Data Science for Energy System Modelling
Lecture 1: Organisation & Introduction

Dr.-Ing. Fabian Neumann

f.neumann@tu-berlin.de
Department of Digital Transformation in Energy Systems
Technical University of Berlin, Germany

Compiled on 2025/10/15 at 15:49:38

Hybrid Format Information: Zoom and Recordings

The recordings will be **publicly available** in this ISIS course and may also be published on YouTube or other platforms.

- The camera and microphone are directed **only at the lecturer**.
- Student contributions are **not recorded**.
  When interaction takes place, the recording will be **paused**.
- If you **voluntarily speak** while the recording is running, you **consent** to the recording and publication of your contribution.
- You may **withdraw** this consent at any time for the future; that part will then be deleted or edited.
- Participants who wish to remain anonymous may join under a **pseudonym** and/or use the **chat or Q&A** function instead of speaking.

Who is teaching?

Dr.-Ing. Fabian Neumann
f.neumann@tu-berlin.de
Department of 'Digital Transformation in Energy Systems', Institute of Energy Technology

- 2021: PhD in Computer Science, Karlsruhe Institute of Technology (KIT)
- 2017: MSc in Sustainable Energy Systems, University of Edinburgh, Scotland, UK
- 2016: BSc Industrial Engineering and Economics, KIT

Group: `https://www.tu.berlin/en/ensys` Personal website: `https://fneum.org/`

We are energy system modellers researching the most cost-effective pathways to reduce greenhouse gas emissions in the energy system with open-source software and open data.

Who are you?

Instructions

Go to

www.menti.com

Enter the code

1918 2923

Or use QR code

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Course Materials I – ISIS

You can find links to lecture notes, assignments, announcements, forums on ISIS:

https://isis.tu-berlin.de/course/view.php?id=44803

[WiSe 2025/26] Data Science for Energy System Modelling

Kurs Einstellungen Teilnehmer/innen Bewertungen Aktivitäten Mehr

Welcome to Data Science for Energy System Modelling

Alles einklappen

All the relevant materials and organisational details for the lectures, workshops, and assignments will be made available here during the semester.

Course Outline:
https://moseskonto.tu-berlin.de/moses/modultransfersystem/bolognamodule/beschreibung/anzeigen.html?nummer=31027&version=2&sprache=2

Course Schedule:
https://moseskonto.tu-berlin.de/moses/verzeichnis/veranstaltungen/veranstaltung.html?veranstaltung=313612

Register for Portfolio Examination:
https://moseskonto.tu-berlin.de/moses/modultransfersystem/modulpruefung/anmeldungwizard.html

It is strongly recommended to take this course *after or while* taking "Energy Systems".
Alternatively, "Energy Economics" covers some of the prerequisites. This is a recommendation, but no strict requirement.

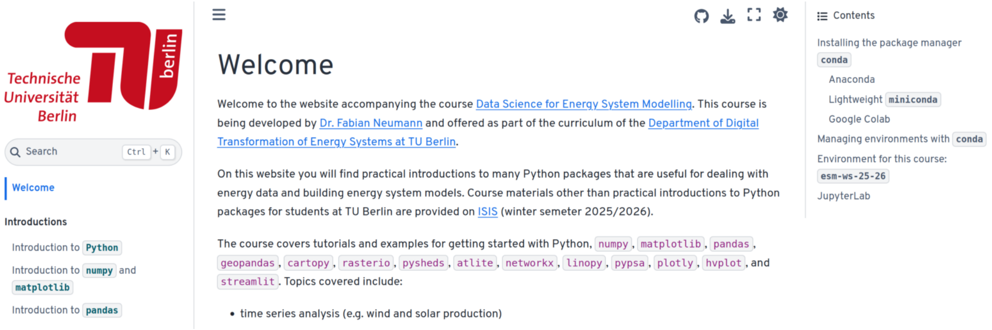
This **6 ECTS** course will take place in person in 4-hour blocks on Thursdays, starting on **16 October 2025**.

	Lecture	Workshop
Thursdays	16:15 - 17:45	18:15 - 19:45
Lecture Hall	H 0110	H 0110

Course Materials II – Website

The practical introductions to Python packages are hosted on another website:

https://fneum.github.io/data-science-for-esm



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Course Structure and Lectures

1. **Lectures:** introduction to new topics with content about methods, data, and analysis
2. **Workshops:** tutorials for Python libraries, exercises, consultation on assignments
3. **Assignments:** see info a few slides ahead →

Lectures

Day	Start	End	Location
Thursdays	16:15	17:45	H 0110 (hybrid)
Thursdays	18:15	19:45	H 0110 (hybrid)

First lecture today until 17:45; **no lectures** on 18 December 2025.

Zoom:
Meeting ID: 691 6630 2473
Passcode: 717343

Other courses on energy in our department

Course	Type	S	ECTS	Lecturers
Energy Systems	IV	SS	6	Brown
Energy Economics	IV	WS	6	Brown
New Developments in Energy Markets	Seminar	WS	3	Brown, Erdmann, Grübel
New Research in Energy System Modelling	Seminar	SS	3	Brown, Luderer
Data Science for Energy System Modelling	IV	WS/SS(?)	6	Neumann

Course 'Energy Economics'

6 ECTS course started Tuesday 14 October at 14:00, led by Prof. Dr. Tom Brown.

- learn about functioning of international energy markets for fossil fuels and CO_2
- discussion of last year's energy crisis and other recent developments
- electricity markets including rising generation from renewable energy sources
- market designs to deal with increasing power grid congestion
- study various renewables support mechanisms
- energy trading: futures, options, hedging, risk management, PPAs
- finance: cost accounting and capital budgeting for developing wind and solar parks

ISIS course link: `https://isis.tu-berlin.de/course/view.php?id=44801`

Seminar 'New Developments in Energy Markets' $\rightarrow$ today

Optional 3 ECTS seminar

- analyse a current topic in energy markets, prepare a presentation and present it
- Presentations as a block at the end of the lecture-free period
- Supervision by Profs. Erdmann & Grübel and employees of the department
- Students work on topic with a supervisor during semester (2-3 meetings)
- Topics will be presented in November 2025, presentations in March 2026
- **Example topics:** market reform, EEG, European Green Deal, e-mobility, hydrogen economy, industrial decarbonisation, flexibility markets, etc.

