POWER EXCHANGES
PRACTICALS

Each student will write a report including the description of the computation done, the analysis of the results obtained. Scripts that allowed obtaining the results will be joined as well as the log of their output. The report will be in PDF and will include the graphics. The whole package will be zipped into a file named '*LAST_NAME_first_name.zip*' and sent by email to nicolas.omont_tp_rest at m4x.org within three weeks after the last session, end of week. Warning: do not include any executable file (.exe) in your archive as the entire email will be dropped by email servers. One different report per person is expected.

A. <u>Installation of AMPL and KNITRO</u>

- Create a directory.
- Copy `ampl.exe` and `knitroampl.exe` in the directory.
- Copy the license files `ziena_lic….txt` in the directory (There should be 2 of them).
- Copy the `technology_mix.mod`, `technology_mix.dat`, `consumption.dat` and `technology_mix.run` files in the directory.
- Open a command box, go to the directory and run the following command:
    `ampl technology_mix.run`

    Some results will print out. To log them into the file `log.txt`, you can type `ampl technology_mix.run > log.txt`. You can then import it into excel to plot graphics.

- Install a good text editor, like notepad++ in order to edit `.mod`, `.dat` and `.run` files.
- Do not forget that:
    - KNITRO is a numerical optimizer. Its usual precision is around 1E-6.
    - KNITRO is a mathematical solver. It is meaningless to apply moral judgments on its results; however you are encouraged to understand the link between the hypothesis and the results.
- The manual of KNITRO (probably useless except if you want to try to tune the optimizer) is available at
    `http://www.artelys.com/en_EN/products/optimization_tools/knitro`
- The manual of AMPL (quite useful, especially the reference manual given in the Annex A) is available at:
    `http://www.artelys.com/index.php?page=AMPL&hl=en_EN#manuals-tab`

B. <u>Optimization of generation</u>

The French consumption time series C(h) in MW is given for each hour h year of 2010 in the file `consumption.dat` ranked in decreasing order.

The goal of these practicals is to study what would be the ideal French generation park under various hypotheses (the "optimal mix"). This hypotheses are pedagogical and simplified so that comparisons with the real mix are not possible. Let us assume that is possible to satisfy the French consumption with generation assets with the following cost structure: for each technology is given:

- The cost of installing one MW of generation capacity is Kc(i), in €/MW, in other words the fixed cost (CAPEX), more or less equal to the annualized cost of the investment.
- The cost of producing one MWh of energy is Ke(i), in €/MWh, provided, of course that you have installed enough capacity, in other words the variable cost, more or less equal to the cost of the combustible.

Some technologies -like nuclear power- have a high fixed cost and a low variable cost, while some other -like fuel powered units- have a low fixed cost and a high variable cost. A basic technology description (coal and hydro) is given in `technology_mix.dat`.

Look at the file `technology_mix.mod`. It describes the optimization model: the objective, found on the line starting with `minimize` is to satisfy the demand at the lowest cost. In addition, the model takes into account the possibility to model several countries with exchange capacities between them and the possibility to model hydro power generation. They will be useful at a later stage.

Question 0: explain in words the optimization problem described in `technology_mix.mod`. In particular, comment the objective (line beginning by `minimize`) and constraints (lines beginning by "`subject to`").

These data are pedagogical. These practicals are not a realistic study of the French system.

Finally, look at the file `technology_mix.run`. It describes the following process:

- Load the model
- Load the data files
- Solve the problem
- Display some results
1- *Run it with the command `ampl technology_mix.run` and try to understand the output.*

Now, you are ready to modify the data, the model and the script:

- Complete the technology description (`param capacityCost, energyCost` and `maxCapacity`) with the following technologies:

Name	Fixed cost	Variable cost
Nuclear	237,000	10.32
Gas	68,000	45.46
Fuel	46,000	66.30

- Look at the result:
  - *2-a What happened to coal? Why (Answer by computing the number of running hours for which coal and gas and other interesting couples of technologies have equivalent marginal costs. The computation can be illustrated graphically by plotting the cost of installing 1 MW of each technology and using it H hours during the year, i.e. Cost per MW = function of the number of hour of use) ?*
  - *2-b How much capacity is produced by nuclear power? Which proportion of the total capacity does it represent?*
  - *2-c How much energy is produced by nuclear power? Which proportion of the total energy capacity does it represent?*
  - *2-d How many hours are they run? And gas power plants?*

- Practically, one important element of the mix is missing: hydro power. It can be modeled in two parts:

- One part is run-of-the-water generation: it is comparable to a fixed generation at no marginal cost but with a fixed capacity and no possibility to expand it. Set its maximum capacity (`param capacityCost, energyCost` and `maxCapacity`). *Why is it reasonable to model the run of the water power in this way? Try to change the fixed costs of "RunOfTheWater". Does it change the result?*

