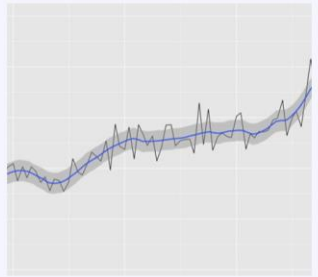
DATA

Detect-Energy

A machine learning framework to detect energy assets from satellites

DATA

Demand-Creator



A general framework to create demand timeseries in subnational resolution

WHAT IS PyPSA?

PyPSA meets Earth

Purpose:

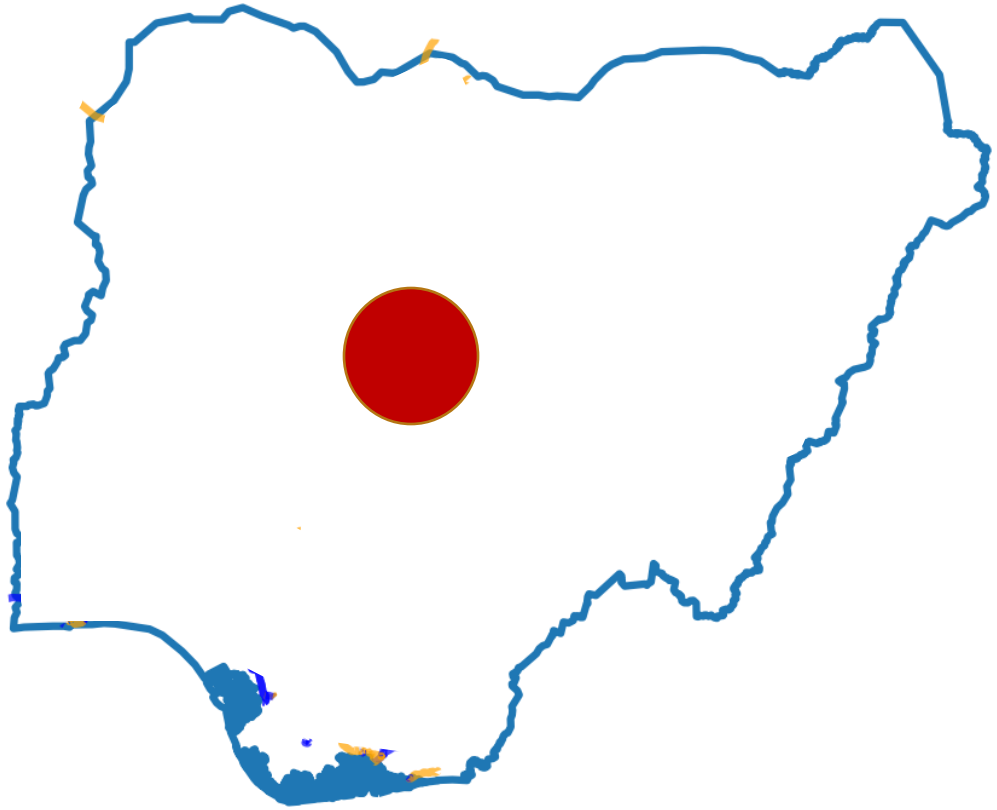
- A tool that can do both **economic analysis** and **grid analysis (load flow studies)**
- Developed for **large scale optimization** and
- Studies in **high spatial resolution**

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

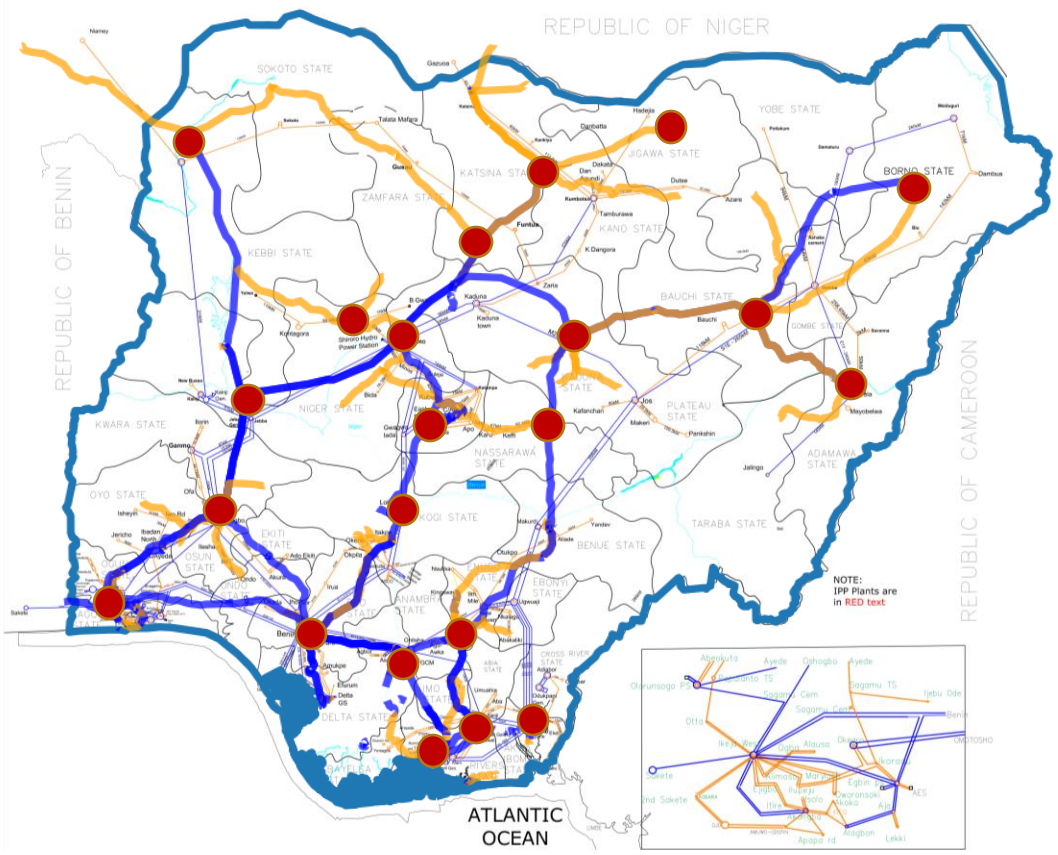
Source: Tom Brown, Jonas Hoersch, David Schlachtenberger (2017), https://arxiv.org/abs/1707.09913

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)



HOW DO WE DESIGN OUR DATABASE ?

PyPSA
meets Earth
HOW DO WE DESIGN OUR DATABASE ?
(WE DON'T HAVE ONE FOR EVERYTHING)

1. Provide data extraction scripts for primary open databases

e.g. OpenStreetMap, Era-5 (environment+weather)

- By default global & GIS-based
- Do you have better local country data? Contributions are welcome. Be a part of our community.

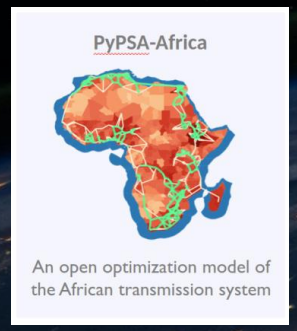
2. Provide data manipulation scripts

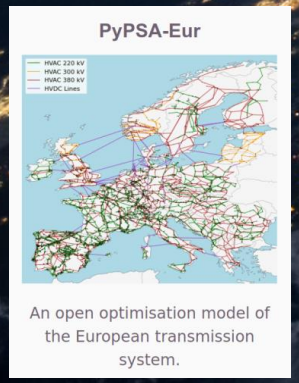
e.g. to convert wind speed (m/s) to wind power (MW) or building meshed OpenStreetMap network

3. Provide data validation scripts

e.g. compare results to research or institutional studies (IRENA etc.)

Example of automated workflow I/O





Data Collection

GIS Inputs

Infrastructure
- T&D Network
- Substation and trafo.
- Power plants
- (road network)
- ...

Env. Data
- Solar irradiation
- Wind speed
- Temperature
- Humidity
- ...

Socio-Economic
- Population raster
- GDP raster
- Productive activities
- ...

Other layers
- Demand raster
- Night time lights
- Elevation
- Land classification
- ...

Non-GIS Inputs

Other inputs
- Emission target
- Technology cost
- Technology specs.
- Fuel prices
- Policies & legislation
- Equity constraints
- Others

Data creation

- Renewable timeseries and potentials
- Infrastructure detection
- Data-driven demand forecast

Data Fusion and Modification

- Fusion of multiple datasets to one
- Cleaning. Processing, preparation
- Calibration with national statistics
- ...

PyPSA = problem formulator

- Add data to optimization framework
- Rich set of modular components
- Constraint writing
- Power flow, LOPF formulation
- Solver integration

Solver

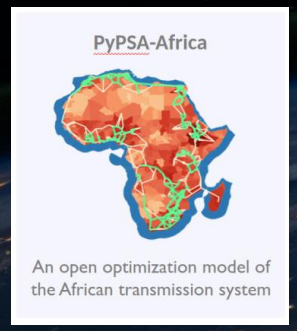
- Open source and commercial solver integration
- Finds optimal solution e.g. least cost system

