Assignment 3 – Electricity Markets

Due Wednesday, 26 June 2024 23:59 [100 points]

Instructions and Rules

- Submission on ISIS requires two-factor authentication. Justified exceptions can be granted.
- Submissions must include both written answers and code that shows how answers were obtained.
- Always clearly mark which task and subtask you are working on.
- Always provide units for quantities (e.g. energy, power, emissions) for your results.
- All plots must have appropriate axis labels with units if applicable.
- The quality of the presentation of your results will be factored into the grading.
- Partial points will be deducted for any missing labels or units.
- Submissions must be own work, plagiarism from the web or peers will be checked and sanctioned!
- Please upload a single `.ipynb` file and the corresponding `.html` export of the notebook.
- Do not upload data!
- It must be possible to run submitted code without manually setting variables or executing code cells multiple times to retrieve all results (exception: local file paths)!
- You may use additional Python packages as long as they are available via `pip` or `conda`.

Task 1: European Gas Transmission Network [20 points]

Required Tools: `pandas`, `matplotlib`, `cartopy`, `geopandas`, `networkx`

The electricity transmission network is not the only network for energy transport in Europe. In this task, you will perform some network analysis on data about the European natural gas transmission network as provided by the SciGRID_gas project:

Source: https://www.gas.scigrid.de/posts/2020-Sep-02_iggielgn.html

Files:

https://tubcloud.tu-berlin.de/s/8SMwwWQyn6GiPez/download/scigrid-gas-nodes.geojson

https://tubcloud.tu-berlin.de/s/fF6KKpWtJyS3BmD/download/scigrid-gas-pipelines.geojson

[2 points] (a) Read the edges and nodes representing gas transmission pipelines into two separate `GeoDataFrame` objects.

[4 points] (b) Plot the transmission network data on a map, such that the colors of the line indicate the capacity of the pipelines in million cubic metres per day and the width of the lines is proportional to the rated pipeline pressure. The figure should have a size of 18 by 12 inches, a valid projection, and a colorbar for the colours showing the pipeline capacity. A legend for the line width is not required. Add coastlines and country borders for orientation.

[2 points] (c) Which is/are the pipeline/s with the highest maximum pressure?

[4 points] (d) Identify the subset of pipelines which cross borders. Check your code visually by plotting only the crossborder pipelines on a similar map as before. What percentage of lines crosses borders?

The following tasks require the use of some `networkx` functions to analyse the network graph.

[4 points] (e) Create a `networkx.Graph` from the pipeline data using the function `nx.from_pandas_edgelist()`. As attributes include the length, diameter, capacity and pressure of the pipeline.

[2 points] (f) Plot the frequency distribution of degrees as a bar chart or histogram.

[2 points] (g) Compute and plot the incidence matrix of the network.

Task 2: Merit Order [40 points]

Required Tools: `pandas`, `matplotlib`

In this task you are asked to build and plot merit order curves for the German day-ahead electricity market given a dataset on operational power plants and some additinal carrier-specific data:

- https://tubcloud.tu-berlin.de/s/P9qPttqFg3ciKEy/download/powerplants.csv
- https://tubcloud.tu-berlin.de/s/XjtnxyNPtPP6eDQ/download/technologies.csv

The attributes contained in the two CSV files have the following units:

Attribute	Description	Unit
carrier	technology	–
co2_emissions	specific carbon dioxide emissions	t/MWh (thermal)
color	HEX color code	–
efficiency	conversion efficieny	MWh (electric) / MWh (thermal)
marginal_cost	STMGC	€/MWh (electric)
p_max_pu	capacity factor in particular hour	p.u.
p_nom	rated/nominal capacity	MW

Assume that all storage has sufficient energy filling levels to dispatch at full capacity.

[2 points] (a) Read the provided datasets into two separate `pandas.DataFrame`.

