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Guideline to EnergyPLAN Exercise 4:

Advanced Energy System Analysis: Excess diagrams

In Exercise 4, you are asked to make Excess Electricity, CO_2 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 "External Electricity Market" window under the "Cost" tab 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 "Electricity Only" 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 CO_2 emission and the Primary Energy Supply (PES), excluding the wind power RES.

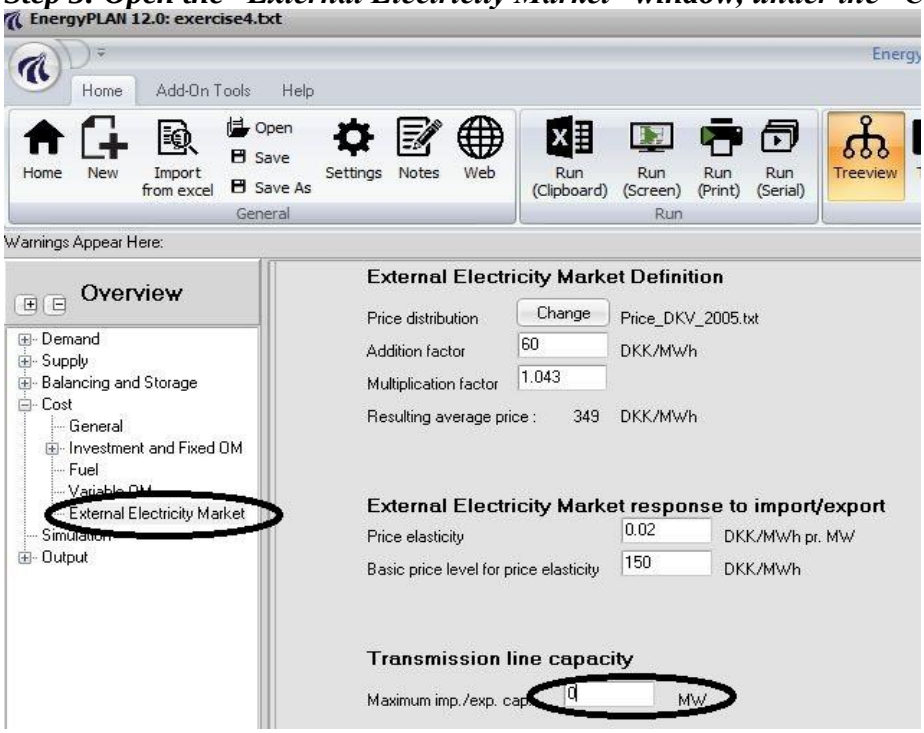
Wind prod. TWh/year	Wind cap. MW	Offshore MW	CEEP TWh/year	PES excl.RES TWh/year	CO2-emission Mt/year
0	0	0	0	280,91	60,57
5					
10					
15					
20					
25					
30					
35					
40					
45					
50					

How to do exercise 4.1:

Step 1: Open the EnergyPLAN model and load the input data set "Denmark2030Reference.txt"**.** The data set is part of the files, when you download the EnergyPLAN model. If for some reason, you do not have the data set, it can be downloaded from the following address: http://www.energyplan.eu/wp-content/uploads/2014/06/EnergyPLAN_DK.zip.

