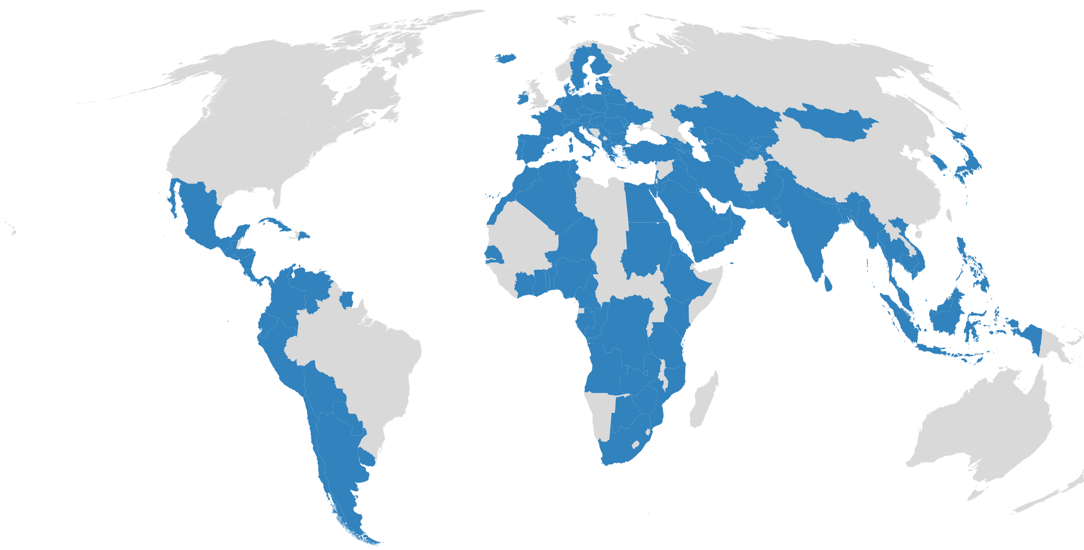
Assignment 4 – Group Assignment on System Planning

Due Thursday, 5 February 2026, noon [100 points]

Introduction

In this group assignment, you will investigate scenarios for a 100% renewable electricity system for a country of your choice. The deliverables consist of a 10-minute presentation, a slide deck including supplementary slides, and the code used to build and run the analysis.

Your first decision as a group consists of picking a country. In the map below, you can find in blue where the availability of the base data you need has been checked. Medium-sized countries will be a good choice; avoid very large or very small countries. You may disregard overseas territories (e.g., if you pick France). After consultation, it is also possible to model only part of a larger country (e.g., Sumatra instead of all of Indonesia).



For the presentation, next to presenting modelling results, prepare one introductory slide that characterises the current state of the electricity system in the country. For instance, you can present the electricity mix, a timeline of past deployment of wind and solar, and/or the fleet of power plants.

Datasets

The basic datasets needed to complete this group assignment are provided here:

https://tubcloud.tu-berlin.de/s/567ckizz2Y6RLQq

Where applicable, they are already chunked per country so that you only need to download the data for your selected country.

You are free to use additional datasets provided that you reference them adequately; it is even encouraged to do so.

In the list below, you find information about the datasets provided and references to documentation.

Filer / Folder	Dataset
marineregions/*	Includes the world's Exclusive Economic Zones.
wdpa/*	Includes the world's Protected Areas.
gegis/*	Includes approximate load time series projections for 2030 for countries around the world, built with GlobalEnergyGIS.jl.
gadm/*	Includes layer 1 of the administrative regions per country from the GADM project (e.g. federal states in Germany).
gebco/*	Includes elevation data from the GEBCO dataset (e.g. mountains, water depth).
copernicus-glc/*	Copernicus Global Land Service: Land Cover at 100m. Documentation on categories can be found at https://zenodo.org/record/4723921#.Y8RMRafMIvg.
global-power-plant-database/*	Includes a global database of power plants from WRI.
country_shapes.geojson	Includes country shapes.
ne_10m_airports.gpkg	Includes the location of large airports, taken from www.naturalearthdata.com.
ne_10m_roads.gpkg	Includes the location of large roads, taken from www.naturalearthdata.com.

Furthermore, data on technology and cost assumptions can be found here:

https://github.com/PyPSA/technology-data/tree/master/outputs

You are free to choose any of the years for the technology projections, but make sure you document which projection you used.

Shapes

Take the GADM dataset to split the country of your choice into at least 5 regions on which all further modelling will build. If there are more GADM regions, you may aggregate the regions down to that number, or continue with more than the required number of regions. For each region determine a representative point (e.g. centroid). If your country is not landlocked, also extract the shape of the Exclusive Economic Zone (EEZ).

Renewable Potentials

Renewable potentials should be computed for solar PV, onshore wind and, where applicable, offshore wind. The preparation consists of two main components.

First, perform a land eligibility analysis, like in previous assignments, based on the criteria listed in the table below. Make your own judgement about which land cover classes would be suitable; you can deviate from the suggested numbers below with reasonable justification.

Onshore Wind	Offshore Wind	Solar (rooftop & utility)
10km distance to airports 300m distance to major roads no natural protection areas maximum elevation of 2000m 1000m distance to built up areas only on suitable land cover classes	within EEZ up to water depth of 50m no natural protection areas 10km minimum distance to shore	only on suitable land cover classes no natural protection areas

Second, using `atlite` download historical weather data from the ERA5 dataset into an `atlite.Cutout` as shown in the group work preparation for a year of your choice and the geographical bounds of your selected country (add a buffer of 0.25 degrees).

