Assignment 3 – LNG Terminals & Electricity Markets

Due Wednesday, 11 January 2022, 23:00 [100 points]

Instructions and Rules

- Submission on ISIS requires two-factor authentication.
- Justified exceptions may be granted. Contact f.neumann@tu-berlin.de.
- Submission must include both written answers and code that shows how answers were obtained. All submitted material will be factored in for the grading.
  - **Option A**: combined answers and code in `.ipynb` file + `.html` export of notebook
  - **Option B**: `.pdf` with written answers (incl. figures) + `.py`/`.ipynb` with code and comments
- Submissions must be your own work, plagiarism from the web or your peers will be sanctioned!
- Always clearly mark which task and subtask you are working on.
- Always provide units for quantities (e.g. energy, power, emissions).
- All plots must have axis labels with units if applicable.
- 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: LNG Terminals [30 points]

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

In this task, you will analyse data from the Global Gas Infrastructure Tracker published by Global Energy Monitor. This dataset includes data on liquefied natural gas (LNG) import and export terminals around the globe. You can find the dataset here:

File:

https://tubcloud.tu-berlin.de/s/QWXsKqHTnfWxRzj/download/GEM-GGIT-LNG-Terminals-July2022.xlsx

[2 points] (a) Read the Excel table into a `pandas.DataFrame` using the `pd.read_excel` function. Make sure to identify the following strings as NaN values when reading in the file: "Unknown", "TBD", "–", " ".

[2 points] (b) Using the coordinates included in the dataset, build a `geopandas.GeoDataFrame`.

[2 points] (c) Convert the capacities given in Mtpa (mega tonnes per year) into TWh and store the resulting values in a new column "CapacityInTWh".

[2 points] (d) How many LNG terminals are included in the dataset and what is the median capacity in TWh?

[2 points] (e) What share of import terminals is floating?

[2 points] (f) Print the information of the oldest operating LNG terminal. In which country is it located?

[2 points] (g) Create a bar plot outlining the 10 countries with the largest LNG terminal capacity.

[2 points] (h) Create a bar plot outlining the LNG terminal capacity per status code.

[2 points] (i) Create a table of the German LNG terminals including information on the name, status, capacity, owner, whether it is floating, and sorted by aspired start year.

[2 points] (j) Create a line chart depicting the number of new LNG termianls per year. Include a vertical line for the year 2022 for orientation.

[5 points] (k) Write a function that takes an extract of the LNG terminals in the `geopandas.GeoDataFrame` and plots it with the following characteristics:

- Mercator projection with coastlines displayed.
- Marker size proportional to capacity (no legend for size necessary)
- Colors according to status, including a legend.
- Semi-transparent markers (`alpha=0.6`).

[5 points] (l) Use the function you created to plot:

- all LNG terminals
- only LNG import terminals
- only LNG export terminals
- only future LNG import terminals (i.e. start year after 2022)
- only floating LNG terminals

Task 2: Merit Order [42 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 (link 1) and some additinal carrier-specific data (link 2):

- 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`.

[4 points] (b) Plot a pie chart with the distribution of capacities per technology. Color the chart segments according to the given colors, label the segments with the carrier and its capacity share in % rounded to one decimal point.

[8 points] (c) Write a 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 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.

(d) 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 80 €/t_{CO_2} (assume that previously no carbon pricing was included)

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

[2 points] iv. **additionally to ii. and iii.** without Germany's nuclear power plant fleet

(e) For each of the cases, use code to determine for an electricity demand of 70 GW

[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

[4 points] vi. the carbon intensity of the system

[4 points] (f) Describe the major differences you observe between the four cases.

Task 3: Tools for Electricity Market Modelling [28 points]

Build a simple electricity market model for minimising operational costs within technical constraints for South Africa, Mozambique and Eswatini 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	South Africa	30	35000
Wind	South Africa	0	3000
Gas	South Africa	60	8000
Oil	South Africa	80	2000
Hydro	Mozambique	3	1200
Gas	Mozambique	55	500
Hydro	Eswatini	5	600

The electricity demand in the countries reads as follows:

Country	Demand [MW]
South Africa	42000
Mozambique	650
Eswatini	250

The transmission capacities read as follows:

Start	End	Capacity [MW]
South Africa	Mozambique	500
Mozambique	Eswatini	100
South Africa	Eswatini	250

Assume equal reactances for the transmission lines.

(a) Build and solve the problem using `pyomo`. You'll need to:

[3 points] i. create all variables for generation and transmission,

[2 points] ii. formulate the objective function for minimising the operaitonal costs,

[5 points] iii. build the necessary constraints, including the technical limits of generation and transmission and the Kirchhoff Laws,

[2 points] 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 units!

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

[1 point] i. create a new network,

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

[2 points] iii. olve the built network with a solver of your choice,

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

[2 points] (c) Check that both models yield the same generator dispatch, objective function, and market prices.