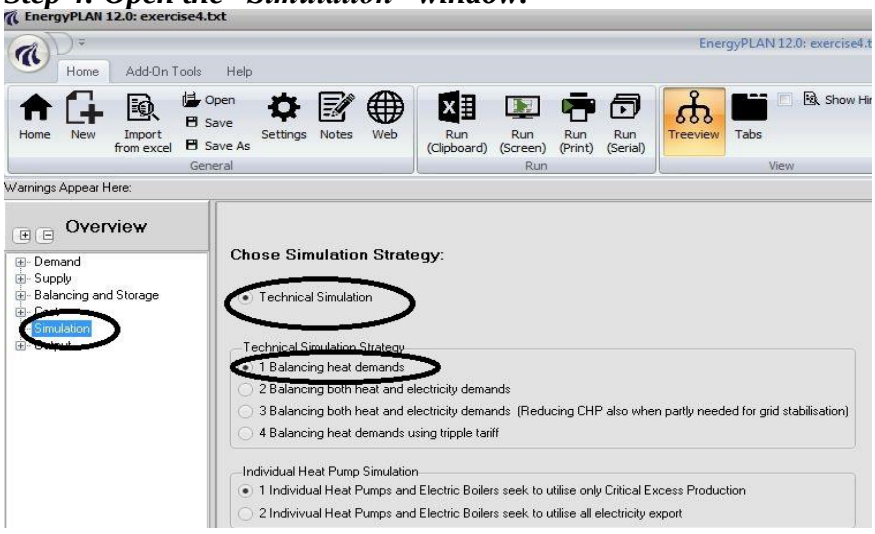
Step 2: Save as exercise 4.

Step 3: Open the "External Electricity Market" window, under the "Cost" tab:



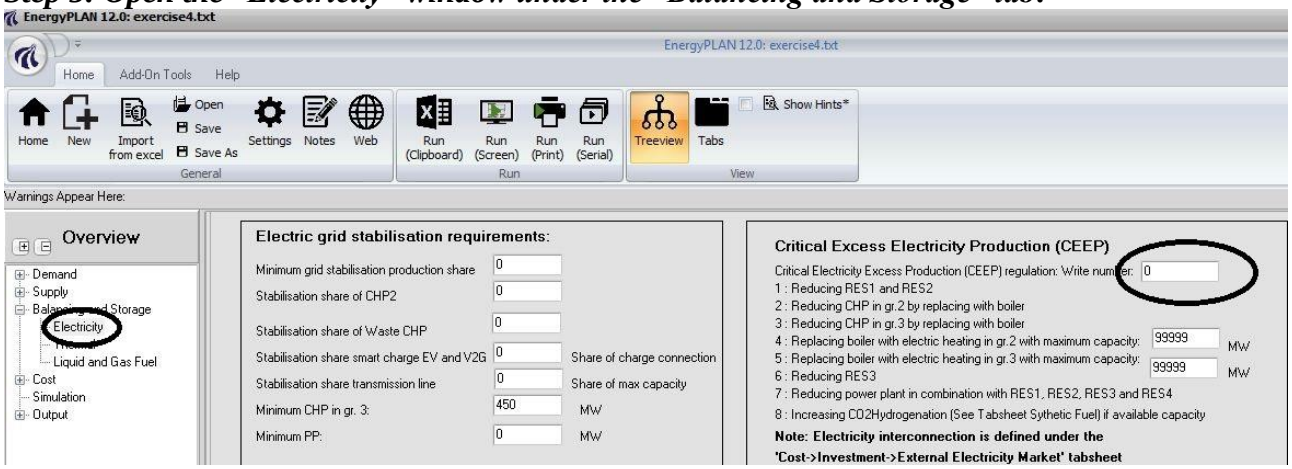
Set Transmission line capacity to zero

Step 4: Open the "Simulation" window:



Choose Technical Simulation
Choose Technical Simulation Strategy 1

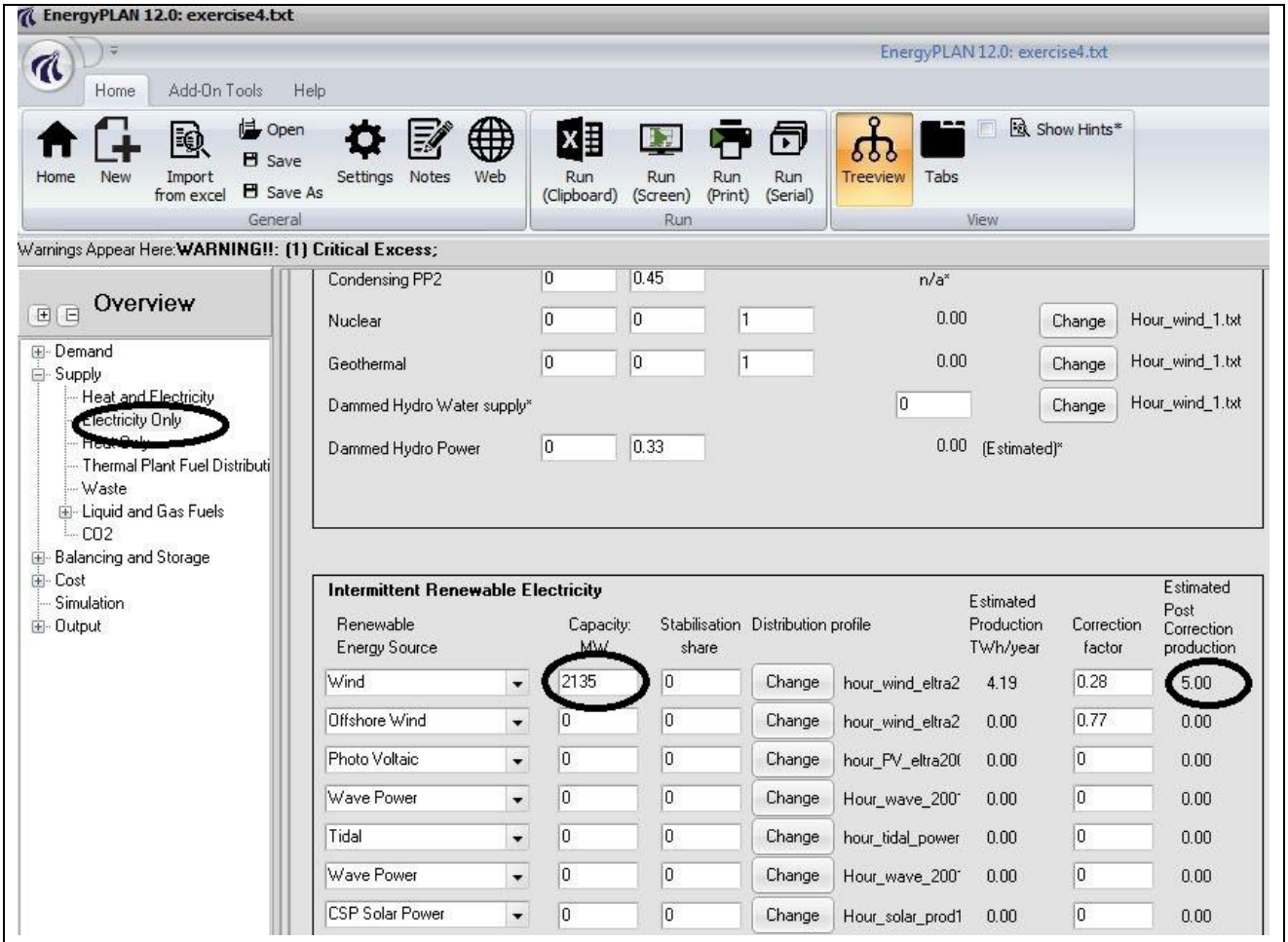
Step 5: Open the "Electricity" window under the "Balancing and Storage" tab:



Set CEEP regulation at zero

Step 6: Open the "Electricity only" window under the "Supply" tab:
Set all wind capacities at zero and calculate.
The electricity excess production is 0 TWh/year,
the CO_2 emission is 60.57 Mt/year,
and the PES excluding RES is 280.91 TWh/year.

Step 5: Change wind capacities
Identify the wind power capacity of an annual production of 5 TWh (Estimated Post Correction Production) and calculate.
The critical excess in electricity production is 0.13 TWh/year,
the CO_2 emission is 58.19 Mt/year,
and the PES is 276,65 TWh/year including RES and 271.64 excluding RES (wind power).