Registration

We recommend that you have taken or are taking *Energy Systems* or *Energy Economics*.

This course is limited to **70 participants**. Need to register **via MTS until 20 October**:

https://moseskonto.tu-berlin.de/moses/modultransfersystem/modulpruefung/meineanmeldungen.html

Random selection from people who registered. No waiting list. Guaranteed participation for students who previously failed. Outcome announced in on Tuesday, 21 October.

If limit is not reached, registration period can be extended until slots are filled.

As **Freie Wahl / Zusatzmodul** for any degree or as **Wahlpflichtmodul** in these degrees:

- Energie- und Verfahrenstechnik / SEPE (Master of Science)
- Process Energy and Environmental Systems Engineering (Master of Science)
- Regenerative Energiesysteme (Master of Science)

Examination

This **6 ECTS** course can be completed by passing a **portfolio examination** consisting of

- 3 individual assignments (25% each)
- 1 group assignment (25%)

There is **no final exam**! But requires **continuous work** during the semester!

After the first assignment, **withdrawal** only possible with proven cause.

Assignment	Rough Topic	Tentative Due Date
Assignment 1	renewable potentials	Monday, 17 November 2025, midnight
Assignment 2	storage and networks	Monday, 8 December 2025, midnight
Assignment 3	electricity markets	Monday, 12 January 2026, midnight
Group Assignment	system planning	Monday, 12 February 2026, midnight

Rules for assignments

Individual Assignments:

- Published $\approx$ 3 weeks before deadline
- Individual submissions, including code
- Can discuss assignments with others
- But submissions must be your own work
- Code plagiarism detection $\rightarrow$ fail
- Submission and grading through ISIS

Group Assignment:

- Renewable electricity system planning
- Choose a country of your choice
- Group strength $\approx$ 4 students
- Support for finding a group via ISIS
- Presentation in last week of semester
- Uniform grade per group
- Submission and grading through ISIS

Submissions require **Two-Factor Authentication (2FA)**! Use mock assignment to test.

Course outline (from module description)

- time series analysis of wind and solar generation and energy demands
- renewable energy potentials – wind, water, solar
- daily and seasonal energy storage
- power flows and transmission networks
- electricity market designs with renewable electricity
- system planning (renewables, energy storage, transmission infrastructure)
- sector-coupling and demand-side management
- interactive visualisation tools

Source: https://moseskonto.tu-berlin.de/moses/modultransfersystem/bolognamodule/beschreibung/anzeigen.html?nummer=31027&version=1&sprache=2

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Course Schedule

Week	Thursday - Slot 1	Thursday - Slot 2
1	L: Intro & Motivation	–
2	L: Time Series Analysis	W: Introduction to Python and Installation
3	W: Intro to `numpy` and `matplotlib`	W: Intro to `pandas`
4	L: Wind and Solar Potentials	W: Intro to `geopandas` and `cartopy`
5	W: Intro to `atlite` and `rasterio`	Consultation for Assignment 1
6	L: Storage and Hydroelectricity	L: Networks
7	L: Optimization in Electricity Markets	W: Introduction to `linopy`
8	Intro to `networkx` / `pysheds`	Consultation for Assignment 2
9	W: Electricity Markets in `pypsa`	L: Capacity Expansion Planning
10	–	–
11	W: Capacity Expansion Planning in `pypsa`	Consultation for Assignment 3
12	L: Sector-coupled Energy Systems	W: Sector-coupled Energy Systems in `pypsa`
13	*open topic / backup*	Consultation for Group Assignment
14	L: Uncertainty and Sensitivity Analysis	Consultation for Group Assignment
15	W: Interactive Visualization Tools	Consultation for Group Assignment
16	Presentation of Group Assignments	Presentation of Group Assignments

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Learning outcomes (from module description)

- **undertake** evaluation of geographical and socio-economic renewable energy potentials
- **explain** the challenges when integrating renewable energy in energy systems
- **critically appraise** different concepts for the integration of renewable energy
- **perform** analysis based on energy system optimization models and interpret solutions
- **process** public datasets to retrieve geographical, meteorological and energy systems data
- **program** energy system models with widely-used open-source tools and public data

Source: https://moseskonto.tu-berlin.de/moses/modultransfersystem/bolognamodule/beschreibung/anzeigen.html?nummer=31027&version=1&sprache=2

What do you want to learn from this course?

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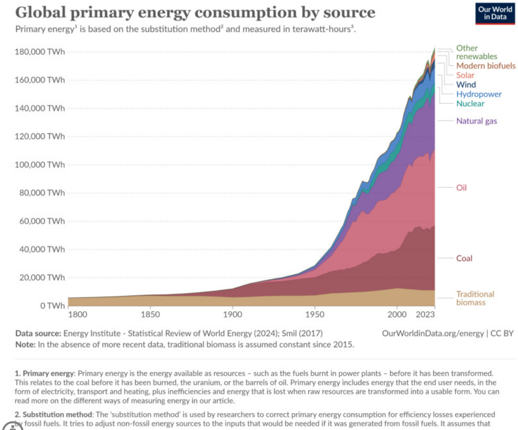
Invitation

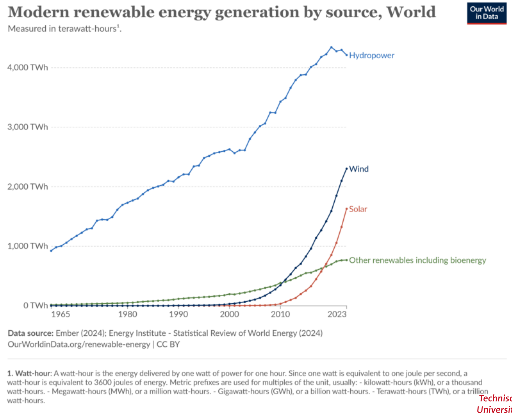
Why it is a useful skill to be able to process data in the energy sphere.