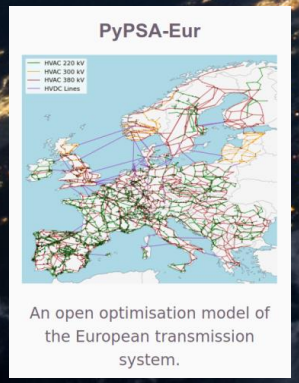
Outputs – data and plots

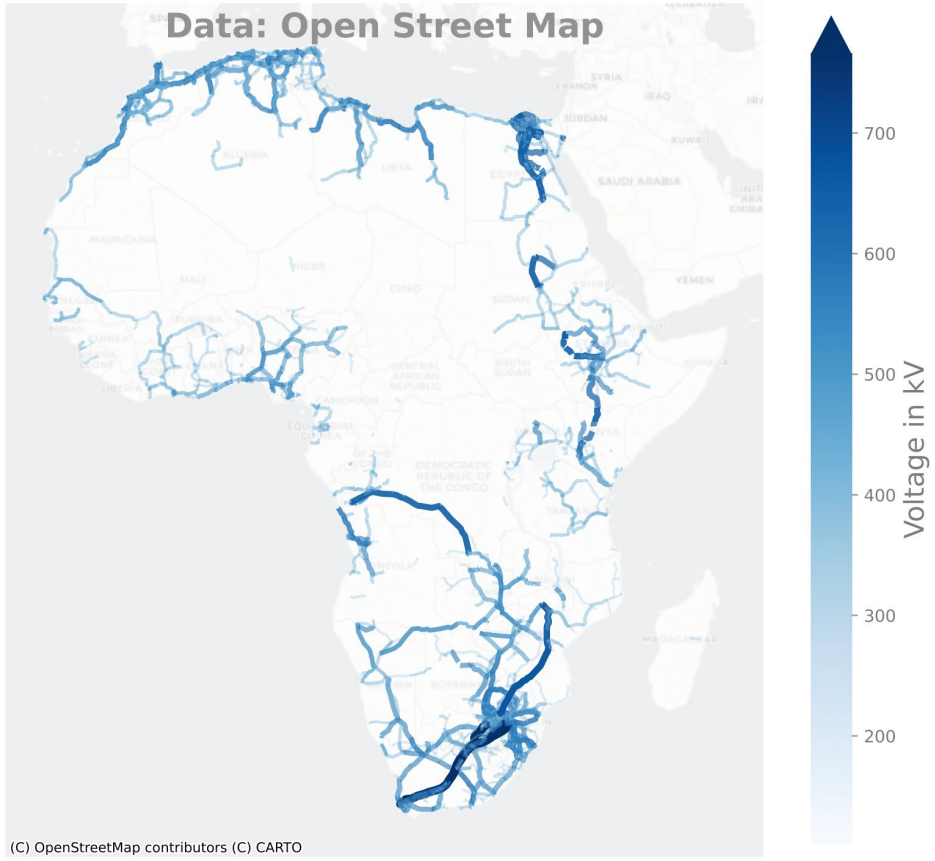
.csv .geojson

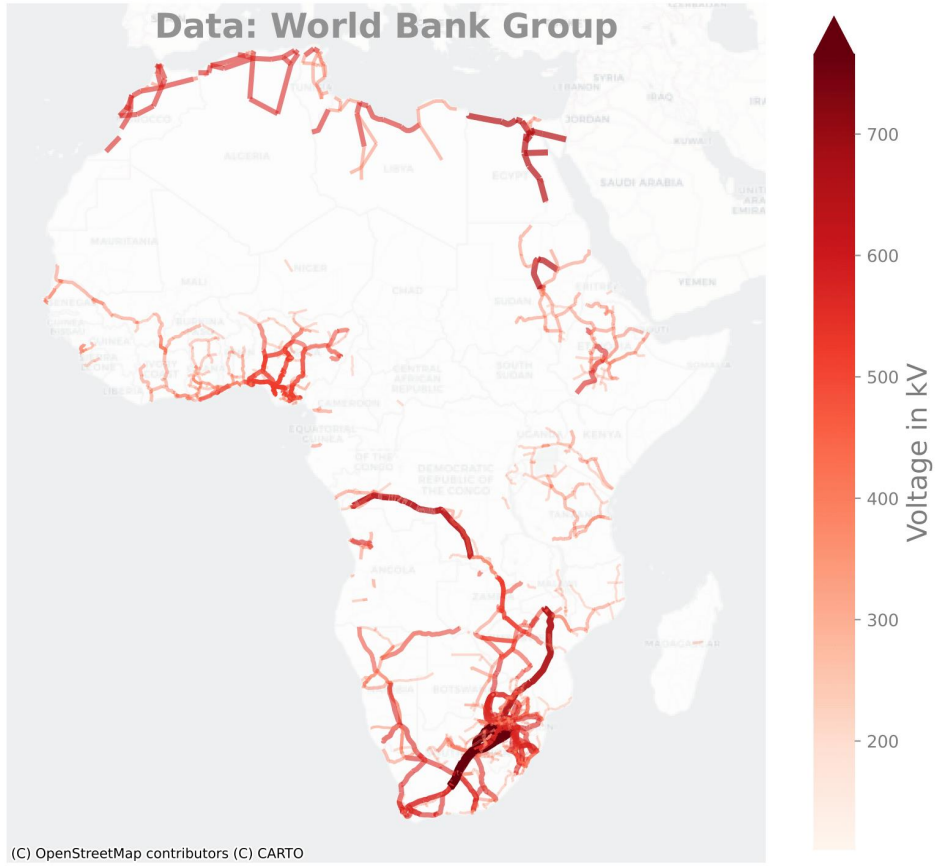
.nc (netCDF)

Example of automated workflow I/O









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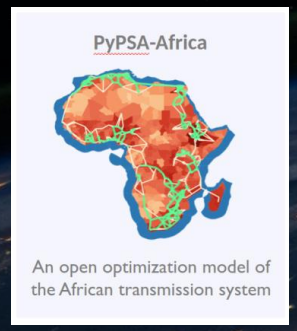
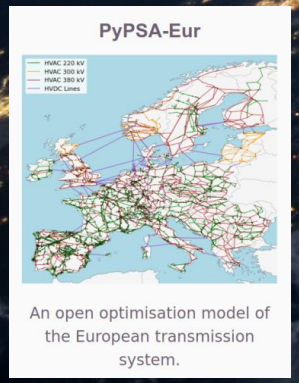
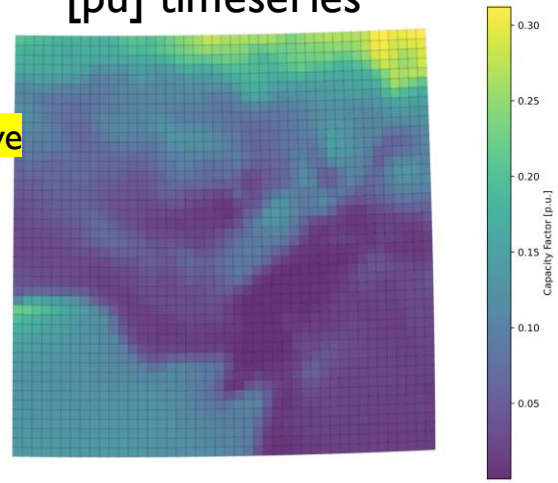




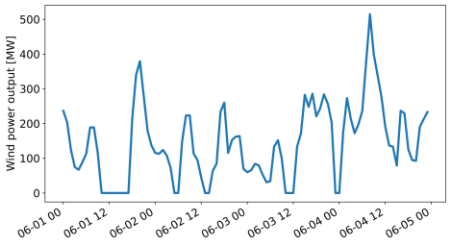
20x20km resolution
Wind speed

Power curve

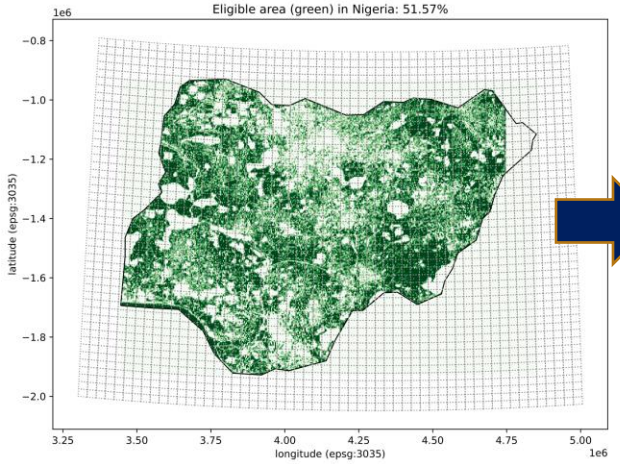
20x20km resolution
Capacity factor calc. from [pu] timeseries



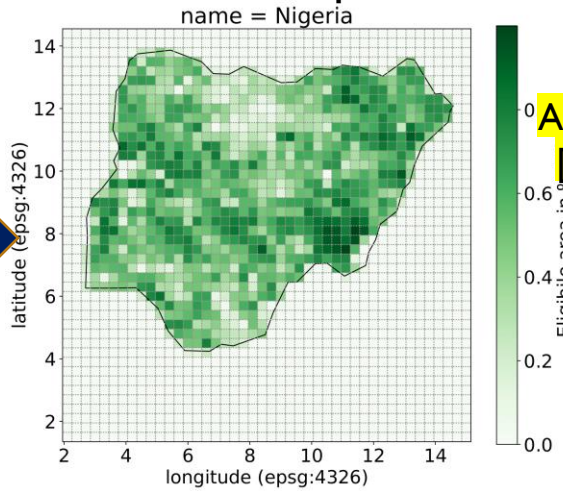
Technical available wind potential per cell



100x100m resolution.
Eligibe area for wind

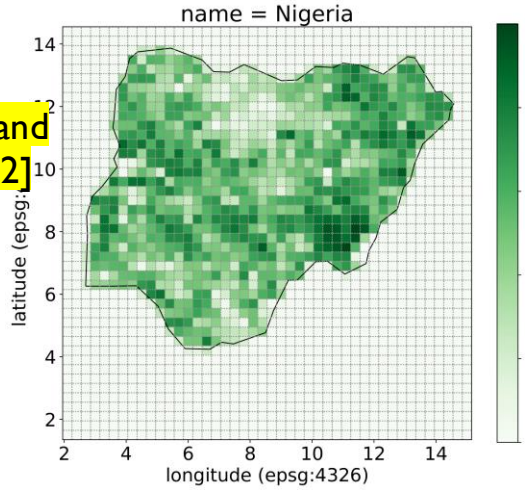


20x20km resolution
Downsampled



Area demand [MW/km2]

20x20km resolution
Installable capacity [MW]



WHY THIS STRUGGLE?
WHY NOT PROVIDING MODEL-READY DATA?

Photo by christopher lemercier https://unsplash.com/photos/12yvdCiLaVE

PyPSA meets Earth

WHY THIS STRUGGLE?
WHY NOT PROVIDING MODEL-READY DATA?

Data creation, manipulation and validation:

- needs to be transparent
- needs to be reproducible
- needs to be editable

… because big risk of cheating or mistakes.

