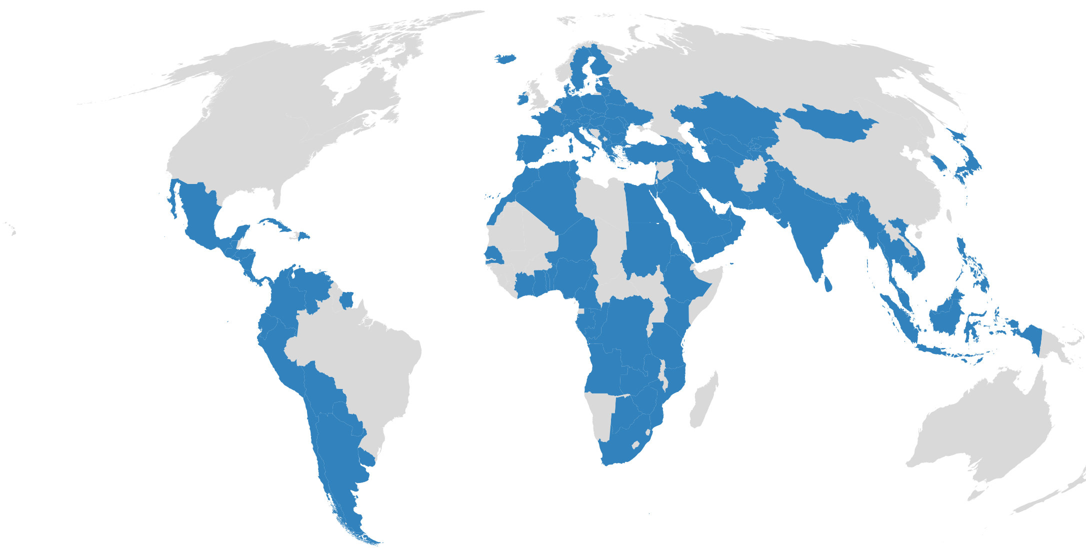
# Assignment 4 – Group Work

Due Monday, 6 February 2022, 14:00 [100 points]

## Introduction

In this group assignment, you will investigate scenarios for a 100% renewable electricity system for a country of your choice.

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 data you need has been checked. Medium-sized countries will be a good choice. You may disregard overseas territories. In consultation with the lecturer, it is also possible to model only part of a country, e.g. Sumatra instead of all of Indonesia.



For the presentation, prepare one 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 core 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.

You are free to use additional datasets.

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). |
| `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 airports, 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

## Shapes

Take the GADM dataset to split the country of your choice into at least 5 regions on which all further modelling will built. If there are more GADM regions, you may aggregate the regions down to that number. 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.

## 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.

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

Second, using `atlite` download historical weather data from the ERA5 dataset into an `atlite.Cutout` as shown in the lecture 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, use a "Vestas_V112_3MW" as reference turbine.

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

For solar, 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.
- 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 upfront investment costs as well as fixed operation and maintenance costs (FOM).
- Add the fleet of **existing power plants** to the network. This data should be aggregated to one representative generator per technology and region. All existing power plants should not be extendable and should have no capital cost. Disregard existing wind and solar capacities. Hydro power plants should be represented in a very simplified way; they should be modelled as `Generator` with a constant available capacity factor corresponding to the ratio of rated capacity and estimated historical electricity generation in a given year.
- Add the **load time series** from the GEGIS dataset. Since this data is given on a country-level, distribute the load to the regions by population. You'll need to research the population per region of your country.
- Add one **solar and on-/offshore wind generator** per region to the model, including the maximum installable potential and capacity factor time series.
- Add the option to build a bidirectional `Links` as **transmission lines** between neighbouring regions (neglecting Kirchhoff's Voltage Law and transmission losses). Assume costs of 400€/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 6h.
- Add an option to build **hydrogen storage** as `StorageUnit` with an energy-to-power ratio of 504h.

## 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 Gurobi as a solver.

The following analysis should be conducted for the scenario with no carbon-dioxide emissions.

Pick two categories of sensitivity analyses from the list below:

1. **Variations of grid expansion:** Analyse the differences between a scenario with full grid expansion, one with maximum 5 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) down to 0% in 20% steps and describe how the optimised system changes.
3. **Variations of renewable potentials:** Successively reduce the installable potential of a technology of your choice (e.g. solar, on-/offshore wind) down to 0% in 20% steps and describe how the optimised system changes.
4. **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.
5. **Variations of nuclear cost:** In each region, add the option to build a nuclear power plant. Assume zero $CO_2$ emissions. Run the model multiple times with different capital costs for nuclear and compare how the role of nuclear generation changes as a function of its capital cost.

How you present the results 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.

| 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 (8-minutes) on 6 February (in presence) or 8 February (on Zoom).
- Presentation slide deck with up to 25 supplementary slides with further analysis conducted.
- Code used to build and run the analysis.

Please organise one submission per group on ISIS. The group picks the presenters.

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

## Evaluation Criteria

| Category | Points |
|---|---|
| Quality of presentation | 25 |
| Quality of supplementary slides | 15 |
| Quality of visualisations | 20 |
| Quality of analysis & results | 20 |
| Quality of model & code | 20 |