Probably we don't need to talk about it . . . but here's a recap:

Hard to overstate the historic worldwide rise of (fossil) energy consumption. . .

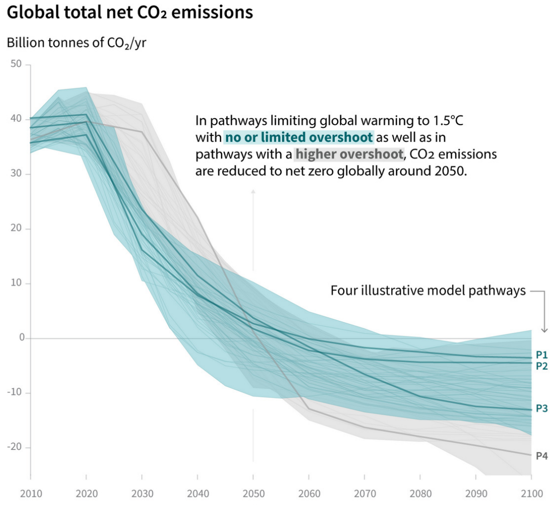
. . . but, on the upside, supply by carbon-free and renewable energy sources is catching up!





Source: https://ourworldindata.org/energy-key-charts

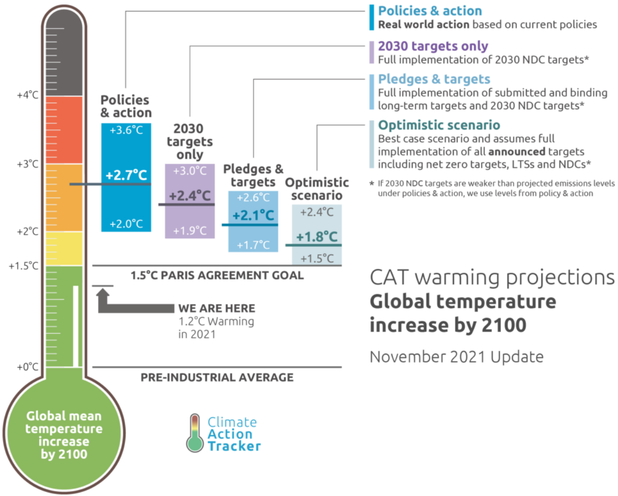
To avert the catastrophic consequences of climate change. . .



- **net-zero** greenhouse gas emissions to be achieved by **mid-century** (2050)
- **left:** scenarios for global CO_2 emissions that limit warming to 1.5°C about industrial levels (**Paris agreement**)

Source: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SPM3a.png

Keeping a tap on actions to achieve net-zero GHG emissions. . .



- governments across the world have made **pledges** to reach Paris agreement goals
- but to date, **policies lack behind pledges**
- **big question:** how do we achieve the goals we set?

Source: https://climateactiontracker.org/global/cat-thermometer/, GHG = Greenhouse Gases, NDCs = Nationally Determined Contributions, LTS = Long-Term Strategies

How can **energy system modelling** help?

- **Energy system modelling** is about the design and operation of energy systems.
- This is complex as it involves **many interacting parts**:
  - renewables differ in space and time
  - transmission grids may constrain the cost-effective integration of renewables
  - new concepts like storage and demand-side management
- **Need a lot of data** to model the system.
- Need to apply tools and methods from **data science** to digest this data.

Today – Current Energy Systems

- ensure stable/reliable system operation
- study impacts of price shocks
- study impacts of policy changes

Tomorrow – Future Energy Systems

- transition to sustainable energy system
- infrastructure for renewables integration
- system operation with many renewables
- trial new market designs in simulations

What data do you think we need to model energy systems?

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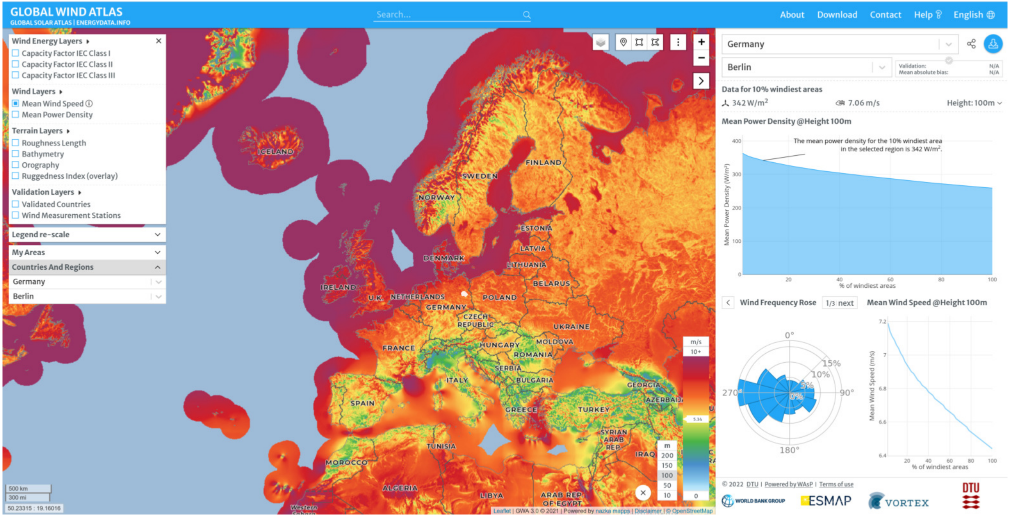
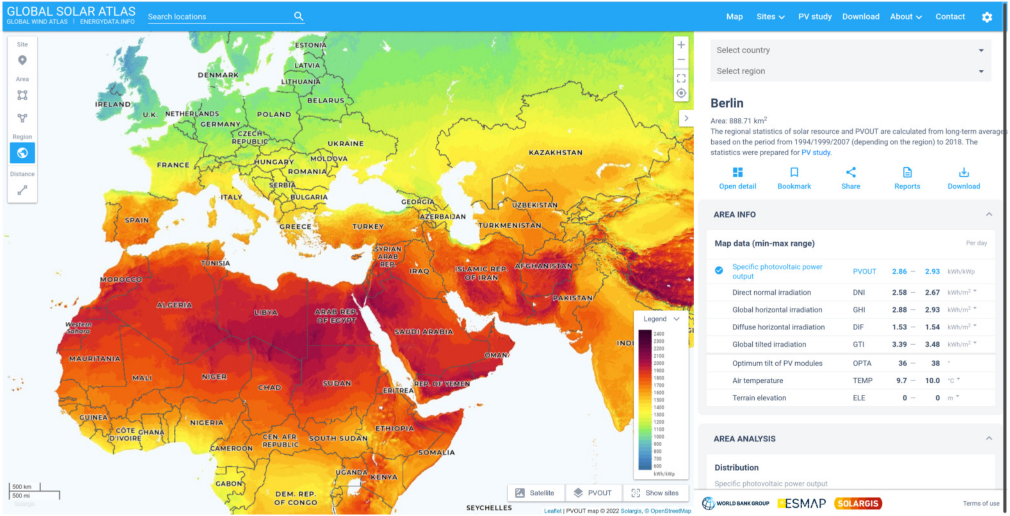
Renewable Potentials

