MVE165/MMG631
Linear and integer optimization with applications
Lecture 11b
Assignment 3b – The Scandinavian electricity system

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Outline

The Scandinavian electricity system

System overview

- An electricity system should be designed for the three regions in Scandinavia, e.g. Denmark, Norway and Sweden.
  - Investments should be made in different electricity generation technologies.
  - To make informed decisions about which investments to do, the system should operate for one year and meet the demand at all time steps.
- The regions have their own annual demand, which varies over time.
- Each region will generate electricity by themselves, but it is also possible to freely trade between the regions.
  - There is, however, a transmission loss of a few percent when trading.

The Scandinavian electricity system (cont'd)

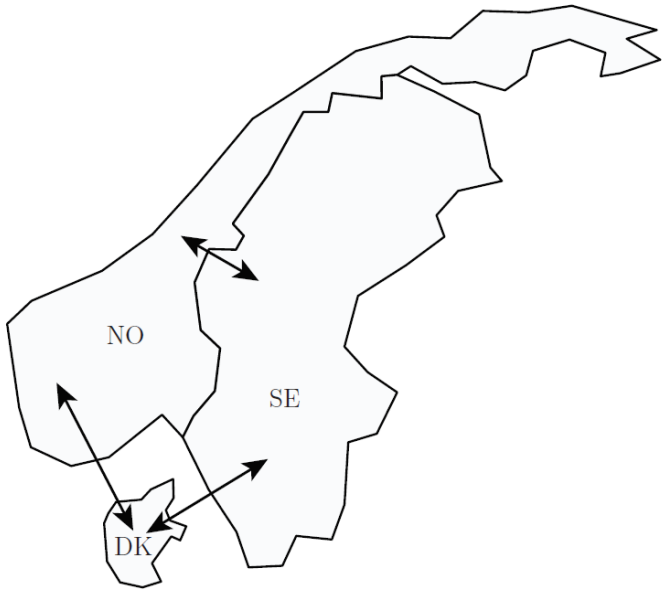


Figure 1: The Scandinavian transmission possibilities

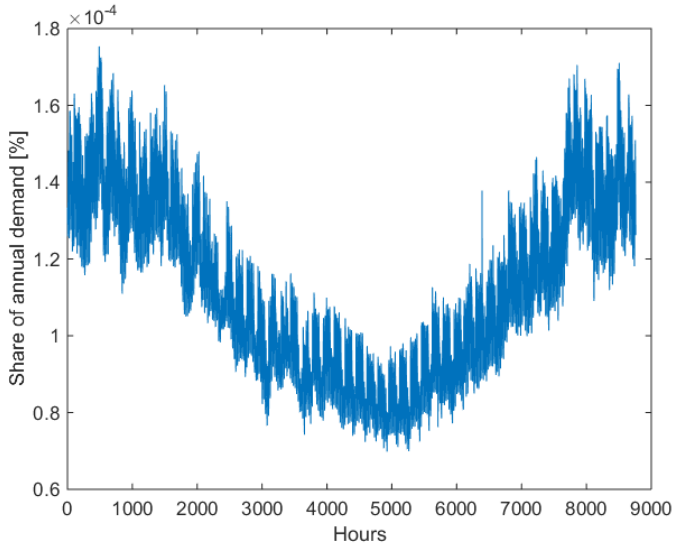


Figure 2: Example of a demand profile

Electricity generation technologies

Different electricity generation technologies

An electricity system is comprised of different electricity generation technologies. In this system, the technologies are:

- Hydropower
- Wind power
- Nuclear power
- Fossil fuels (coal and natural gas)

Aggregated continuous capacity

For each region and technology type, all power plants are combined. Thus, we consider one giant power plant per technology type in each region.

Electricity generation technologies (cont'd)

What is the difference between capacity and an amount of energy?