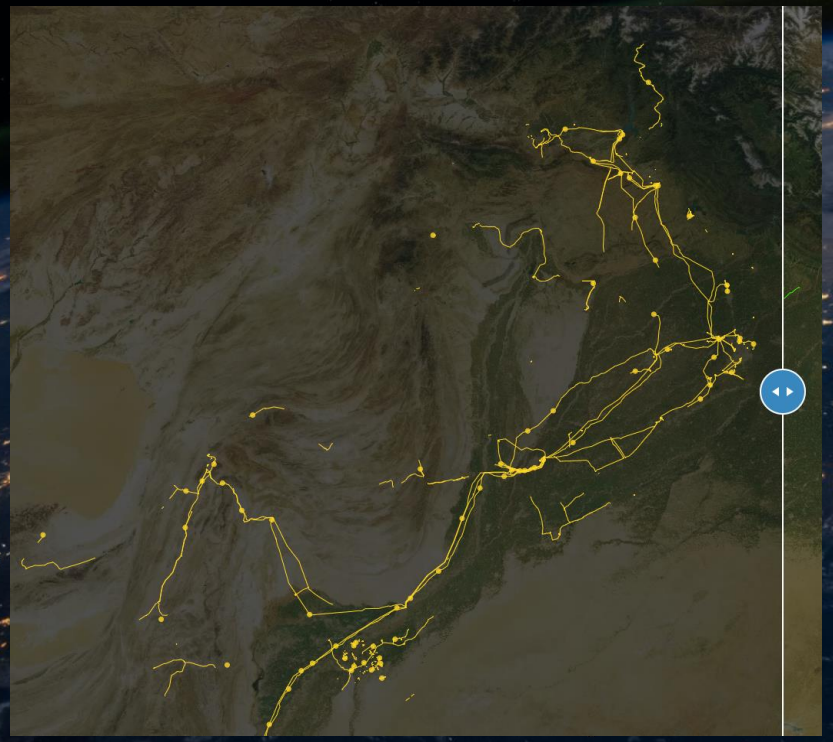
We also want to continuously improve.

WHAT ABOUT REMOTE SENSING ?

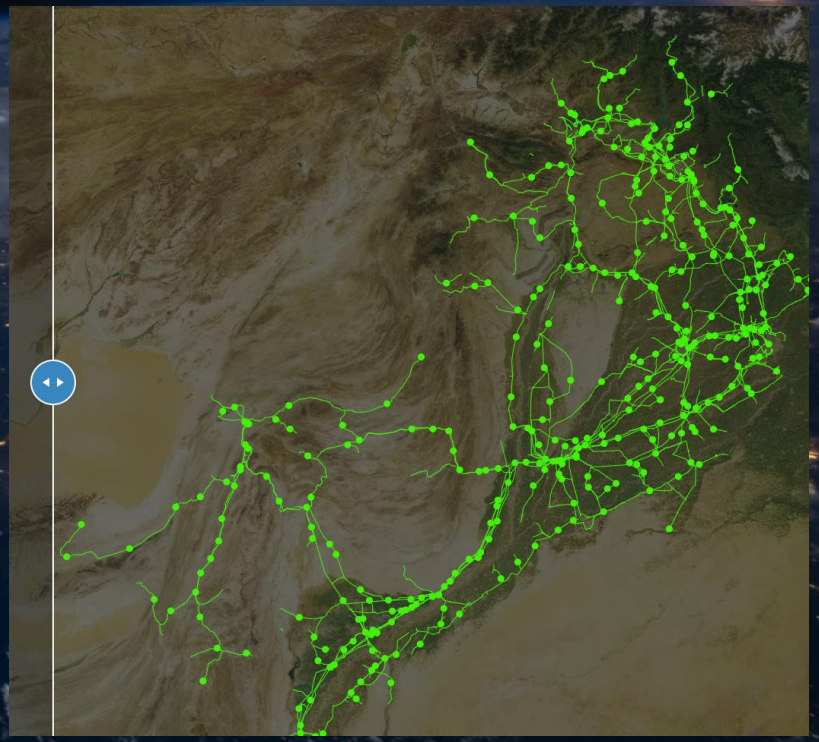
PyPSA meets Earth

Infrastructure detection:

Before



After



http://devseed.com/ml-grid-docs/results/mapping-output-and-speed/

CC

PyPSA meets Earth

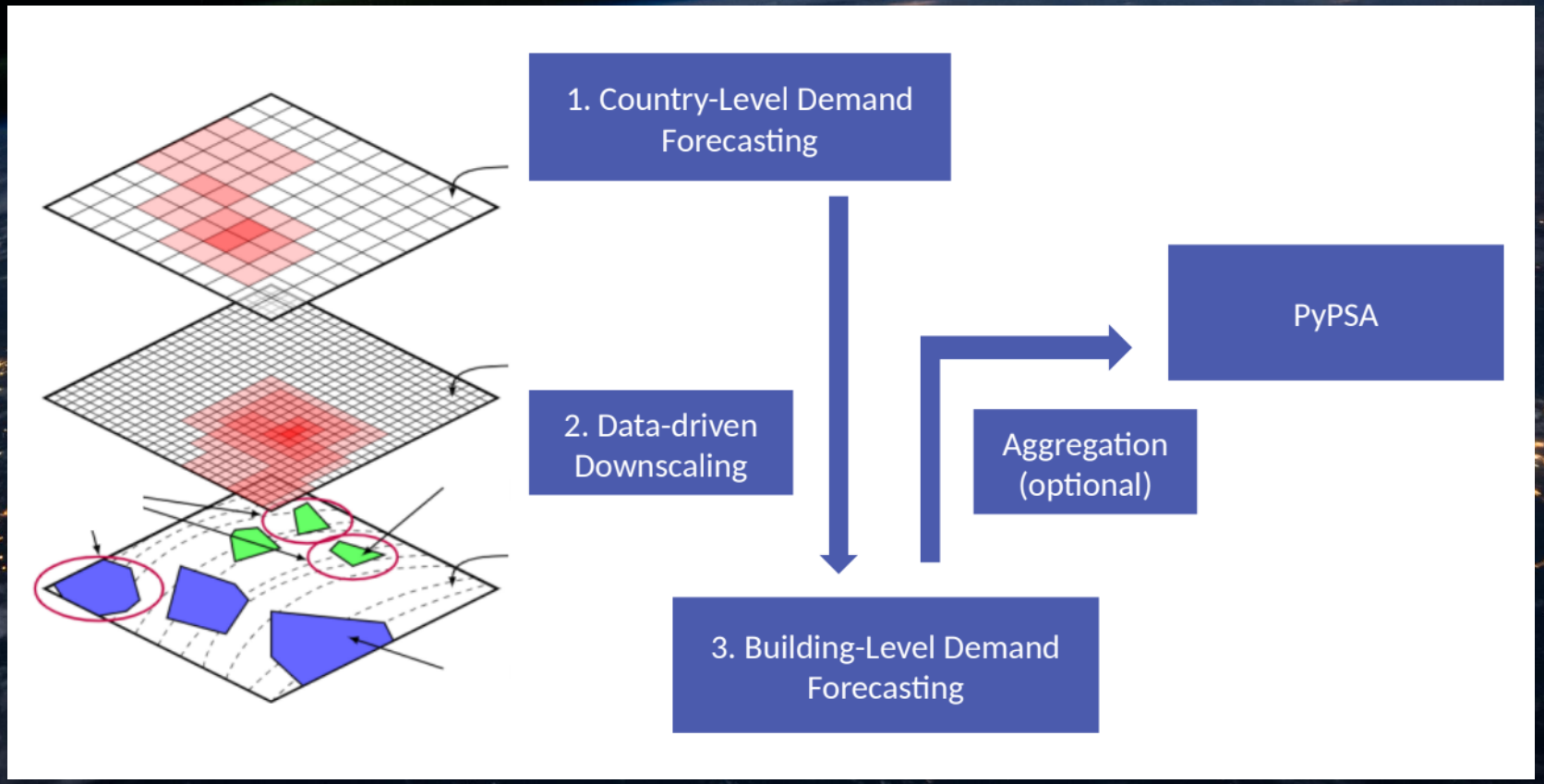
NEW:

1. Cycle-GAN to use multiple data sources

2. Reproduceable workflow to detect infrastructure across the world

Demand forecasts:

VISION: high-resolution demand data around the world



PyPSA
meets Earth
WHAT'S NEXT ?

OPEN Global Independent Research Initiative

PyPSA meets Earth

SOLVER

ENERGY SYSTEM MODELS

DATA

USER AND DEVELOPER COMMUNITY

PyPSA-EARTH

- 1 MODEL 1 EARTH COMMUNITY -

"Model your province, your country, your continent or the whole planet in one model"

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

TEAM
Professors
Professional
Researchers
PhD students
Bachelors …

MAXIMILIAN PARZEN

Co-steering the PyPSA meets Earth initiative

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+49 176 70889068

Contact: https://pypsa-meets-africa.github.io/

max.parzen@ed.ac.uk

THE UNIVERSITY of EDINBURGH

APPENDIX

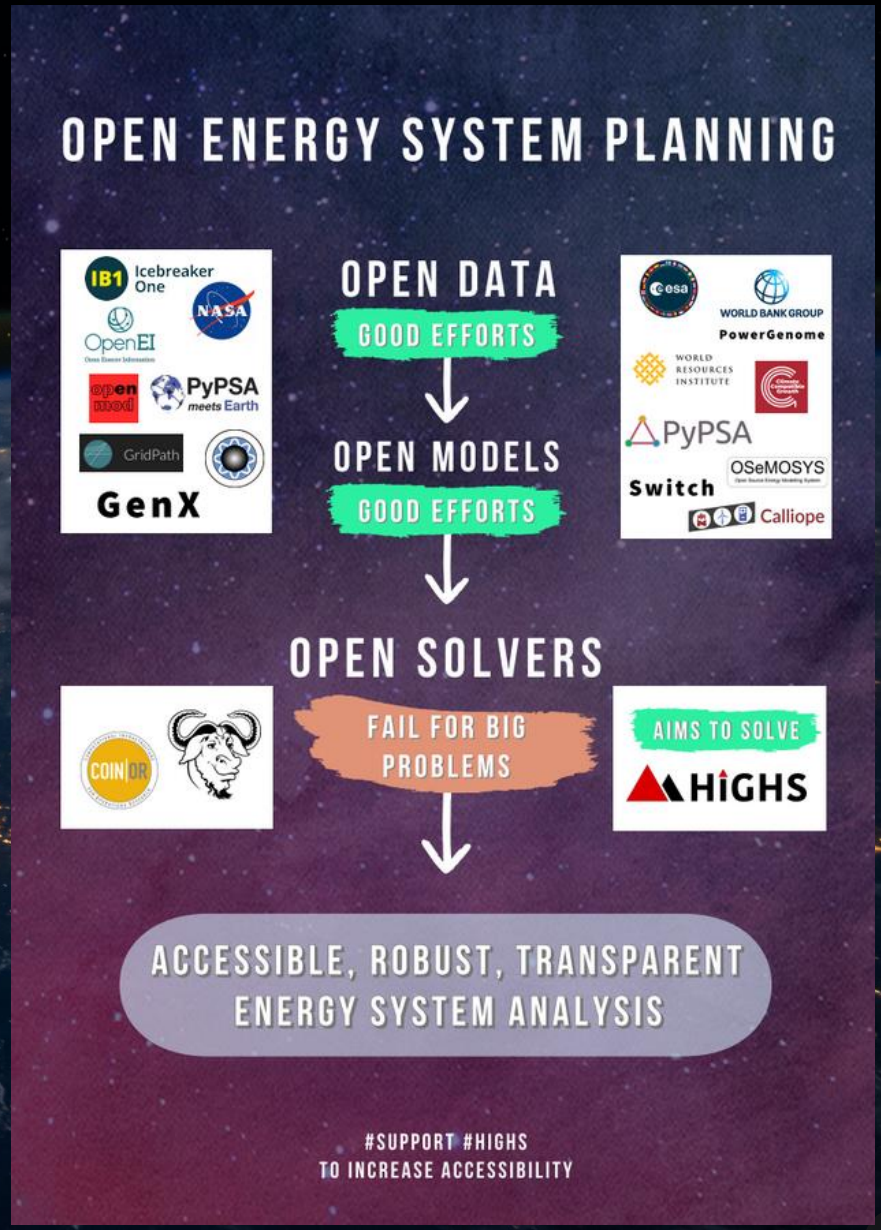
DONATE NOW.