[8 points] (b) Write a Python function for plotting the merit order curve (supply side), by adapting the code from an online tutorial at https://tinyurl.com/plt-merit-order or https://archive.vn/Ljroc. The following criteria should be satisfied:

- The function should take at least two arguments: a `pandas.DataFrame` for the power plant data, and another for the carrier-specific information.
- The bars of the merit order curve should by coloured according to the given technology colors.
- The extent of the plot should start at the (0,0) origin and be limited to the highest marginal cost and total power plant capacity.
- Axes must be appropriately labelled with units. The preferred unit for the x-axis is GW.

(c) Plot the merit order curve using the function you created for the following cases (i.e. do not duplicate the code for merit order plotting):

[2 points] i. for the marginal costs given in the dataset

[2 points] ii. with an added carbon price of 70 €/t_{CO_2} (assume previously no carbon pricing was included)

[2 points] iii. **additionally to ii.** with a gas price increased by 50 €/MWh_{th}

(d) For each of the cases, use code to present for an electricity demand of 69 GW in a single table:

[4 points] i. the market clearing price,

[2 points] ii. the total power dispatched per technology,

[2 points] iii. the resulting revenue per technology,
[2 points] iv. the operational costs per technology,
[2 points] v. the profits per technology,
[6 points] vi. the carbon intensity of the system,
[6 points] (e) Describe the major differences you observe between the four cases.

Task 3: Tools for Electricity Market Modelling **[40 points]**

Required Tools: `linopy`, `pypsa`, `pandas`

Build a simple electricity market model for minimising operational costs within technical constraints for three fictive countries Aloria, Baray and Corsova considering the following information:

The operational fleet of power plants in the three countries is specified as follows:

Technology	Country	Marginal Cost [€/MWh]	Capacity [MW]
Coal	Aloria	34	51000
Wind and Solar	Aloria	0	9000
Gas	Aloria	75	12500
Hydro	Baray	5	2100
Gas	Baray	70	1000
Hydro	Corsova	8	1400

The electricity demand in the countries reads as follows:

Country	Demand [MW]
Aloria	64000
Baray	1200
Corsova	800

The transmission capacities read as follows:

Start	End	Capacity [MW]
Aloria	Baray	600
Baray	Corsova	50
Aloria	Corsova	200

Assume equal non-zero reactances for the transmission lines.

(a) Build and solve the problem using `linopy` (or `pyomo`). You will need to:
[3 points] i. create all variables for generation and transmission,
[2 points] ii. formulate the objective function for minimising the operational costs,
[6 points] iii. build the necessary constraints, including the technical limits of generation and transmission and the Kirchhoff Laws,
[1 point] iv. solve the optimisation model with a solver of your choice,
[3 points] v. retrieve the generator dispatch, power flows, objective function and market prices. Label all units!

(b) Build and solve the same problem in PyPSA. You will need to:

[1 point] i. create a new `pypsa` network,

[6 points] ii. add the generators, lines, and loads to the network,

[1 point] iii. solve the prepared network with a solver of your choice,

[3 points] iv. retrieve the generator dispatch, power flows, objective function and market prices. Label all units!

[3 points] (c) Check with automated code that both models yield the same generator dispatch, objective value, and market prices using code.

[6 points] (d) Using the PyPSA plotting function `n.plot()`, plot a map (that includes country borders) showing the dispatch per technology as a pie chart for each node sized in proportion to the total generation per node, the line loading as color of the lines, the line capacity as the width of the lines. You may need to add the carriers to the network, specifying their respective colors, and appropriate coordinates to the buses to present the countries on a map. A legend is only required for the colors of the carriers.

Hint: The API reference for the plotting function can be found here: `https://pypsa.readthedocs.io/en/latest/api_reference.html#pypsa.plot.plot`

[5 points] (e) What measure would you recommend to Aloria to increase the import capacity of hydro-electricity from its neighbouring country? Explain why. How much cheaper (in percent) could the dispatch cost for the particular hour under investigation become through this measure?