Then, together with the availability matrix and the corresponding `atlite` conversion functions, calculate the wind and solar capacity factor time series per modelled region.

For onshore wind, you can use a "Vestas_V112_3MW" as reference turbine.

For offshore wind, you can use a "NREL_ReferenceTurbine_5MW_offshore" as reference turbine.

For solar, you can use a "CdTe" solar panel with optimal latitude orientation.

For both wind and solar, assume a deployment density of 3 MW/km^2.

Building the Model

Build a PyPSA model that minimises total annual system costs with the following characteristics:

- For the **spatial** resolution, take the regions you defined above. The model should include at least 5 buses, representing the regions. For the coordinates, take the representative points of the region shapes.
- For the **temporal** resolution, you may downsample the time series to a 3-hourly resolution. But you can also use hourly or 2-hourly time steps.
- For technology assumptions (costs, efficiencies, lifetimes, etc.) refer to the `technology-data` repository referenced in the list of datasets above. Pick a projection for a year of your choice from the `outputs` directory. Calculate annuities with a discount rate of 7%. For the marginal cost include fuel costs and variable operation and maintenance costs (VOM). For the capital cost include the annualised upfront investment costs as well as fixed operation and maintenance costs (FOM).
- Add the fleet of **existing conventional power plants** to the network, excluding wind and solar. This data can be aggregated to one representative generator per technology and region. You may choose that the existing conventional power plants are not extendable. Hydro power plants can be represented in a very simplified way; you may model them as `Generator` with a constant capacity factor (`p_max_pu`) corresponding to the ratio of estimated historical electricity generation in a given year and rated capacity.
- Add the **load time series** from the GEGIS dataset. If you chose a European country, you can also use data from OPSD. Since this data is given on a country-level, distribute the load to the regions using each regions' share of the country's population as a distribution key. You will need to research

the approximate population per region of your country. Should load time series be missing for your country, take time series from a neighbouring country scaled in proportion to the population.

- Add one **solar and on-/offshore wind generator** per region to the model, including the maximum installable potential (`p_nom_max`) and capacity factor time series (`p_max_pu`). Assume a starting capacity of zero.
- Add the option to build a bidirectional `Links` as **transmission lines** between neighbouring regions. This simplification neglects Kirchhoff's Voltage Law and transmission losses. Assume costs of 700€/MW/km and a length of 1.5 times the crow-fly distance between the regions' representative points.
- Add an option to build **battery storage** as `StorageUnit` with an energy-to-power ratio of 2h, 4h, 6h (multiple units).
- Add an option to build **hydrogen storage** as `StorageUnit` with an energy-to-power ratios of 168h, 336h, 672h (multiple units).

Investigation

First, perform two model runs. One without a limit on CO_2 emissions and another with a CO_2 emission reduction of 100% (no emissions). Describe how the electricity systems differ.

If you want to save some time, install and use the commercial Gurobi as a solver.

Additionally, pick at least <u>one</u> category of sensitivity analyses for the scenario with <u>no carbon-dioxide emissions</u> from the list below:

1. **Variations of grid expansion:** Analyse the differences between a scenario with full grid expansion, one with a maximum 1 GW per line expanded, one autarky scenario with no transmission between the regions.
2. **Variations of technology costs:** Successively reduce the capital cost of a technology of your choice (e.g. solar, wind, electrolysis, battery, grid expansion) down to 0% in 25% steps and describe how the optimised system changes. Alternatively, repeat your analysis for at least one other cost projection year (e.g. 2020, 2030, and 2050) across all technologies.
3. **Variations of renewable potentials:** Successively reduce the installable potential of a technology (or group of technologies) of your choice (e.g. solar, on-/offshore wind) down to 0% in 25% steps and describe how the optimised system changes.
4. **Variations of nuclear cost:** In each region, add the option to build a nuclear power plant. Assume zero specific CO_2 emissions for this technology. Run the model multiple times with different capital costs for nuclear (for instance, between 2500€/kW and 10,000€/kW in steps of 2500€/kW) and compare how the role of nuclear generation changes as a function of its capital cost.
5. **Variations of weather year:** Prepare data for two additional historical weather years of your choice and rerun the model. Compare how the optimised system changes in response to different weather data. Describe how the input weather data differs. (More work compared to other sensitivities).

How you present the results in the presentation is up to you. In the table below you can find a few suggestions for data worth visualising. It is not necessary to compute all of these statistics, but you should make a qualified selection based on your interests and chosen sensitivities. You can also include additional slides at the back of your presentation.

It is possible to deviate from the suggested sensitivity analysis if you have your own ideas.

Inputs of interest	Outputs of interest
land eligibility analysis	total system cost split by technology
power plant capacities	capacities built per technology
load time series and regional distribution	electricity mix
capacity factors of solar PV, on-/offshore wind (per region, time series for a month)	CO_2 shadow price
	price duration curves
	average electricity prices per region
	rate of curtailment
	storage filling levels throughout the year
	operation of the system (e.g. week with abundance or scarcity of renewables)

Deliverables and Instructions

- Presentation (10-12 minutes) on 5 February 2026 (groups A-L) or 12 February 2026 (groups M-X).
- Presentation slide deck with supplementary slides with further analysis conducted.
- Code used to build and run the analysis.

Please organise <u>one</u> submission per group on ISIS. The group can freely decide who presents the work.

The groups should consist of 4 students each. A uniform grade will be awarded per group.

Evaluation Criteria

Category	Points (out of 100)
Quality of presentation and supplementary slides	40
Quality of visualisations	20
Quality of analysis & results	20
Quality of model & code	20