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

DETAILED PROPOSAL*:

https://pypsa-meets-africa.github.io/highs.html

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



OPEN Global Independent Research Initiative

SOLVER

Help sustaining

Support developers

Reveal bottlenecks

Initiate new paths

ENERGY SYSTEM MODELS

High resolution

Features

Performant

Problem formulator

Modular

DATA

Creating open data

Predicting data

Data workflow

High resolution

USER AND DEVELOPER COMMUNITY

Open

Collaborative

Dialogue

Training

Empower

WHAT IS PyPSA?

PyPSA meets Earth

Purpose:

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

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	Software	Version	Citation	Free Software	Power Flow	Continuation Power Flow	Dynamic Analysis	Transport Model	Linear OPF	SCLOPF	Nonlinear OPF	Multi-Period Optimisation	Unit Commitment	Investment Optimisation	Other Energy Sectors
Power system tools	MATPOWER	6.0	[6]	✓	✓	✓		✓	✓		✓				
	NEPLAN	5.5.8	[2]		✓		✓	✓	✓	✓	✓				✓
	pandapower	1.4.0	[9]	✓	✓			✓	✓		✓				
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Energy system tools	calliope	0.5.2	[11]	✓				✓				✓		✓	✓
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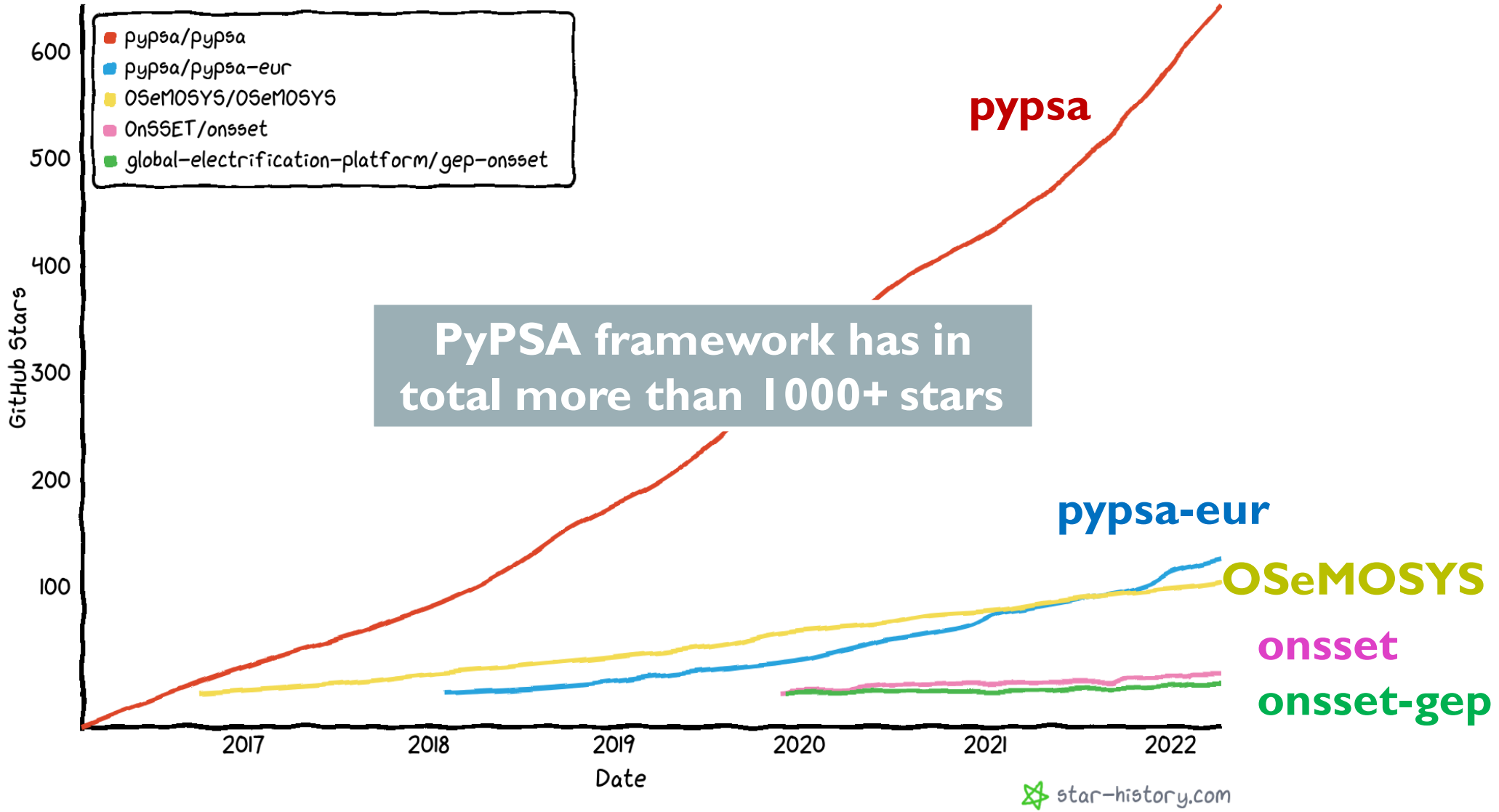
	TIMES	2017	[19]					✓	✓			✓	✓	✓	✓
	urbs	0.7	[20]	✓				✓				✓	✓	✓	✓

Source: Tom Brown, Jonas Hoersch, David Schlachtenberger (2017), https://arxiv.org/abs/1707.09913

Is PyPSA popular?

PyPSA meets Earth

GitHub stars – indicating the user popularity



PyPSA framework has in total more than 1000+ stars

Applied Methods

PyPSA 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, Time-series 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 reproducibilty and ease of use)

Validation approaches

PyPSA meets Earth

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)

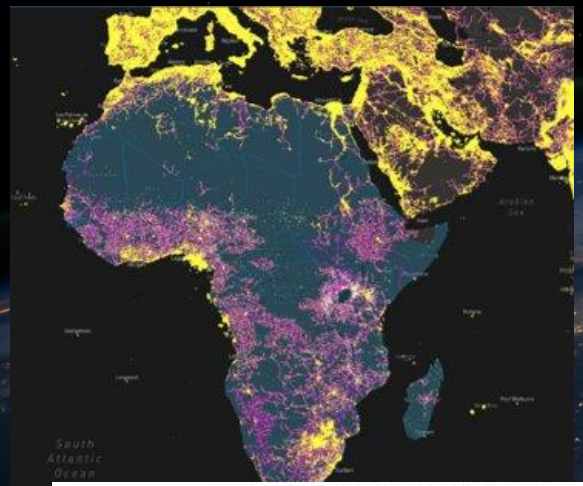
For Machine Learning:

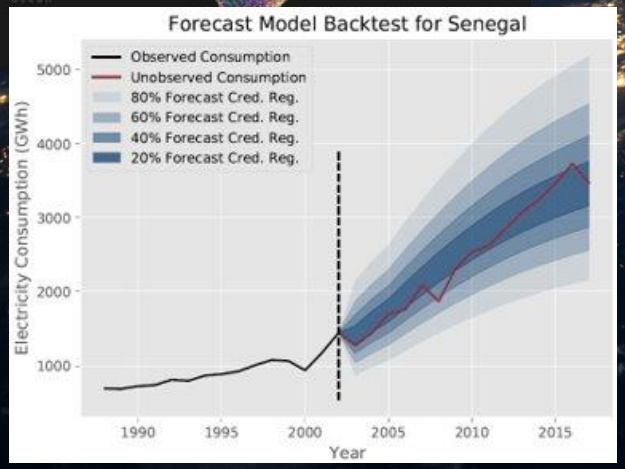
- Back-testing of historic data
- Validation data from manual validation (e.g. satellite detected images) or existing data (e.g. smart meter data)

Source: Tom Brown, Jonas Hoersch, David Schlachtenberger (2017), https://arxiv.org/abs/1707.09913