Step 6: Continue and achieve the following results:

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	2135	0	0,13	271,65	58,19
10	4270	0	1,04	263,86	56,19
15	4270	1283	2,7	257,51	54,56
20	4270	2566	5,21	252,76	53,34
25	4270	3849	8,38	249,26	52,44
30	4270	5132	12,07	246,75	51,79
35	4270	6415	16,08	244,86	51,31
40	4270	7698	20,33	243,42	50,94
45	4270	8981	24,76	242,34	50,66
50	4270	10264	29,32	241,5	50,45

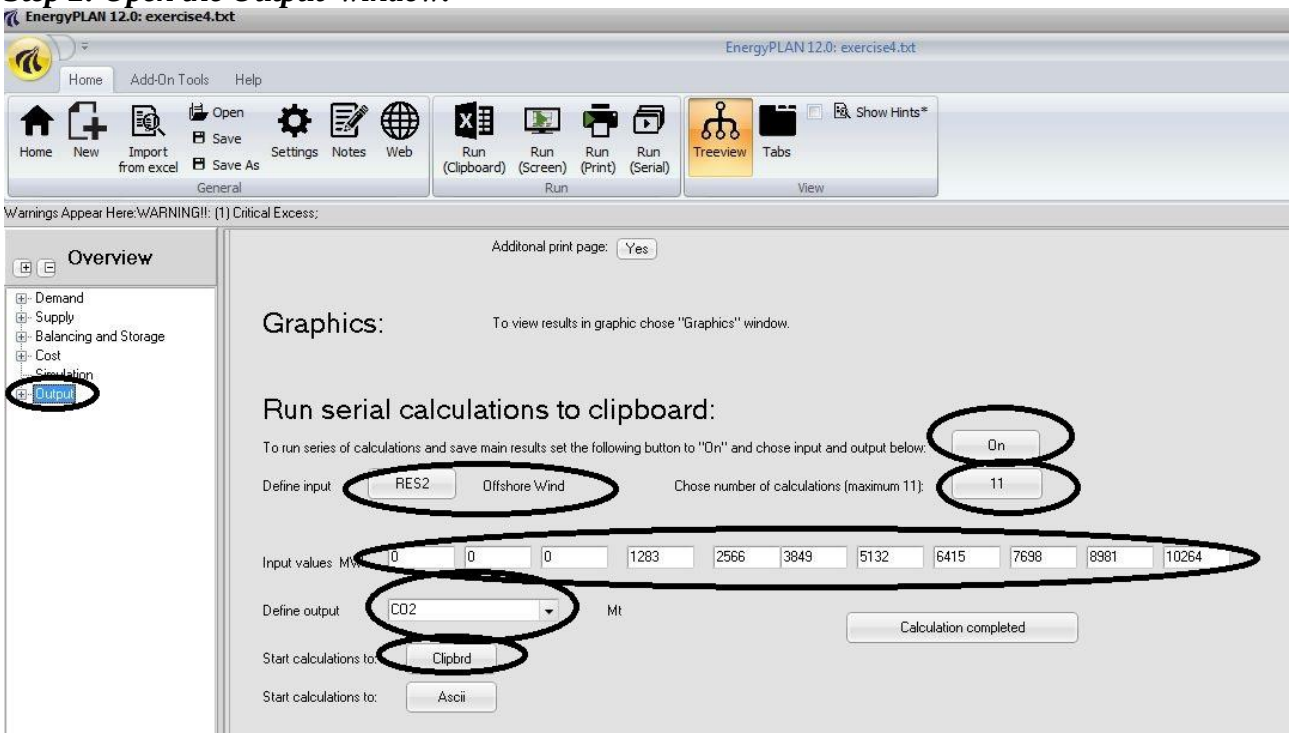
Exercise 4.2: Use the model "Run serial calculation" function

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 CO_2 as functions of the wind power input. You can 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 Wind) value to 4270 MW and change RES2 (Offshore wind) inputs form 0 to 10264 MW.

