Welcome to LPtown

You are an energy system analyst at the local energy utility in the municipality of LPtown. You have inherited a linear programming model of the district heating system from a previous colleague who has quit her job in order to pursue a PhD, but you have no intention of repeating her mistake and trading away your high salary and straightforward career path for an uncertain future and a worthless academic degree.

Your current task is to propose how each heating plant should be optimally operated over the course of a year, and appropriate investments in new CHP plants that are under consideration. The table below lists the installed capacities of the existing plants.

plant type	fuel	installed capacity (MW_{heat})	efficiency	power/heat ratio	investment cost (kr/kW_{heat})
heating plant	wood chips	100	0.9	-	-
heating plant	solid waste	120	0.9	-	-
heating plant	heavy fuel oil	300	0.9	-	-
heat pump	electricity	220	-	-	-
CHP	natural gas	300	0.9	1	6500
CHP	wood chips	0	0.9	0.3	3600

To account for seasonal variations of heat demand, electricity price and other key parameters and variables, the year has been divided into 6 “time slices” as follows.

parameter	winter day	winter night	summer day	summer night	other day	other night
days per slice	122	122	121	121	122	122
hours per day	16	8	16	8	16	8
heat demand (MW)	900	900	150	150	450	550
electricity price (kr/MWh)	600	450	350	250	450	350
heat pump COP	4	4	5	5	4.5	4.5

Fuel prices and corresponding CO_2 emission factors appear below. The emission factor for electricity corresponds to the average national mix of electricity generation.

fuel	fuel price (kr/MWh)	CO_2 emission factor ($kg\ CO_2/MWh_{fuel}$)
wood chips	220	0
solid waste	0	90
heavy fuel oil	550	266
natural gas	300	202
electricity	-	250

Finally, use a discount rate of 5%/year and an economic lifetime of 25 years to annualize any new investments made. The capital recovery factor is defined as $CRF = \frac{r}{1-(1+r)^{-T}}$. Further, the amount of solid waste produced annually in LPtown is 400.000 tons/year, with an average heat content of 2.8 MWh/ton. The waste incineration plant has some internal storage capacity that can act as a buffer for a few days of municipal waste production, but seasonal storage is impossible.

To do in class

Unless otherwise noted, run the model using base case assumptions (no new investments allowed and no limit on CO_2 emissions).

1. Choose appropriate sets and variables to represent this problem!
2. Sketch the constraints and the objective function.
3. Spend some time studying the basic model (LPtown1.gms) and how it has been implemented in GAMS. Ask your boss if anything is unclear.
4. Run the model. Try to understand the optimal solution. Which plants are running at maximum capacity and which are not? How does this relate to the shadow price of the capacity constraint (Capacity.m)? And how does the shadow price of heat demand (Demand.m) relate to the running costs of various technologies?
5. Extend the model with a new 'invest' parameter so that it can calculate the optimal operation of all plants assuming ***fixed investments*** in two new CHP plants: 80 MW_{heat} natural gas CHP and 30 MW_{heat} wood chips CHP (both new plants are available simultaneously). Call the new model LPtown2.gms.
6. Run the model and examine the new solution. Answer the same questions as in item 4.
7. Can you find a better level of investment for the new CHPs? Spend 5-10 minutes iterating and re-running the model and try to find the optimal investments manually.

Assignments to be completed before the next class

8. Extend the new model further (call it LPtown3.gms) to include the investment levels of the new CHP plants in the optimization, i.e. make the investments model variables. Compare your solution to your best guess in item 7. Can you explain the shadow price of heat demand in each time slice of the optimal solution?

Now you will perform a scenario analysis by re-running the model using several different assumptions of input data or model constraints. Don't forget to revert to baseline assumptions before running each new scenario! Every time you change assumptions, guess what will happen **before you run the model!** If you were surprised, try to understand why the model result was different. This is very good standard practice for modelers!

9. Increase the electricity price in each slice by 20% and re-run the model. What happens, and why?
10. Local politicians would like to know if the district heating system can become carbon neutral. How does the solution change if you add this constraint? (The simplest way is to directly set an upper bound on the CO2emissions variable, by putting the line "CO2emissions.up = 0;" just before the solve statement.) What is the resulting shadow price of CO_2 emissions (TotalCO2.m)? Incidentally, can you explain why TotalCO2.m has this particular unit?
11. All runs above assume that CO_2 emissions from electricity are relatively low (250 gCO_2/kWh_{elec}). Now assume that coal power is on the margin in the electricity system so that CO_2 emissions from electricity increase to 1000 gCO_2/kWh_{elec}. Can the system still be carbon neutral? What is the shadow price of CO_2? Why? Is the solution strange in any way? If so, explain!
12. Can the local district heating system become carbon ***negative*** if coal power is on the margin in the electricity system? How carbon negative can you make the system? Why? Is this realistic? If not, what is the problem with the model?
13. The neighboring municipalities of CDtown and MP3town would like to reduce the cost of their waste management, and ask if LPtown would be able to incinerate their waste. What price limit (in kr/ton waste) should the representatives of LPtown have in the negotiations? And approximately how much waste can LPtown import at this price? Use the baseline assumptions of item 8 and modify the model so that it can answer these questions (hint: shadow prices are awesome!). Also convert the maximum waste price to kr/MWh and compare with the price of wood chips.