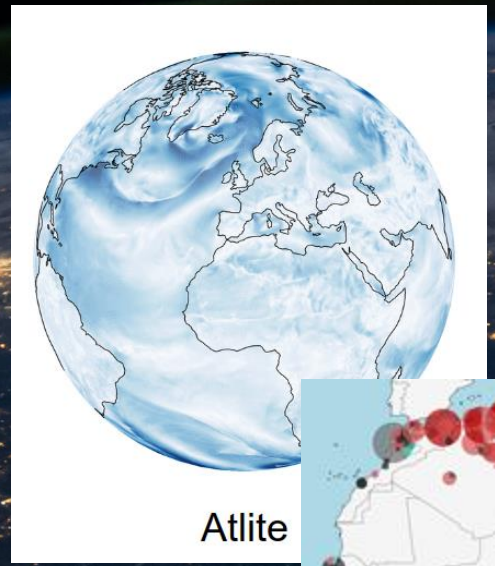
USE EXISTING DATA TO PLAN THE FUTURE

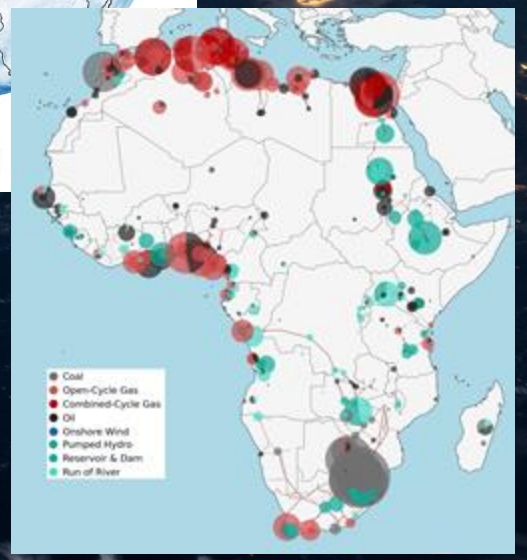
DEMAND



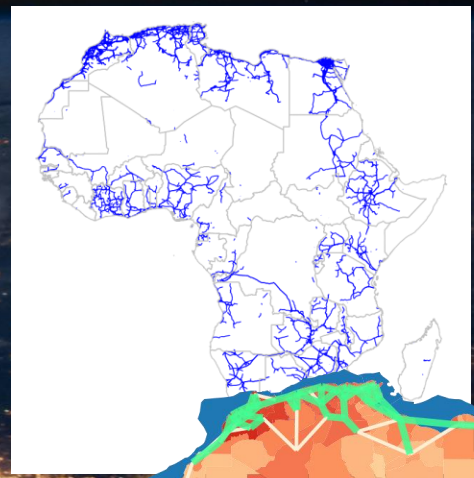


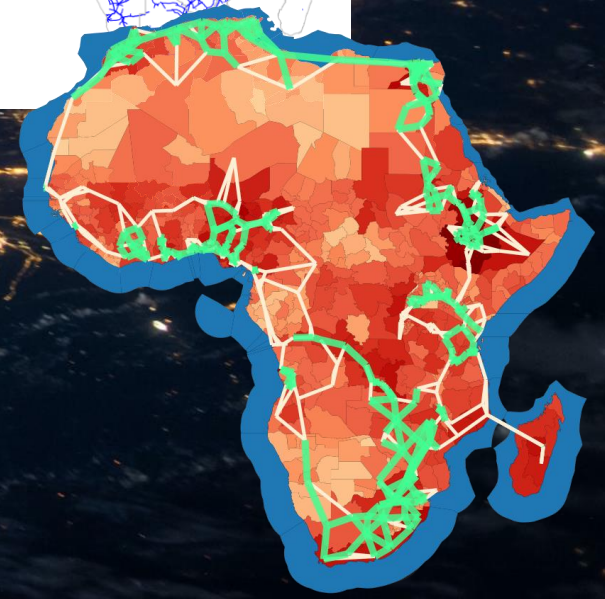
SUPPLY

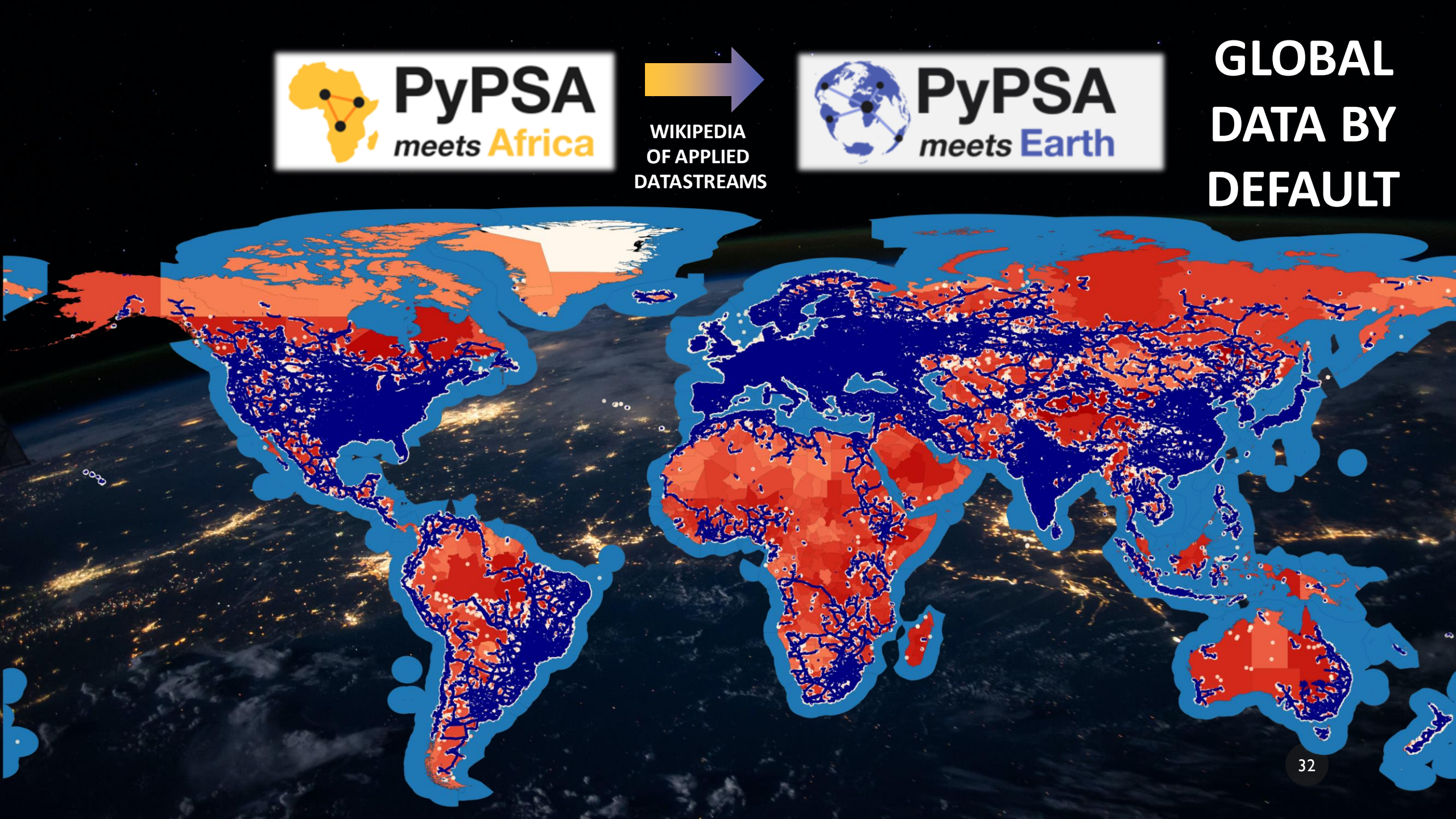




NETWORK





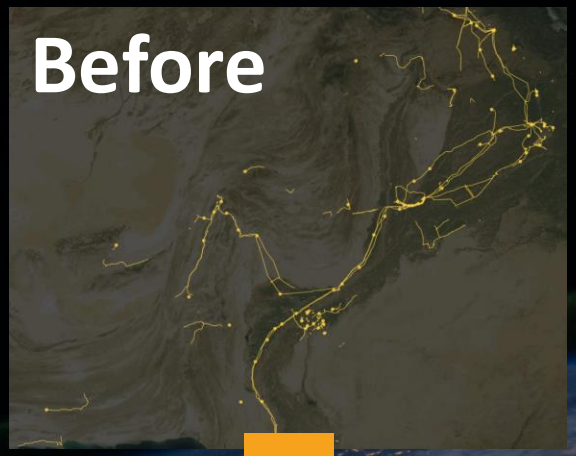

PyPSA
meets Africa
WIKIPEDIA
OF APPLIED
DATASTREAMS
PyPSA
meets Earth
GLOBAL
DATA BY
DEFAULT

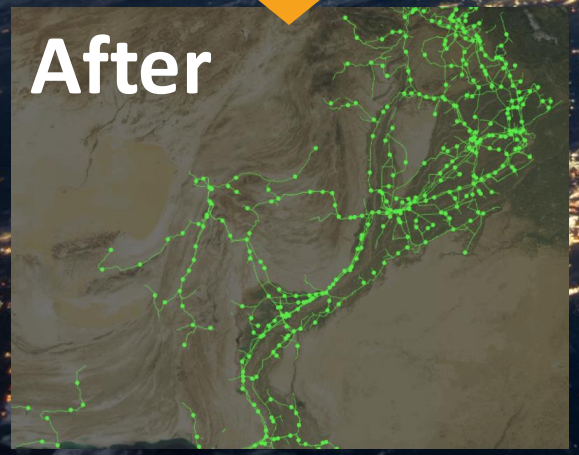
WHAT IF YOU ARE MISSING DATA?