How to do exercise 4.2: Use the input file from exercise 4.1

Step 1: Make sure that RES1 Wind capacity is 4270 MW in the "Electricity only" window

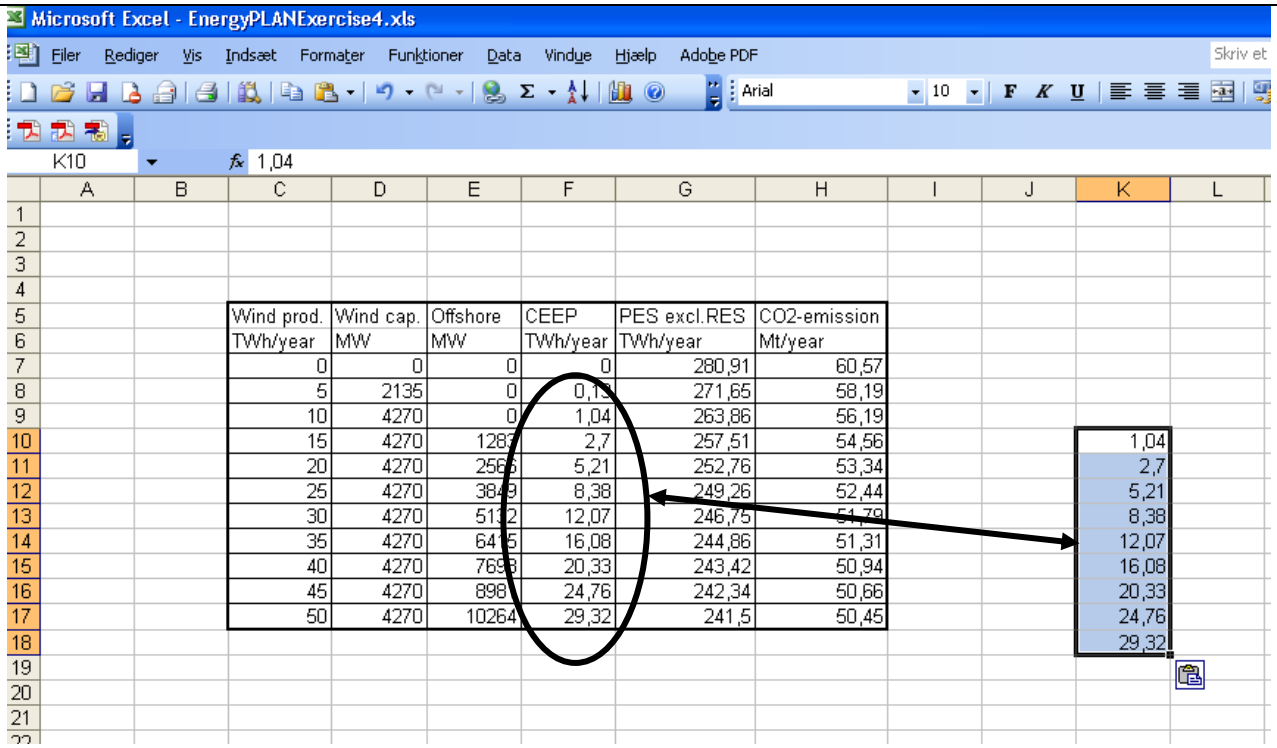
Step 2: Open the Output window:



1) Set Run serial calculation at "On", 2) Define input as "RES2", 3)Type in the offshore wind capacities, 4) Define output to CEEP, CO2 and Fuel excluding RES, respectively
Start calculations by activating the "Clipbrd" button.

The model will now start making 11 calculations and the requested result of each will be transferred to the clipbrd.