Where does the wind blow?



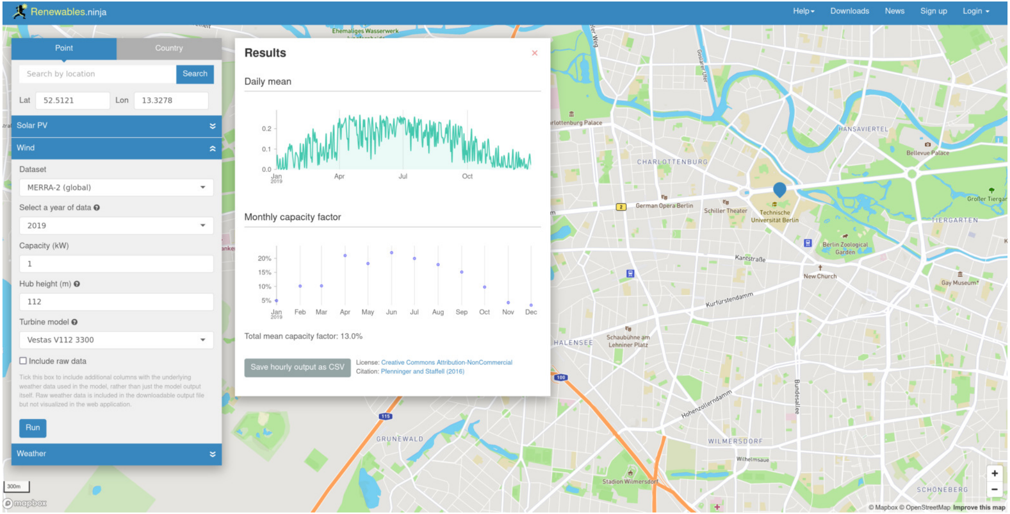
Source: https://globalwindatlas.info/en/area/Germany/Berlin

Where does the sun shine?



Source: https://globalsolaratlas.info/map?c=32.731841,31.816406,4&r=DEU:DEU.3_1

How much wind and solar electricity? When? Where?



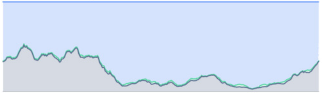
Source: https://www.renewables.ninja

How much wind generation right now?