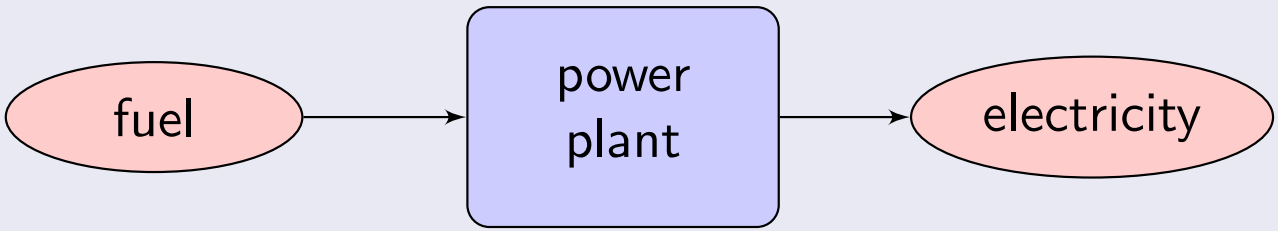
Capacity denotes the maximum possible electricity output over a certain amount of time.

Example

Let τ [h] be an arbitrary time period. If the capacity is, for example, 5 MW, the *maximum* electricity output during the time period τ hours is 5τ MWh.

Notation

- MWh_{fuel} is the energy input into the generation technology.
- MWh_{el} is the electricity output from the technology.



Electricity generation technologies (cont'd)

Properties of a technology

The electricity generation technologies all have different properties, for example:

- Efficiency
  - $\eta = \frac{\text{output}}{\text{input}}$ [%]
- Life span
  - Used to make decisions regarding investments
- Costs
  - Investment costs
  - Fuel costs
  - Operation and maintenance (O&M) costs
- Emissions
  - CO_2

Hydropower

How does hydropower work?

- The inflow to the reservoirs depends on weather and climatic properties.
- Electricity is produced by leading the water through turbines.