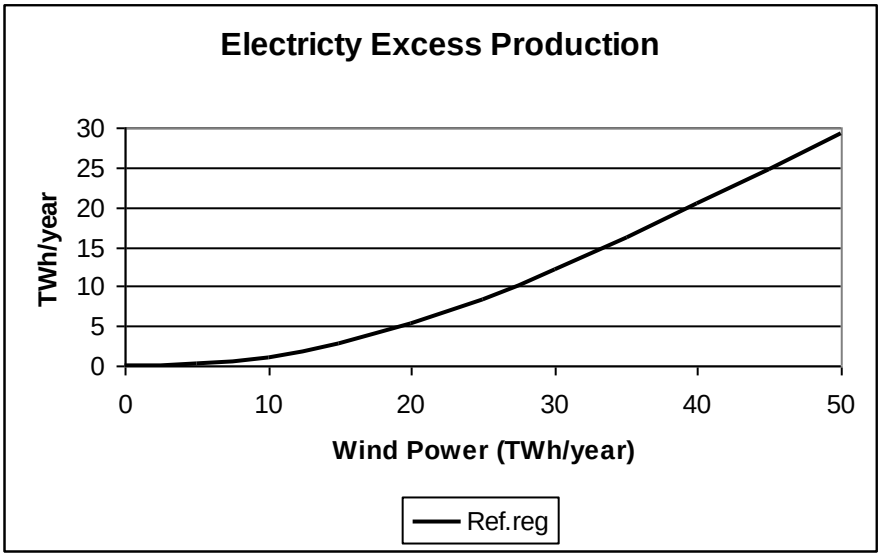
Step 3: Open Excel spreadsheet and load the data:



Load the data into the excel spreadsheet and compare to the results of exercise 4.1
Note that you can not include the first two results in the calculation, since the EnergyPLAN model can only change one value at the time. Thus, for the two first results you have to change wind onshore capacities, while the offshore wind capacity is set to zero.

Step 5: Repeat the procedure for CO2 and PES excluding RES (Fuel excl. RES).

Step 6: Make some diagrams in excel such as e.g.:



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 simulation strategy 2
- 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.

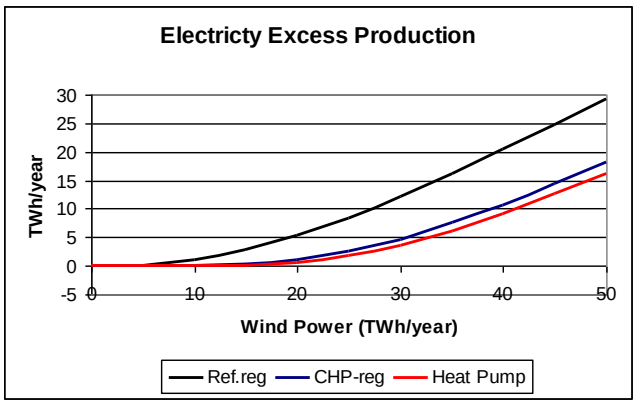
Discuss the results.

How to do exercise 4.3: Use the input file from exercise 4.1

Repeat the guideline for exercise 4.2 and achieve the following results:

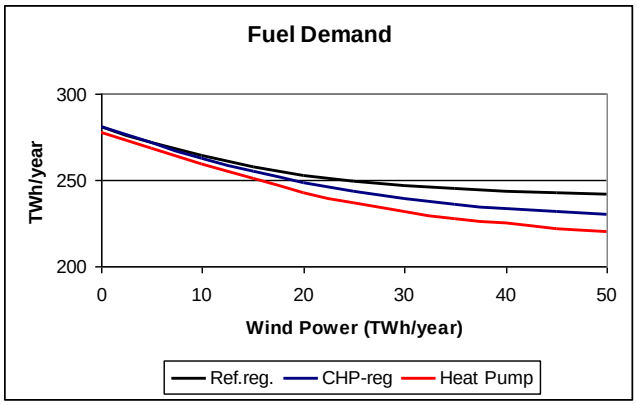
Critical Electricity Excess Production

Wind prod. TWh/year	Wind cap. MW	Offshore MW	Ref.reg TWh/year	CHP-reg TWh/year	Heat Pump TWh/year
0	0	0	0	0	0
5	2135	0	0,13	0	0
10	4270	0	1,04	0,02	0
15	4270	1283	2,7	0,26	0,13
20	4270	2566	5,21	1	0,64
25	4270	3849	8,38	2,47	1,78
30	4270	5132	12,07	4,67	3,65
35	4270	6415	16,08	7,47	6,15
40	4270	7698	20,33	10,73	9,15
45	4270	8981	24,76	14,32	12,53
50	4270	10264	29,32	18,16	16,2



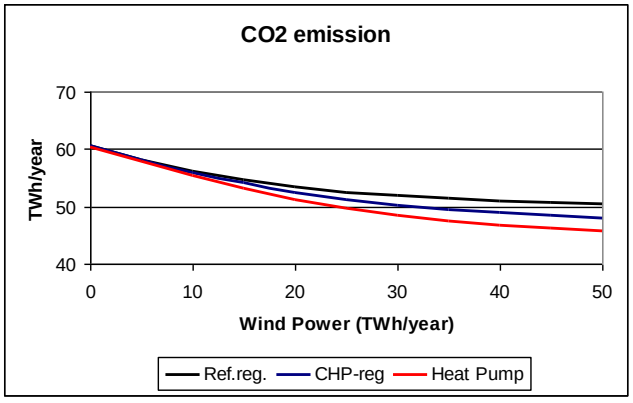
Fuel Demand

Wind prod. TWh/year	Wind cap. MW	Offshore MW	Ref.reg. TWh/year	CHP-reg TWh/year	Heat Pump TWh/year
0	0	0	280,91	280,91	277,89
5	2135	0	271,65	271,51	268,33
10	4270	0	263,86	262,84	259,12
15	4270	1283	257,51	255,01	250,42
20	4270	2566	252,76	248,45	242,81
25	4270	3849	249,26	243,21	236,56
30	4270	5132	246,75	239,18	231,61
35	4270	6415	244,86	236,05	227,71
40	4270	7698	243,42	233,59	224,59
45	4270	8981	242,34	231,65	222,06
50	4270	10264	241,5	230,07	219,97



CO2 emissions

Wind prod. TWh/year	Wind cap. MW	Offshore MW	Ref.reg. TWh/year	CHP-reg TWh/year	Heat Pump TWh/year
0	0	0	60,57	60,57	60,27
5	2135	0	58,19	58,16	57,82
10	4270	0	56,19	55,97	55,38
15	4270	1283	54,56	54,02	53,07
20	4270	2566	53,34	52,41	51,08
25	4270	3849	52,44	51,14	49,57
30	4270	5132	51,79	50,17	48,38
35	4270	6415	51,31	49,42	47,44
40	4270	7698	50,94	48,83	46,69
45	4270	8981	50,66	48,37	46,09
50	4270	10264	50,45	47,99	45,59



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.

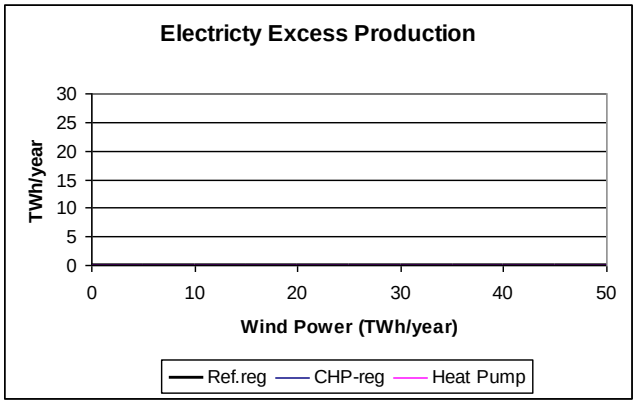
In the regulation window, choose the following CEEP regulation: 23457

Discuss the results of both exercise 4.3 and 4.4.

