Lecture 10: Capacity and dispatch optimisation in a network

DTU Course 46770: Integrated Energy Grids

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Problem 10.1. We build on the models described in Problem sets 8 and 9:

Optimize the capacity and dispatch of solar PV, onshore wind, and Open Cycle Gas Turbine (OCGT) generators to supply the inelastic electricity demand throughout one year. To do this, take the time series for the wind and solar capacity factors for Portugal and Denmark in 2015 obtained from `https://zenodo.org/record/3253876#.XSiVOEdS8l0` and `https://zenodo.org/record/2613651#.X0kbhDVS-uV` (select the file 'pvoptimal.csv') and the electricity demand from `https://github.com/martavp/integrated-energy-grids/tree/main/integrated-energy-grids/Problems/data`. Note that we work without a CO_2 constraint in this exercise.

Consider the annualized capital costs and marginal generation costs for the different technologies in the following table. The efficiency for the OCGT plant is 0.41.

Technology	Capital costs (EUR/MW/a)	Marginal costs (EUR/MWh)	CO_2 emissions (tCO_2/MWh$_{th}$)
Onshore Wind	101,644	0	0
Solar PV	51,346	0	0
OCGT	47,718	64.7	0.198

Table 1: Costs assumptions.

Now, however, we add Denmark as a second node and we connect Portugal and Denmark with an overhead HVAC line. Assume that the annualised capital cost of it is 42 EUR/MWkm/a and that the distance is 2477 km. Set up a network with two nodes and connect them with an overhead AC line.

For (a)-(d), calculate the following:

- total system costs (in bn EUR)
- average electricity price (in EUR/MWh) and number/share of hours with zero prices.
- congestion rent
- utilisation of transmission lines (in % of capacity)
- total generation per technology (in TWh)
- total CO_2 emissions (in MtCO_2)

a) Solve the network in PyPSA while keeping the capacity at 0 GW and assuming it cannot be extended.

b) Now assume the AC line connecting Portugal and Denmark has a capacity of 1 GW.

c) Now assume the AC line connecting Portugal and Denmark has a capacity of 10 GW.

d) Optimise the AC line capacity endogenously (assume its current capacity is 0 GW). Are the costs recovered by the congestion rent?

Problem 10.2. We build on Problem 10.1d), i.e. we optimise the capacity of the transmission line between Denmark and Portugal endogenously (starting at 0 GW). For (a)-(c) calculate the following:

- total system costs (in bn EUR)
- average electricity price (in EUR/MWh) and number/share of hours with zero prices.
- congestion rent
- utilisation of transmission lines (in % of capacity)
- total generation per technology (in TWh)
- CO_2 price (EUR/tCO_2)

a) Set up a network as in 10.1d) and add a CO2 constraint of 2.5 MtCO2/year.

b) The load distribution between Denmark and Portugal is approximately 1:1.5. Impose national targets Assume that both countries have national targets of 1 MtCO2/year and 1.5 MtCO2/year, respectively.

c) Assume the CO2 limits from b), but that the transmission capacities is limited to 1 GW (still endougenously optimised).

d) Change the global CO2 limit to 0.25, 0.5, 1, 1.5, 2 MtCO2/year, and plot the total system costs against the CO2 limit.

Hint:
In order to add national targets for carbon emissions, you need to manually add a constraint and modify the model formulation.

For this, you first need to access the underlying model in linopy with `n.optimize.create_model()`. Then you add the constraint with `n.model.add_constraint(lhs, "<=", rhs, name)`. One way to achieve this is to access the aggregated operational variables for the generators (solar, wind, OCGT) with `gen_var = n.model.variables["Generator-p"].sum("snapshot")`. Then you multiply this with the corresponding CO_2 emission factor for each generator, and group the corresponding constraints as follows: `lhs = (gen_var * co2_emission_factors).groupby(n.generators.bus.to_xarray()).sum()`. In order to now optimise the modified model you need to run `n.optimize.solve_model()`. You can access the dual variables at the end with `n.model.dual()`.