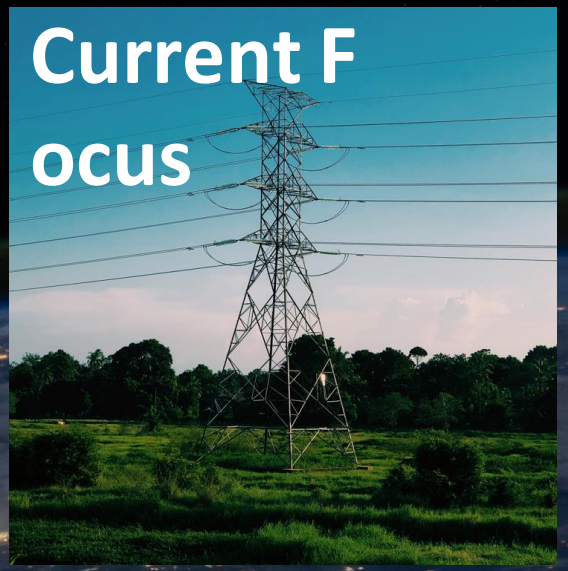
PyPSA meets Earth

I. INFRASTRUCTURE DETECTION

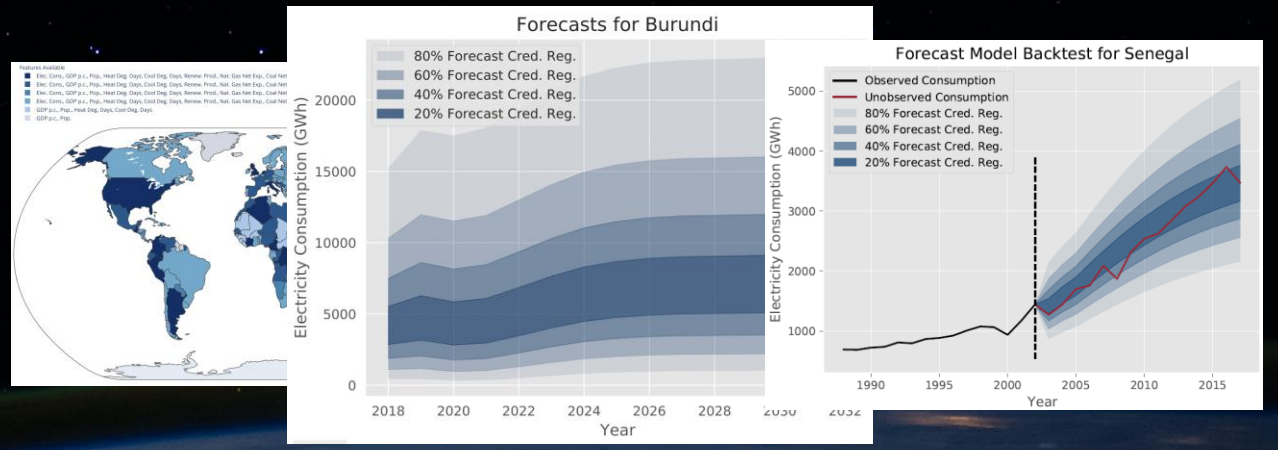
II. DEMAND PREDICTION


Before

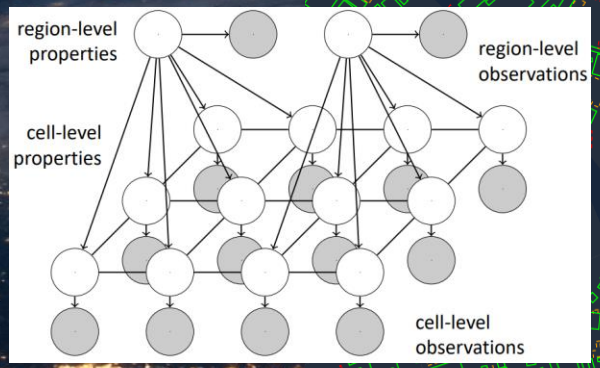

After


Current F
ocus

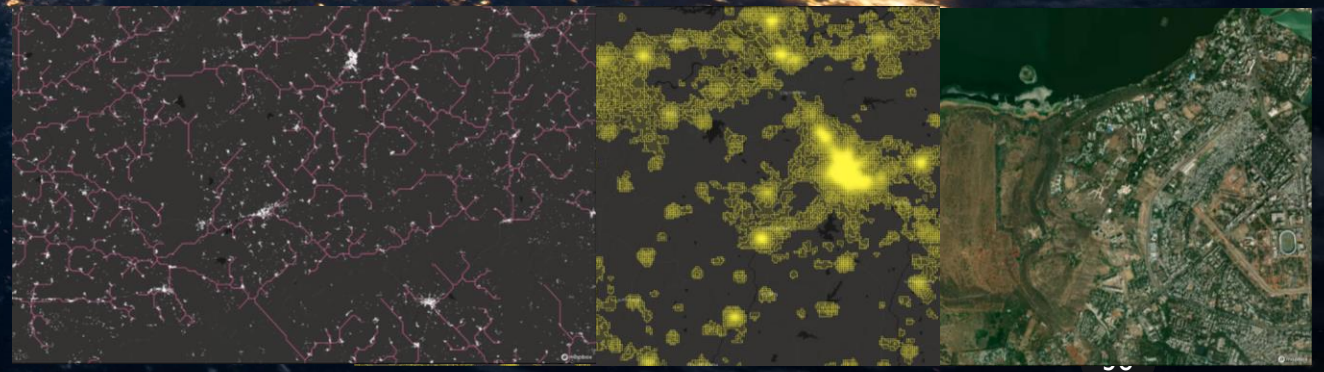
1. Country-Level Demand Forecasting via Bayesian Deep Learning and Others