GB Renewables Map

About & FAQ

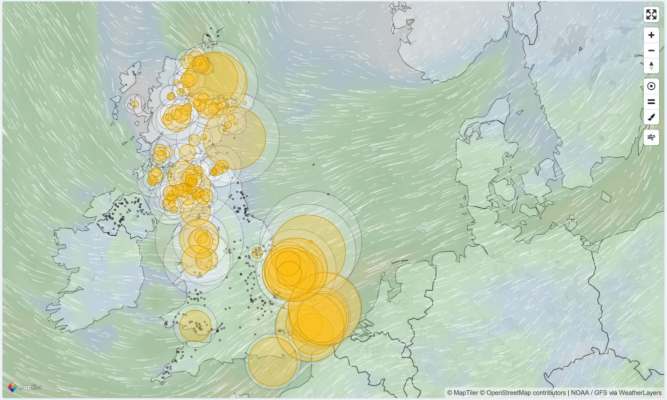
An energy experiment by Robin Hawkes

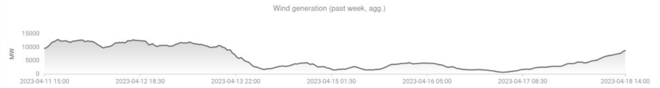


18/04/2023 12:15 | Now

Select a wind farm

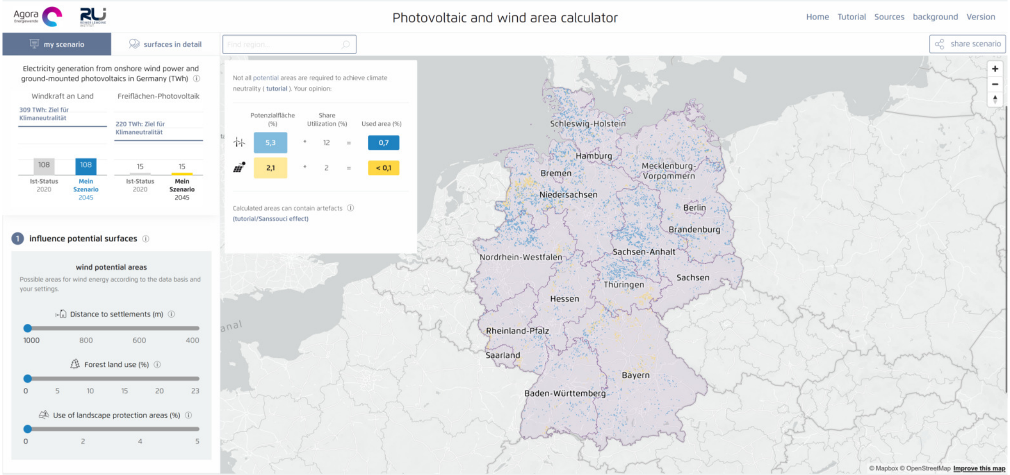
WIND FARM	GEN. (MW)	CAP. (MW)
Hornsea One Offshore Wind Farm	723	1218
East Anglia ONE	680	714
London Array	604	630
Moray East Offshore Wind Farm	521	950
Triton Knoll Wind Farm	513	857
Seagreen Wind Farm	499	1075
Greater Gabbard wind farm	451	504
Race Bank Wind Farm	383	573
Beatrice Wind Farm	339	588
Dudgeon Offshore Wind Farm	317	402
Galloper Offshore Wind Farm	302	353
Rampion Wind Farm	296	400
Sheringham Shoal Offshore Wind Farm	214	317
Thanet Wind Farm	208	300
Walney Wind Farm	187	1026.2





Source: https://renewables-map.robinhawkes.com

Where to put all those wind turbines? – Agora EW's Online Calculator



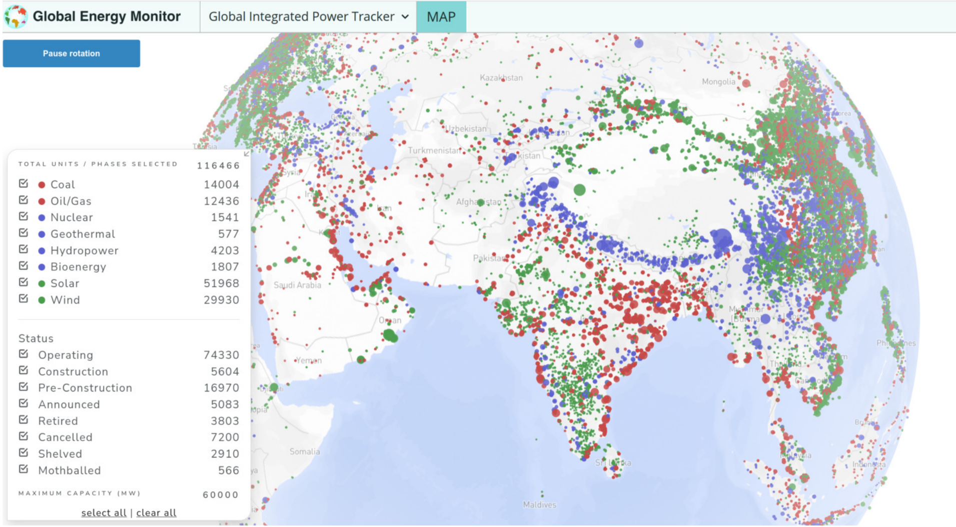
Source: https://www.agora-energiewende.de/service/pv-und-windflaechenrechner/#

Example Topics

- What are the **characteristic time and regional patterns** of wind, water, solar variability in different regions of the world?
- Which **land area** might be available to develop new wind and solar parks? What most limits land availability?
- What is the **cost difference** between building a wind turbine in Brandenburg vs Bavaria vs Patagonia?

Power Plants and Transmission Infrastructure

What are the capacities and locations of existing power plants?



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

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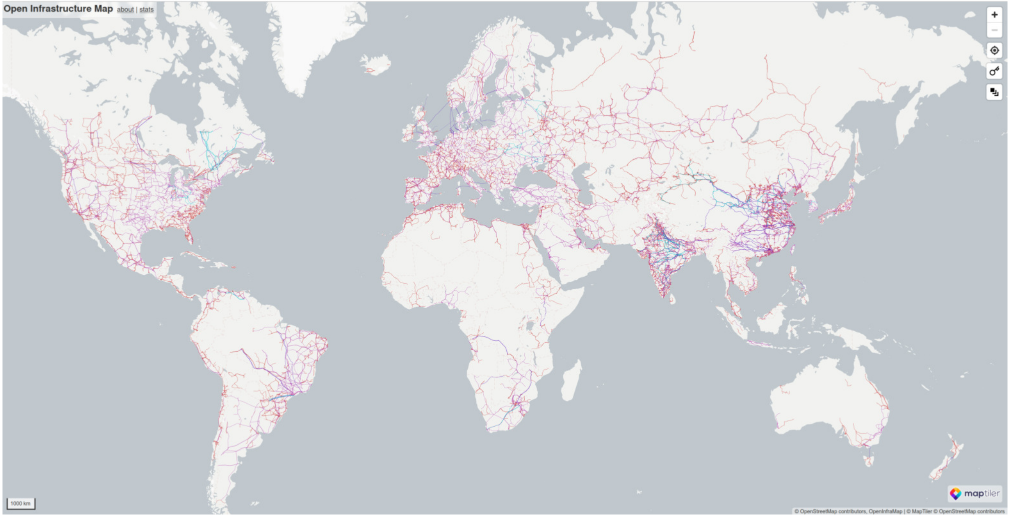
What infrastructure to transport **electricity**? OpenStreetMap data!



Source: `https://openinframap.org/#2/20.93/24.36/P`

Example Topics

- What **kinds of power plants** dominate in different countries?
- What is the **age structure** of the existing power plants? When might they retire?
- Where are capacities for LNG import terminals located across the world?
- How **calculate power flows** and identify frequently **overloaded transmission lines**?

