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# EnergyPLAN Exercise 4:

# Advanced Energy System Analysis: Excess diagrams

In Exercise 4, you are asked to make Excess Electricity, CO2 and Primary Energy Supply Diagrams of a predefined reference system and two alternatives. Such diagrams are able to show the ability of a given energy system to integrate fluctuating renewable energy sources such as wind power. For more information on the methodology, please consult the following articles:

- Henrik Lund. **Renewable Energy Systems. The Choice and Modeling of 100% Renewable Solutions.** Academic Press (Elsevier) 2010. Link
- Lund, H. *Excess electricity diagrams and the integration of renewable energy.* International Journal of Sustainable Energy, Vol 23 (4), pp. 149-156.
- Lund, H. *Large-scale integration of wind power into different energy systems.* Energy, Vol 30 (13), pp. 2402-2412.
- Lund, H. *Large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply.* Renewable Energy, Vol 31(4), pp 503-515, April 2006.

## Exercise 4.1: Make an Excess Electricity Diagram of the Reference System

Open the EnergyPLAN model. Load the input data set "Denmark2030Reference.txt", which is a model of a Danish "Business as usual" scenario made by the Danish Energy Authorities in year 2006. In the "Regulation window" set the import/export transmission at zero, remove any CEEP regulation strategies and choose technical regulation strategy 1.

The annual electricity demand is 49 TWh/year and the expected wind power production is 14.87 TWh, divided into 3100 MW onshore producing 7.26 TWh/year and 1952 MW offshore producing 7.61 TWh/year.

*Question 4.1.1: Identify (in the RenewableEnergy window) the wind power capacities which correspond to an annual production of 0 TWh, 5 TWh, 10 TWh etc. up to 50 TWh/year. Start with only onshore up to 4270 MW followed by additional offshore capacity. For each wind production, calculate the critical excess electricity production (CEEP), the CO2 emission and the Primary Energy Supply (PES), excluding the wind power RES.*

| Wind prod. TWh/year | Wind cap. MW | Offshore MW | CEEP TWh/year | PES excl.RES TWh/year | CO2-emission Mt/year |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 280,91 | 60,57 |
| 5 | | | | | |
| 10 | | | | | |
| 15 | | | | | |
| 20 | | | | | |
| 25 | | | | | |
| 30 | | | | | |
| 35 | | | | | |
| 40 | | | | | |
| 45 | | | | | |
| 50 | | | | | |

## Exercise 4.2: Use the model "Run serial calculation" function

Do the calculations of exercise 4.1 by using the model "Run serial calculation" function and achieve the same results faster. Load the results into an excel spreadsheet and design three diagrams with excess, PES and CO2 as functions of the wind power input. You find the "Run serial calculation" in the "Output" window. Note that you can only change one input value at the time. E.g set the RES1 onshore value to 4270 MW and change RES2 off-shore inputs form 0 to 10264 MW.

## Exercise 4.3: Compare three different energy systems (open system)

Make an excess electricity diagram comparing the following three energy systems:
- System 1: The energy system of exercises 4.1 and 4.2
- System 2: System 1 with technical regulation strategy 2 (Balancing both heat and electricity demand)
- System 3: System 2 plus 500 MWe heat pumps with a COP of 3.5 (250 MW each in DH group 2 and 3). Replace existing 7 MW heat pump.

Make a Fuel Demand (Primary Energy Supply excl. RES) diagram of the same three systems.

## Exercise 4.4: Compare three different energy systems (Closed system)

In the previous exercises, the excess electricity production has been wasted. However, critical excess production is not allowed in the electricity supply. Therefore, you must activate the critical excess regulation in the Regulation window and make the calculations of exercise 4.3 once again.

In the regulation window, choose the following CEEP regulation: 23457

Discuss the results of both exercise 4.3 and 4.4.

## Exercise 4.5: Compare the three energy systems of IDA Energy Year 2006

Use the following input files of IDA energy year 2006:
- Danish Reference year 2030: "Denmark2030Reference.txt"
- IDA Energy Plan 2030: "Denmark2030Alternative.txt"
- IDA 100% Renewable Year 2050: "Denmark100%RES.txt"

Make an excess electricity production diagram and a Fuel Demand diagram comparing the three systems. Use the same wind power input as in the previous exercises from 0 to 50 TWh/year.

Remember to set import export transmission capacity at zero when making both diagrams. And remember to set wind power capacity at 4270 when doing the automatic calculations in the output window.

Moreover, remember to set CEEP regulation at zero when making the Excess diagram.

*Always REMEMBER to save your file under a new name e.g. exercise 4.*