2. Downscaling via Economics-Informed Probabilistic Models and Others

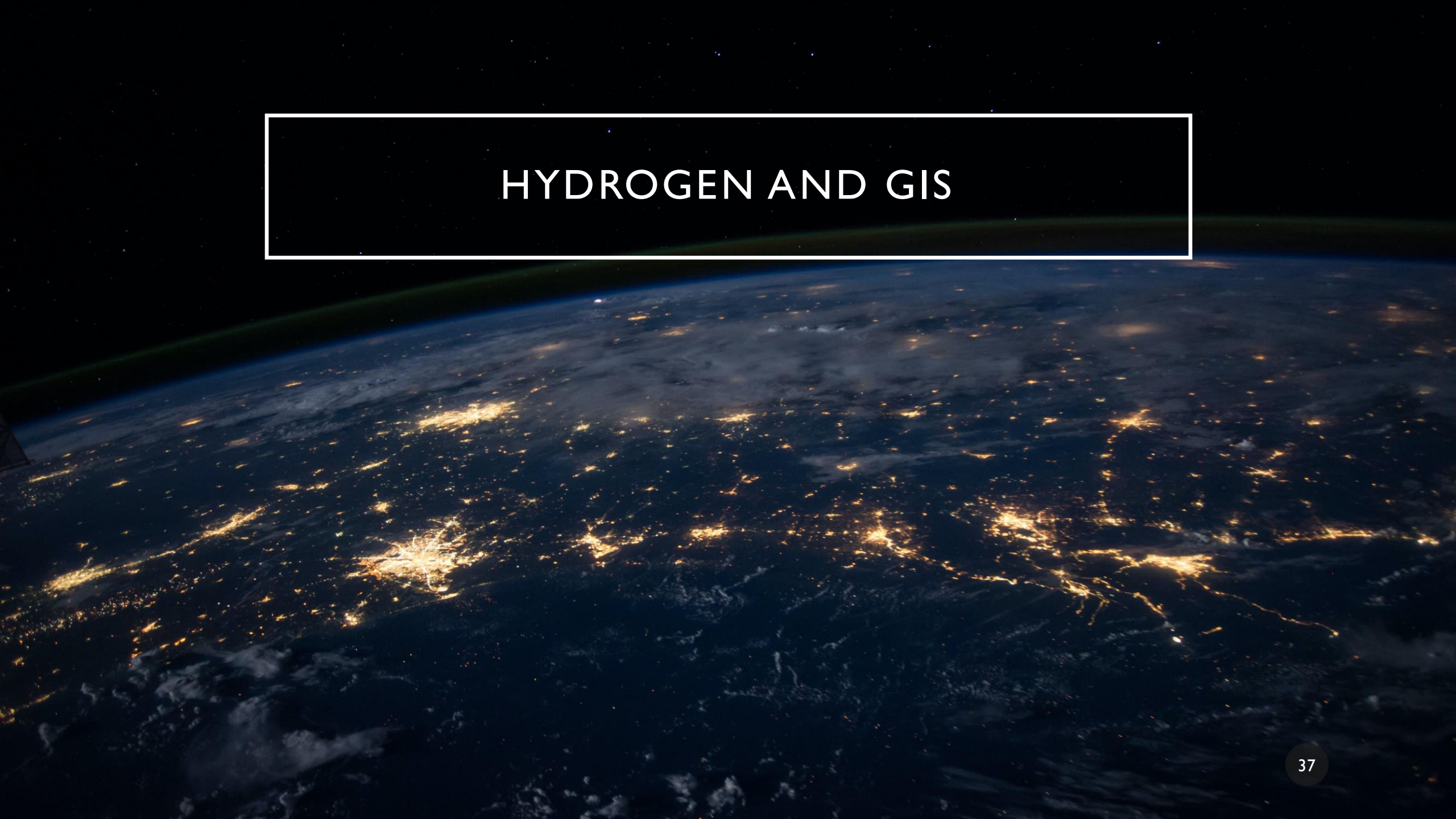


3. Building-Level Demand Forecasting via Bayesian Deep Learning and Others

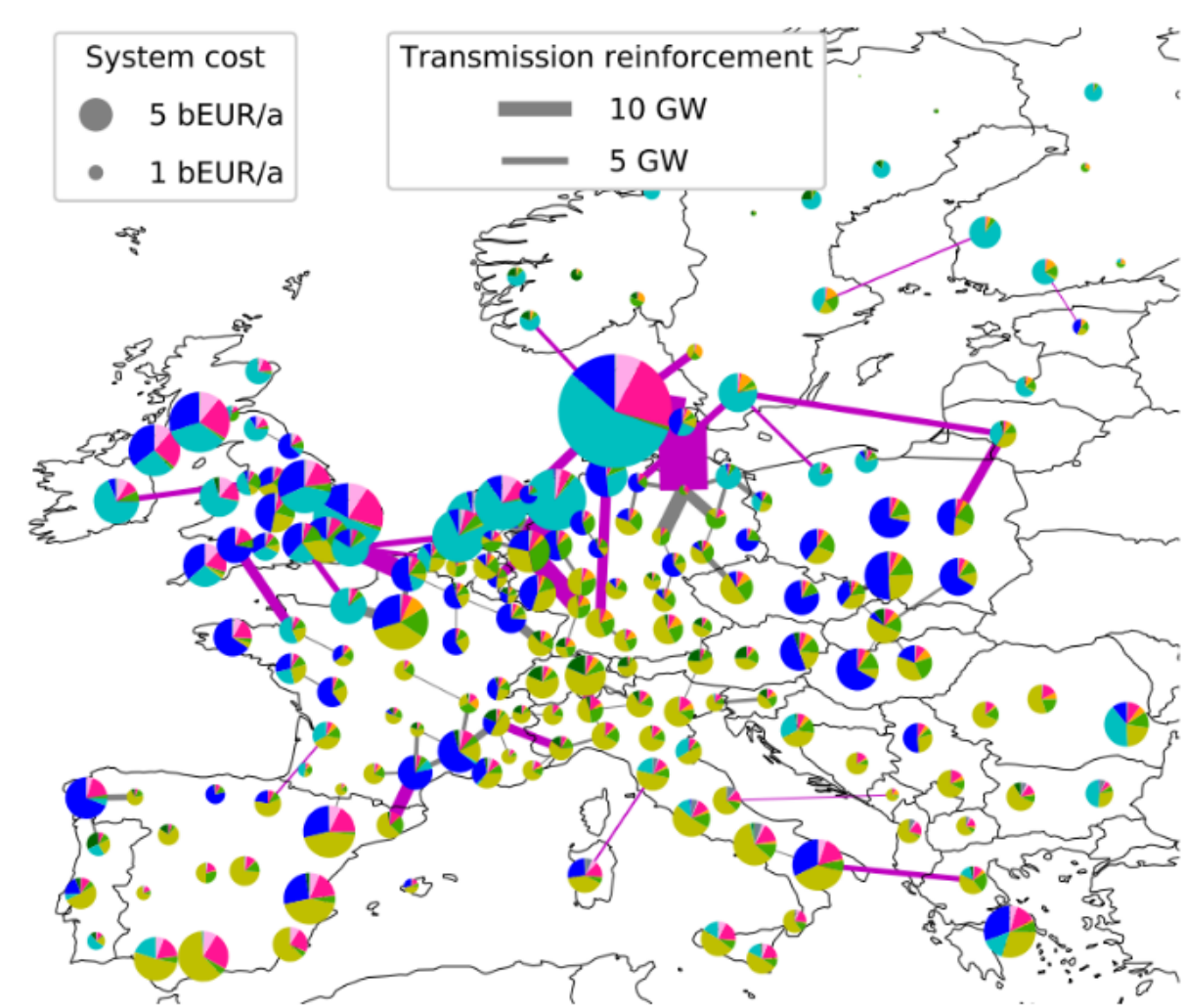


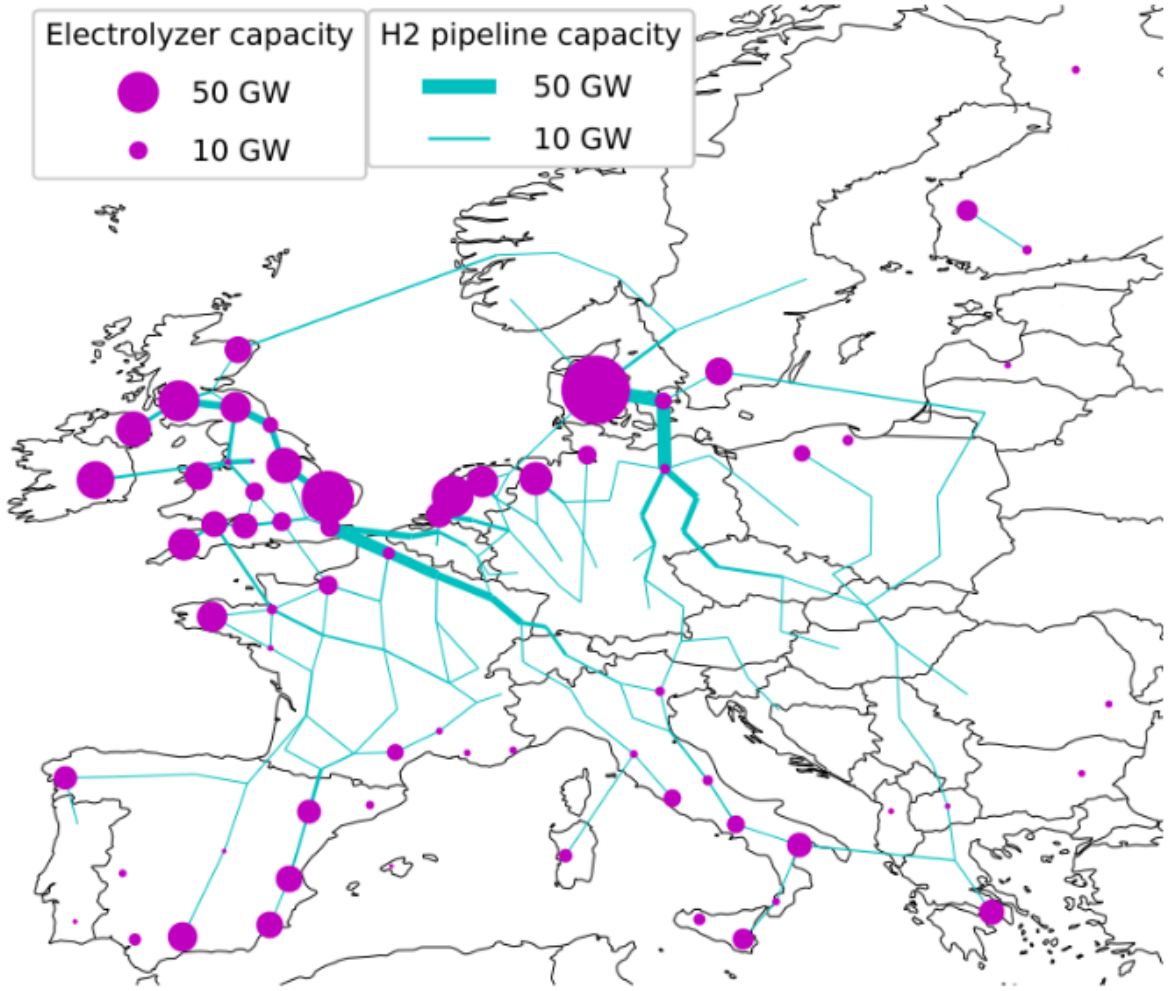
Sources: Lee et al., "How probabilistic electricity demand forecasts can expedite universal access to clean and reliable electricity," *Energy for Economic Growth*, 2021.; Lee et al., "Probabilistic forecasts of country-level electricity demand in Africa," 2022 (not yet public). – Soon to be open-sourced, 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



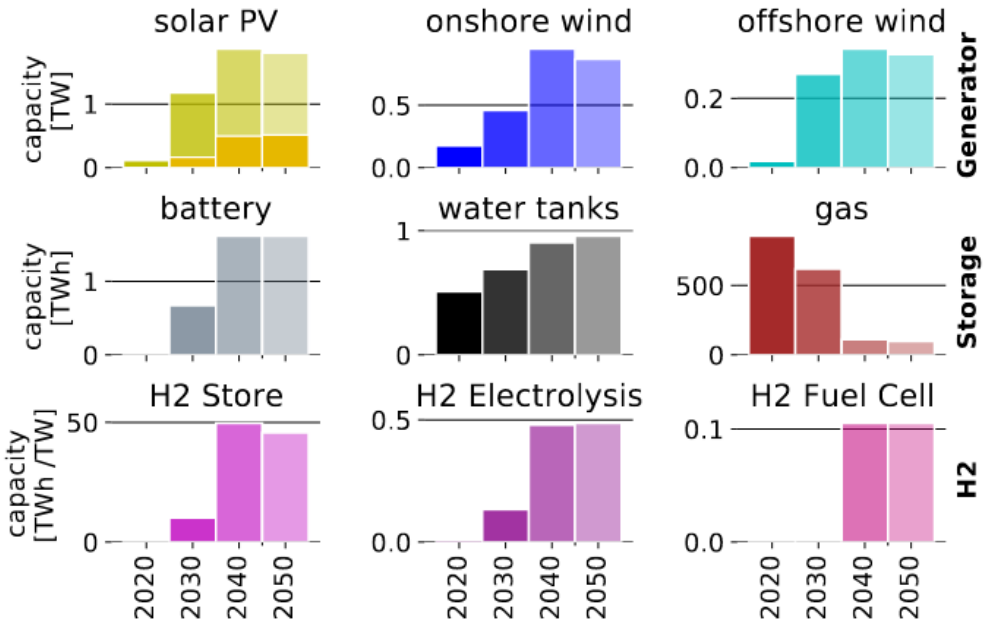
EXAMPLE OUTPUT:
INVESTMENTS FOR 2050 NET ZERO SCENARIOS

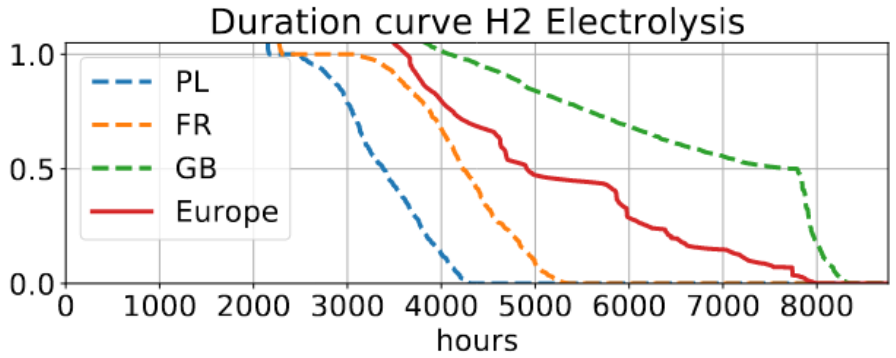


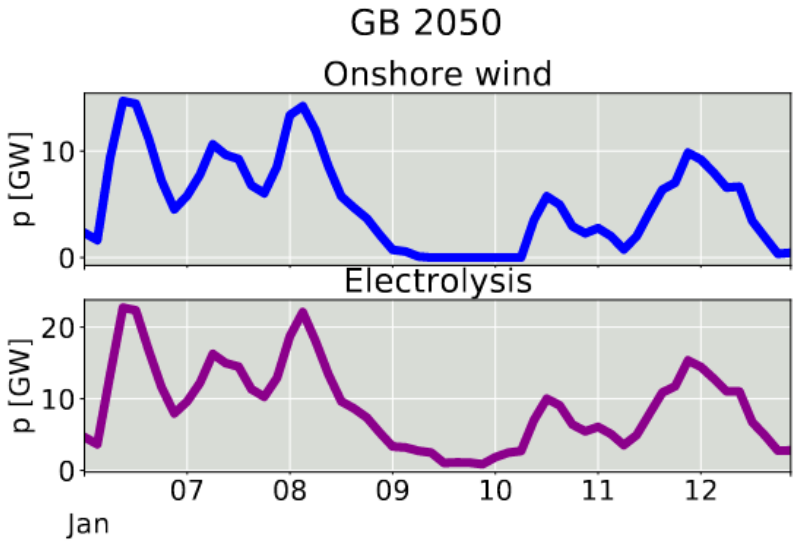


Fabian Neumann and Tom Brown. PyPSA: Free Sofware for Investment Planning in Sector-Coupled Energy Systems
https://www.neumann.fyi/files/pesgm2020.pdf