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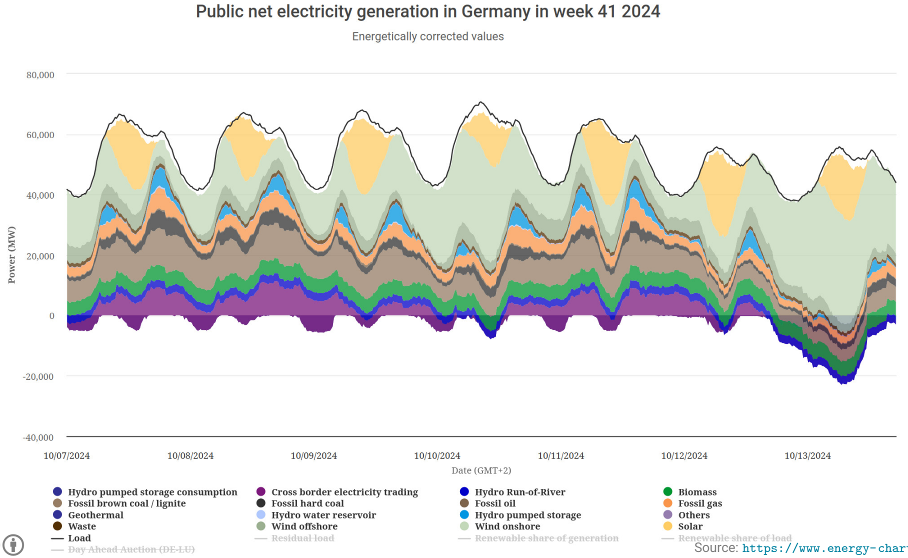
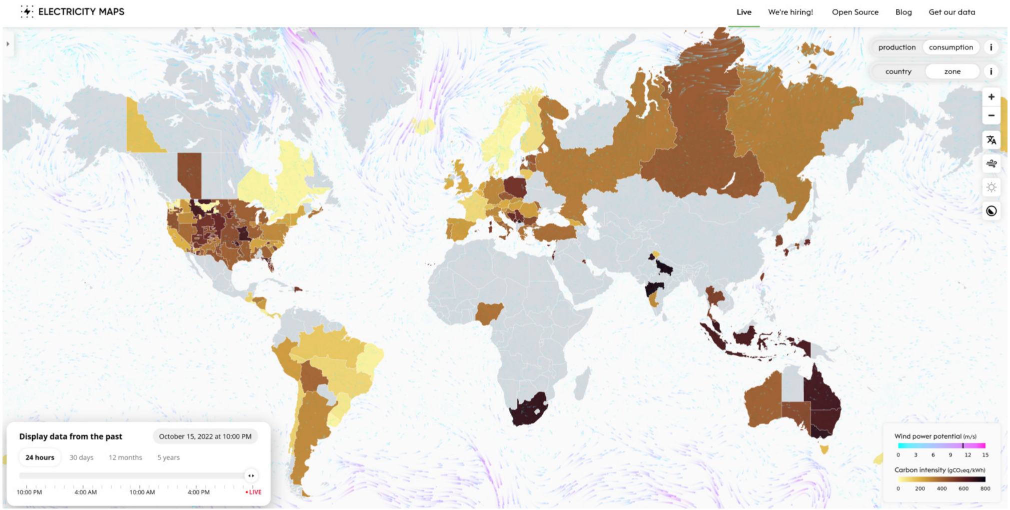
Electricity Markets

Germany's electricity production in various weather conditions:



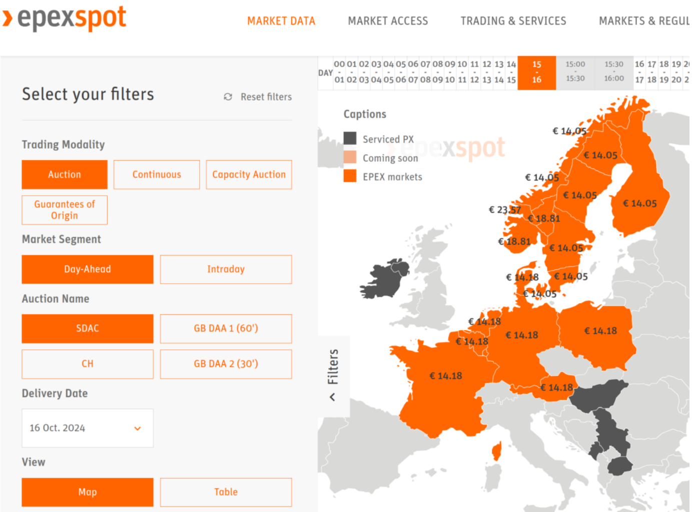
Source: https://www.energy-charts.info

How clean is the electricity we consume?



Source: https://app.electricitymaps.com/map?aggregated=false&wind=true&solar=false

What electricity prices do we observe on the wholesale market?



Source: https://www.epexspot.com/en/market-data

Example Topics

- Can we **reproduce historical market outcomes** with publicly available data?
- How are electricity market **prices and emissions** affected by
  - rising CO_2 prices?
  - rising natural gas prices?
  - effect of phase-outs of coal and/or nuclear power plants in Germany?
  - the unavailability nuclear power plants in France, or hydroelectricity due to droughts?
  - how would storage and demand-side management affect the market?
- How can **network bottlenecks** be reflected more accurately in electricity markets?

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Exploration Task (10 minutes)

Get together with your neighbours and pick one of the following exploration tasks:

A - Existing Infrastructure

Find the
- transmission line (> 200 kV)
- power plant (wind & fossil)

closest to your
- current home
- last holiday location.

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

B - Market Observations

Find
- a recent week each with low and wind and solar production in Germany. Compare electricity prices.
- a recent hour where prices were (a) identical and (b) diverging for many bidding zones.