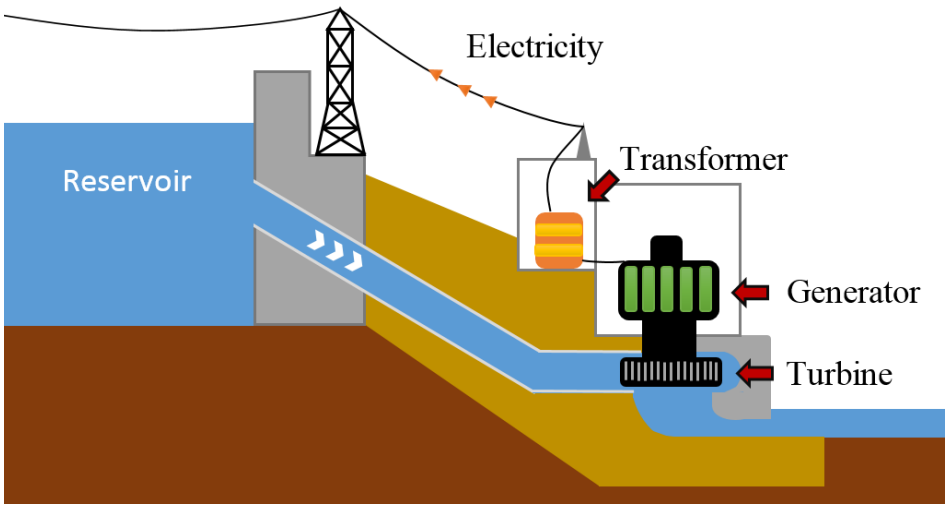


Figure 3: Illustration of hydropower

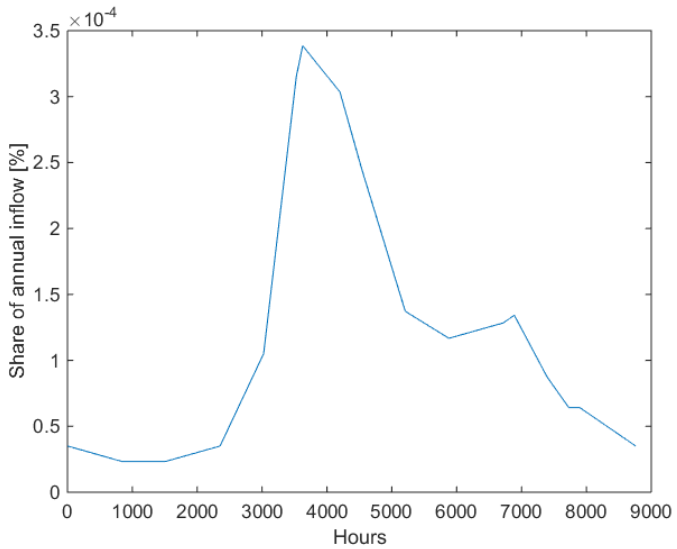


Figure 4: Inflow profile for hydropower

Hydropower (cont'd)

Special properties of hydropower

- No new investments in hydropower are possible.
  - The current capacity installments in Norway and Sweden are 30.6 GW and 16.2 GW, respectively.
  - Denmark does not have any hydropower.
- The reservoir levels at a specific momentary time is measured in $\text{MWh}_{\text{el}}/\tau$, where τ [h] is the length of the time step.
  - The level when the planning period starts can be any (feasible) value, but it is required to be the same level when the planning period ends.

Wind power

Special wind power properties

- Wind power output is intermittent and has a significant variation over shorter time horizons.
- Not all areas are suitable for installment of wind farms since wind speed and terrain varies across the regions.
  - There is an upper limit of the wind power capacity that is available for installment in each region.

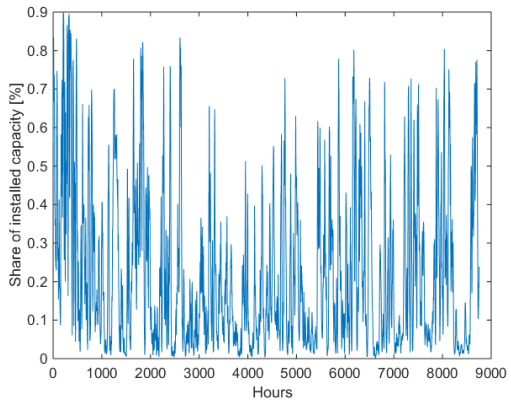


Figure 5: Example of a wind profile

Nuclear power

Special nuclear power properties

- Nuclear power uses uranium as a resource.
- Two different reactor types can be invested into: small and large.
  - The reactors have the same properties besides their capacity size.
  - Several reactors of each type can be bought.

- Having large short-term variations in output is complicated due to the complexity of turning the reactors on and off, and it is also very costly to do so.
  - There is a lower limit to the aggregated amount of nuclear power produced in each region, based on installed capacity.

Fossil fuels

Special properties for fossil fuel power

It is possible to invest into two different fossil fuel power plants: coal and natural gas.

- Coal power plants are relatively cheap to invest into and run, but has a lot of CO_2-emissions.
- Natural gas power plants have low investment costs, but a very high running cost and is often used to cover demand at "peak periods".

Assignment tasks

The assignment tasks

- Formulate a mixed integer linear programming network model that seeks to minimize investment and annual running costs of the Scandinavian electricity system.
- Implement the model in AMPL and solve it using CPLEX.
- Discuss on how to make improvements of the model.
- Introduce the second objective to minimize emissions, implement this new multi-objective optimization problem in AMPL and construct its Pareto front.

Tips & tricks

Hints

- To avoid waiting between model runs, first use fewer time steps while implementing the model (in order to save time when looking for syntax errors etc)
- Since the model will be quite large, it might be easier for us to provide help if you use notation we are used to:
  - x,y,z,u,v,w are typically used for variables
  - a,b,c,d,e can be used as parameters
  - f,g,h might be used as functions
  - i,j,k,l usually denote indices
  - m,n,p,q,r,s,t works as parameters *or* indices