Name	Fixed cost	Variable cost	Maximum capacity
RunOfTheWater	0	0	7000

- The other part is reservoir generation: it will be modeled as a fixed amount of energy that can be used whenever in the year to satisfy the demand. Capacity is unlimited but costly as it is possible to oversize turbines on existing dams. Set its maximum deliverable energy (`param hydroEnergy`). *Why is it reasonable to model the hydro power in this way?*

Name	Fixed cost	Variable cost	Maximum capacity	Maximum deliverable energy
Hydro	200,000	0	`+Infinity`	5,000,000

- Look at the results and answer to the questions below **after adding just the run-of-the-water generation and after adding both run-of-the-water and hydro power**:
  - *What has been substituted by the run-of-the-water (3-a) hydro energy (4-a)? Why?*
  - Display the dual variable of each balancing constraint (Uncomment the "`display energyCtr`" line in the `.run` file). The dual variable of this constraint is equal to the marginal cost of the energy during this hour of the year, i.e. what would be the additional costs if 1 more MWh of energy was consumed. It can be shown that it is also the equilibrium price of a market under perfect competition. *3-b and 4-b Plot on the same graph the consumption and the price. What do you observe? What can you say about the first hour?*
  - 3-c and 4-c Let us assume that each generation units sells its power at the price. Compute the annual profit in M€ associated to each technology (Uncomment the 3 lines corresponding to the `param revenues` in the `.run` file and change them so that they compute the profit (including fixed costs) instead of the revenues). *What do you observe? Why? Does it help you to explain the price of the first hour?*
  - Display the dual variable of the hydro energy storage constraint (`storageCtr`). It can be interpreted as the "value of water", that is how much costs would be avoided with one more MWh of hydro energy. What technologies would replace this marginal water? During how much time? Given its fixed cost and its variable cost, can you recompute the "value of water" as the avoided cost of the last MWh produced?
  - Compare the hourly prices with the previous ones (first "Thermal plants + run of the water vs. thermal plants only" then "thermal plants + run of the water vs. thermal + run of the water + hydro").

- With thermal plants + run of the water + hydro, what is the capacity of the nuclear park? Let us say imagine that, taking into account planned unavailabilities, the current winter capacity of the park is about 50,000 MW.
  - *5-a Assuming the hypothesis made are correct, is the French park optimized for the French consumption?(The optional part tries to answer to this question).*
  - Set artificially the capacity of the nuclear park to 50,000 MW (Command `fix capacity["FR","`*name_of_the_technology*`"]:=50000`) to be added in the .run just before `solve`), compute and plot the new prices and compute the profit per technology. *5-b What do you observe?*

- o Set it artificially lower (20,000 MW). Compute the profit for each technology and compute and plot prices and. *5-c What do you observe?*

- Customers are not ready to pay whatever price for energy: above a given price level, they are curtailed. As it is not easy to determine this price, the French law sets the expected level of curtailment at 3 hours per year. To model this, let model the curtailment as a new "technology" to "satisfy" the demand. It has no fixed cost and only a variable cost. It will be called "`Curtailment`". For more realism, start by setting the "hydro" technology maximum capacity to 10,000 MW (do not forget to remove the "fix" command on the nuclear capacity). Run the optimization to check that prices and volumes change before going through the following questions:
  6-a By trial and error, set this variable cost so that the number of curtailed hours is 3. The current technical roof at the French power exchange is 3,000 €/MWh (i.e. some consumers are not served and all served consumers pay 3,000 €/MWh). *How many hours of curtailment should there be with such a price of energy not served?* Assuming that enough capacity is installed so that the 3 hours of curtailment are satisfied (i.e. assuming that the installed capacity are the ones obtained while setting the price of energy not served at the value you computed before, not the one that would be obtained by setting the marginal cost of unserved energy at 3000 €/MWh), what is the consequence on the profit of each technology if a price cap is put at only 3000 €/MWh?

C. Exchanges (optional)

- Exchanges are now very important to determine the French price and the optimal park. Add a new zone representing the other European countries.
  - o The export capacity (from France) is 10000 MW (create a new parameter called `param maxExchange{a in AREAS, b in AREAS, h in HOURS : a<>b}` in the .`mod` and fill it by adding a new table in the .`dat` and then add a new constraint called `subject to maxExchangeCtr{a in AREAS, b in AREAS, h in HOURS : a<>b})`.
  - o The import capacity (to France) is 7000 MW (set it thanks to the `maxExchange` parameter)
  - o The consumption is fixed all the year round to 10000 MW (replace the '0' in the .`dat`)
  - o Let us consider that the only technology available in the other European countries is gas power, but with a lower variable price than in France:

Name	Fixed cost	Variable cost
Gas EU	68,000	40.00

- Analyze the results and plot the exchanges between France and EU. Keep in mind that only exchange(A->B)+exchange(B->A) is meaningful and not each one individually. Compute the overall financial balance (what customers pay minus what producers earn). What do you observe? Display the dual variable associated to `maxExchangeCtr`. How is it related to the price difference between France and EU? Does it explain the phenomenon?