Sources:
- https://energy-charts.info
- https://www.epexspot.com/en/market-data

C - Wind & Solar Resources

Find a region each with
- high wind, low solar resource
- low wind, high solar resource
- low wind and solar resource
- high wind and solar resource

Sources:
- https://globalsolaratlas.info
- https://globalwindatlas.info

You'll need one device (preferably a laptop) in each group.

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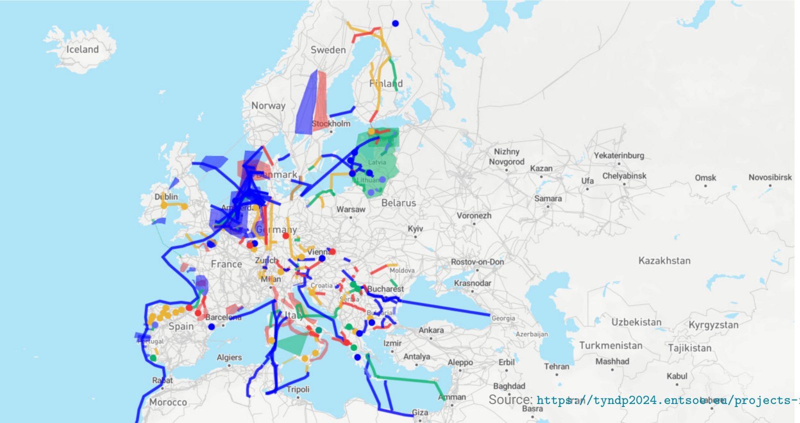
System Planning

How do Transmission Network Operators plan to reinforce the grid?

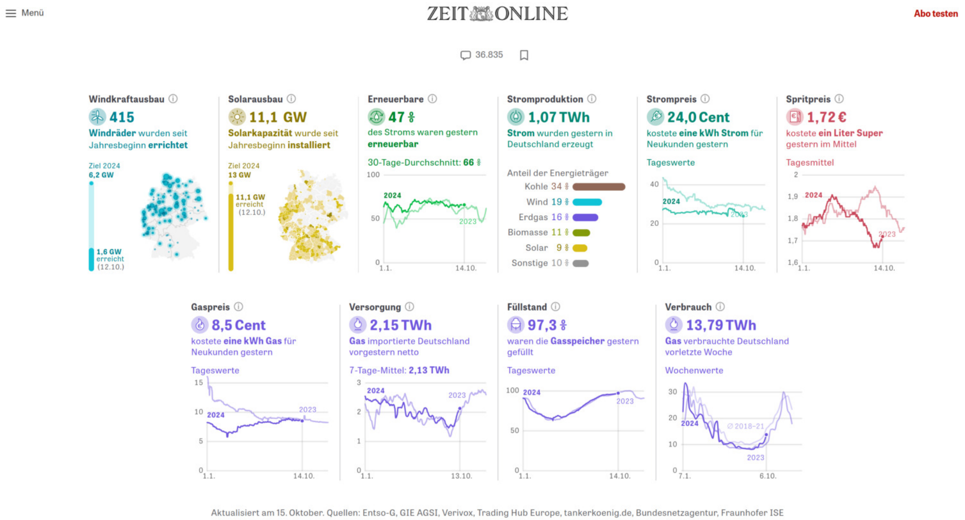
TYNDP 2024 Projects Sheets

The TYNDP 2024 will assess how 176 transmission and 33 storage projects respond to the TYNDP scenarios. Learn more about the projects by clicking on their location on the map below or filter projects by country, type of infrastructure or status. More information about the projects will become available with the release of TYNDP 2024 for public consultation at the end of 2024.



Source: https://tyndp2024.entsoe.eu/projects-map

Data Journalism: Zeit ‘Energiemonitor’ (Energy Monitor)



Source: `https://www.zeit.de/wirtschaft/energiemonitor-strompreis-gaspreis-erneuerbare-energien-ausbau`

Are we on track to meet reach climate-neutrality by mid-century?

Renewable electricity | Search | Source Code 0.10.0 7 4

Germany
- Renewable electricity
  - Solar PV
  - Wind energy
    - Onshore
      - Land use
    - Offshore
  - Shares in the power sector
- Renewable heat
- Electric mobility
- Hydrogen
- Energy consumption
- Current natural gas consumption
- Greenhouse gas emissions
- Energy prices

Deep dives
- Photovoltaics
- Wind energy

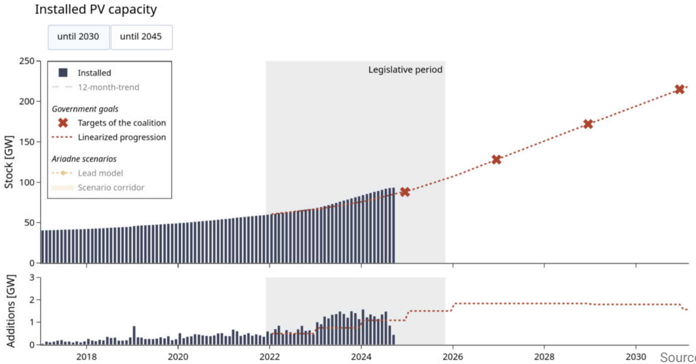
Data

Solar PV

Back to top

Additional information can be found in the background on photovoltaics.

For solar PV, the government coalition has specified a capacity expansion target of 215 GW by 2030 in Renewable Energy Sources Act (EEG).



Source: https://openenergytracker.org/en/docs/germany/renewables/

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Cost-effective ways to achieve to a net-zero electricity system?

Build your own zero-emission electricity supply

Introduction

This tool calculates the cost of meeting a constant electricity demand from a combination of wind power, solar power and storage for different regions of the world.

First choose your location to determine the weather data for the wind and solar generation. Then choose your cost and technology assumptions to find the solution with least cost. Storage options are batteries and hydrogen from electrolysis of water.