EXAMPLE OUTPUT:
INVESTMENTS + OPERATION FOR 2050 NET ZERO SCENARIOS



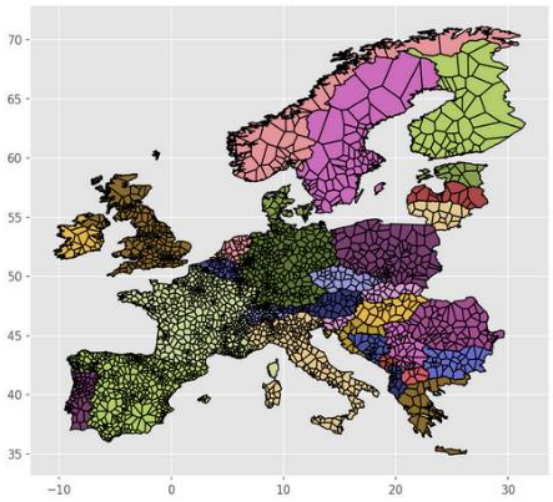




Elisabeth Zeyen, Prof. Marta Victoria, Dr. Tom Brown
https://www.pac-scenarios.eu/fileadmin/user_upload/KIT_Aarhus_University_PAC_scenarios_with_PyPSA-Eur-Sec_15oct20.pdf

EXAMPLE OUTPUT:
INVESTMENTS + OPERATION FOR 2050 NET ZERO SCENARIOS

Installable Potential and Land Eligibility



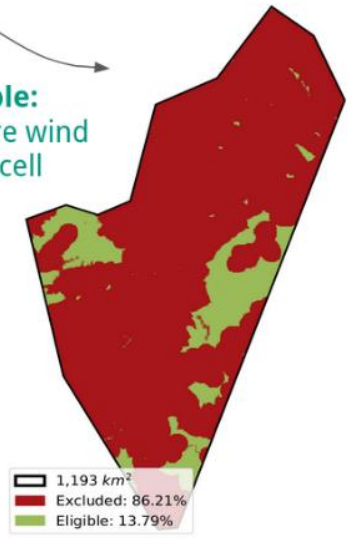
Geospatial Land Availability for Energy Systems (GLAES)

JÜLICH FORSCHUNGSZENTRUM

DOI 10.5281/zenodo.1122558

Severin Ryberg
github.com/FZJ-IEK3-VSA/glaes

example:
onshore wind
in one cell



- **CORINE 2018**
  land cover
  - eligible codes
  - distances
- **NATURA 2000** natural protection areas
- **GEBCO 2018**
  bathymetry dataset
- **Density**:
  capacity per km²

17

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

ATM Africa, North Asia, West-Asia PYPSA-EARTH (POWER)

OUTREACH

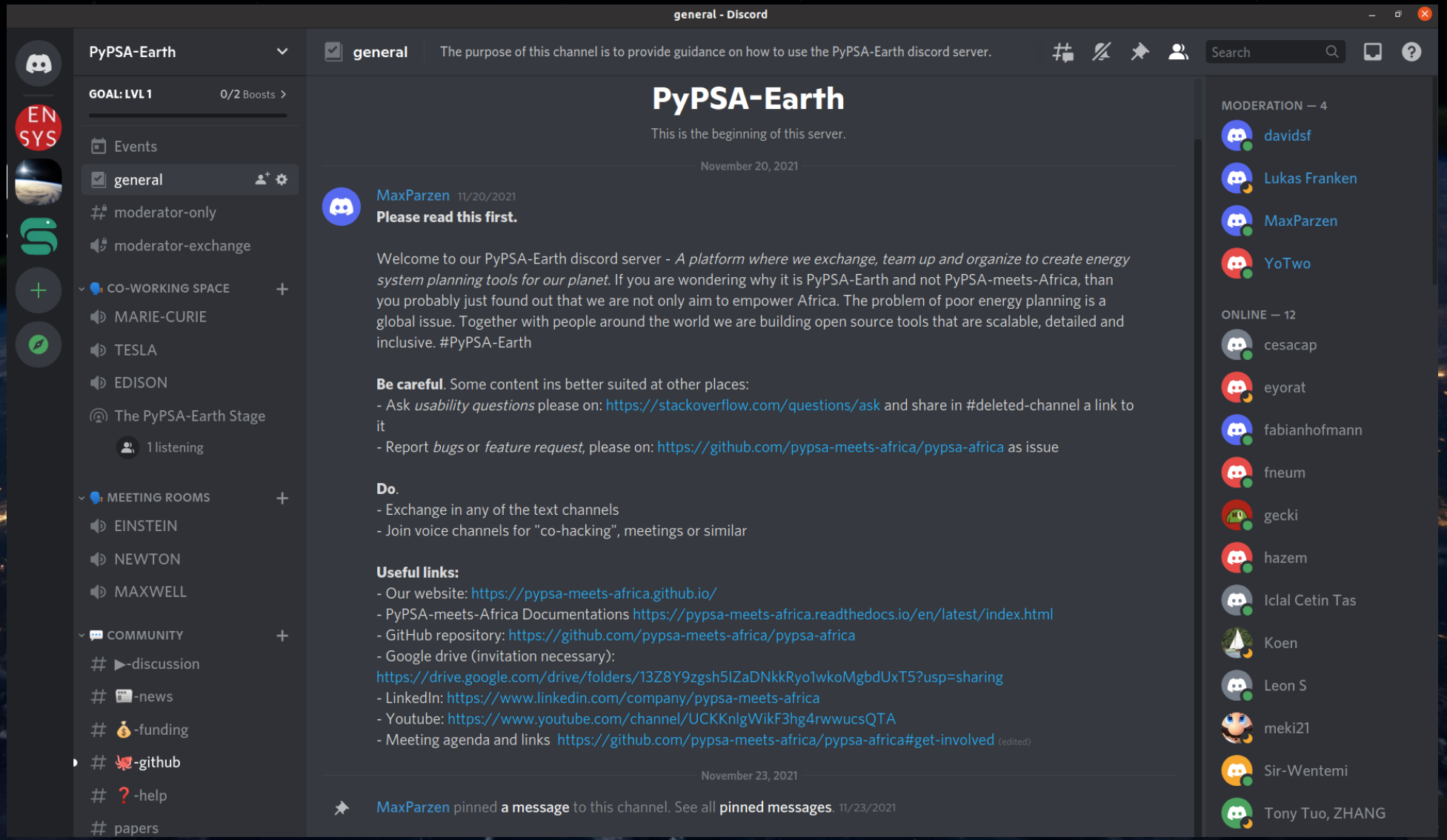
PYPSA-EARTH-SEC (SECTOR-COUPLED)

DEMAND PREDICTION

INFRASTRUCTURE DETECTION

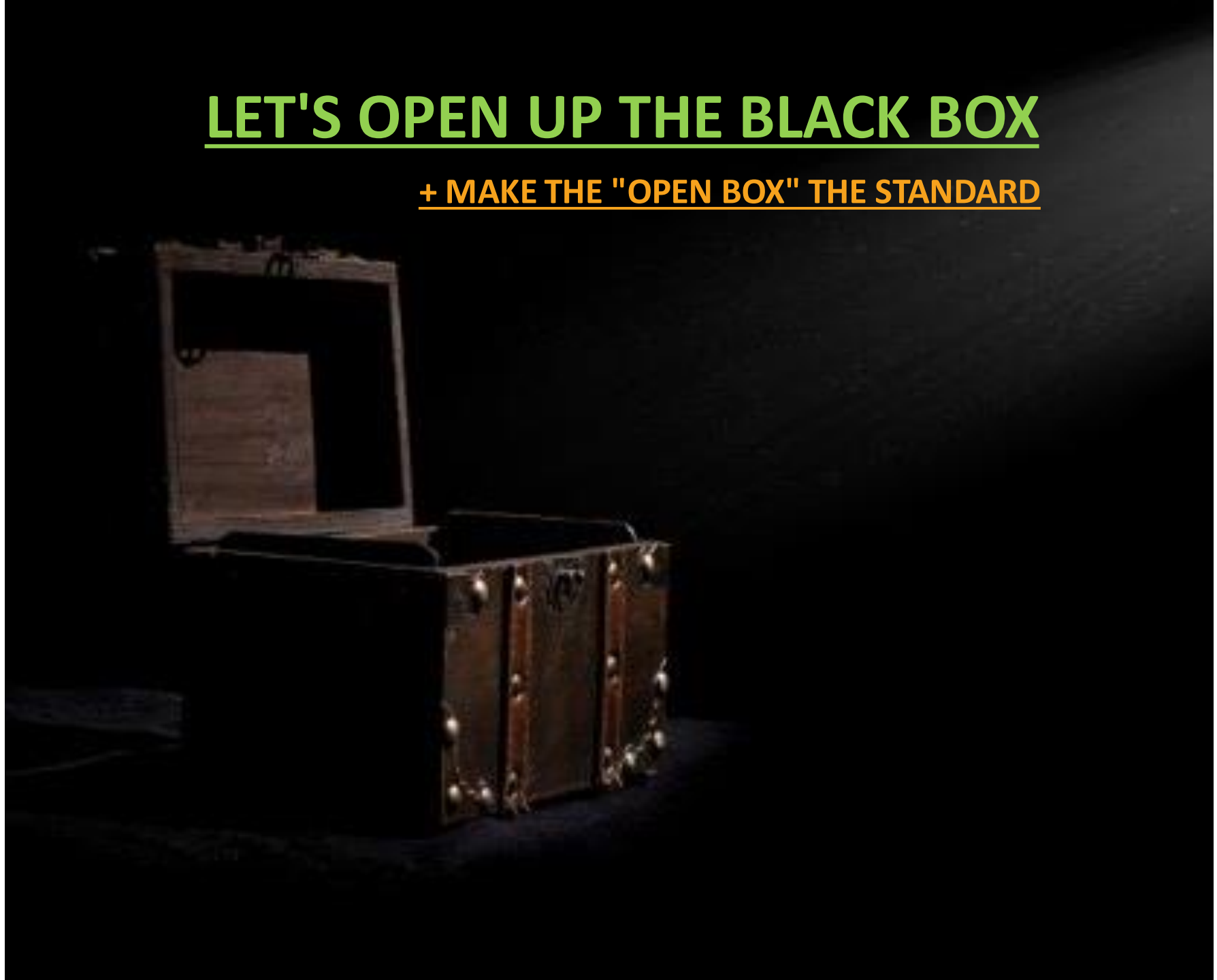
PYPSA-MINIGRID

Open Community!



LET'S OPEN UP THE BLACK BOX

+ MAKE THE "OPEN BOX" THE STANDARD



PyPSA meets Earth