Fun things to try out:

- remove technologies with the checkboxes, e.g. hydrogen gas storage or wind, and see system costs rise
- set solar or battery costs very low, to simulate breakthroughs in manufacturing

See also this Twitter thread for an overview of the model's features and capabilities.

This is a **toy model** with a **strongly simplified** setup. Please read the warnings below.

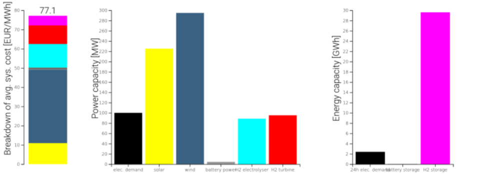
Step 1: Select location and weather year

- Select country
- Select state or province (for Australia, China, Germany, India, Russia and United States)
- Select point, rectangle or polygon, using the toolbox that appears at top-right

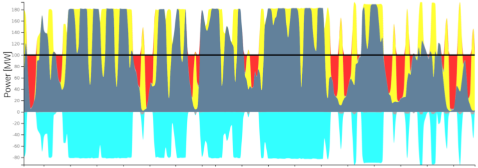
Average system cost [EUR/MWh]: 77.1

Cost is per unit of energy delivered in 2015 euros. For comparison, household electricity rates (including taxes and grid charges) averaged 211 EUR/MWh in the European Union in 2018 & 132 USD/MWh in the United States in 2019

Average marginal price of hydrogen [EUR/MWh LHV]: 78.8, [EUR/kg]: 2.60



Dispatch over a year to meet the constant demand (electricity demand is the black line; you can zoom and pan to see the details; negative values correspond to storage consuming electricity):



Source: `https://model.energy/`

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Example Topics

- What is the **optimal ratio** between wind and solar to match demand?
- What tools do we have to cost-effectively **manage the variability** of wind and solar? Storage? Transmission? Demand-side management? Sector-coupling?
- How can **coupling to other sectors** (e.g. buildings and transport) aid renewables integration? Flexible demands of electric vehicles, heat pumps, hydrogen production.

Methods & Tools

What tools? – Outlook to workshop sessions!

- **Many data sources**, which need cleaning, harmonisation & processing before they can be used
- Many software packages available that **help us handle large datasets**
- **Example functionalities** include time series analysis, processing geographical data (GIS), network analysis, building optimisation models, visualising data, modelling energy systems
- all packages in the course are **open-source**, some of which we develop in our department →

Source: see respective documentations of packages, GIS = Geographic Information System

PyPSA: Python for Power System Analysis

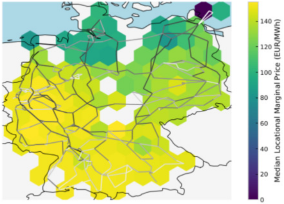
pypi v0.20.0 | conda-forge v0.20.0 | CI failing | CI with conda passing | codecov 70% | docs passing | license MIT

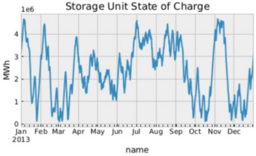
DOI 10.5281/zenodo.3946412 | chat on gitter | pre-commit.ci failure | code style black

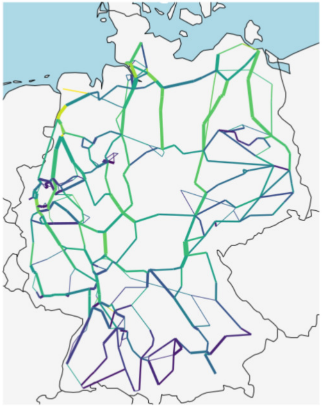
Open-source tool for modelling energy systems at high resolution.

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

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







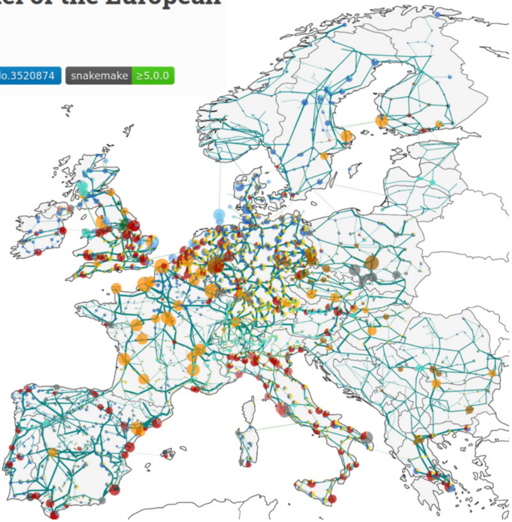
Source: https://github.com/pypsa/pypsa

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

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

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

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



Source: https://github.com/pypsa/pypsa-eur

Atlite: Convert weather data to energy systems data

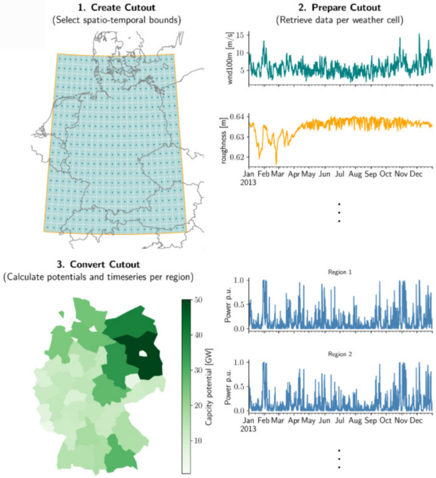
pypi v0.2.9 | conda-forge v0.2.9 | CI passing | codecov 72% | docs passing | license GPLv3 | REUSE compliant

JOSS 10.21105/joss.03294

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

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

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



Source: https://github.com/pypsa/atlite

Next week, slot 2: Introduction to Python and Installation

What you can do to **prepare:**

1. Read the welcome page of the course website:
   `https://fneum.github.io/data-science-for-esm/intro.html`
2. Follow instructions there to install `conda` package manager.
3. Try installing the `conda` environment needed for this course referenced there.

Technische Universität Berlin