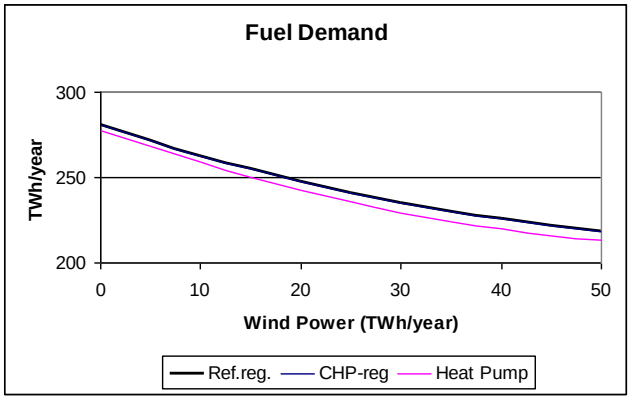
How to do exercise 4.4: Use the input file from exercise 4.3

Add CEEP regulation 23457 and repeat the guideline for exercise 4.3. Achieve the following results:

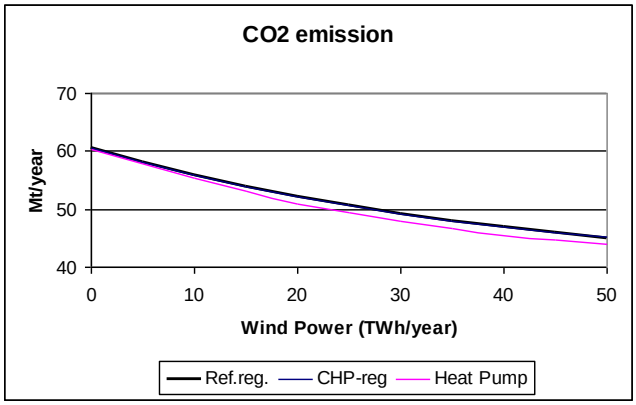
Critical Electricity Excess Production					
Wind prod. TWh/year	Wind cap. MW	Offshore MW	Ref.reg TWh/year	CHP-reg TWh/year	Heat Pump TWh/year
0	0	0	0	0	0
5	2135	0	0	0	0
10	4270	0	0	0	0
15	4270	1283	0	0	0
20	4270	2566	0	0	0
25	4270	3849	0	0	0
30	4270	5132	0	0	0
35	4270	6415	0	0	0
40	4270	7698	0	0	0
45	4270	8981	0	0	0
50	4270	10264	0	0	0



Fuel Demand					
Wind prod. TWh/year	Wind cap. MW	Offshore MW	Ref.reg. TWh/year	CHP-reg TWh/year	Heat Pump TWh/year
0	0	0	280,91	280,91	277,89
5	2135	0	271,52	271,51	268,33
10	4270	0	262,8	262,82	259,11
15	4270	1283	254,77	254,77	250,34
20	4270	2566	247,57	247,58	242,4
25	4270	3849	241,11	241,13	235,46
30	4270	5132	235,32	235,33	229,43
35	4270	6415	230,1	230,11	224,23
40	4270	7698	225,48	225,49	219,8
45	4270	8981	221,47	221,48	216,08
50	4270	10264	218	218,02	212,94



CO2 emissions					
Wind prod. TWh/year	Wind cap. MW	Offshore MW	Ref.reg. Mt/year	CHP-reg Mt/year	Heat Pump Mt/year
0	0	0	60,57	60,57	60,27
5	2135	0	58,16	58,16	57,82
10	4270	0	55,96	55,97	55,38
15	4270	1283	53,97	53,96	53,06
20	4270	2566	52,2	52,2	51,02
25	4270	3849	50,63	50,64	49,3
30	4270	5132	49,24	49,24	47,85
35	4270	6415	47,98	47,99	46,6
40	4270	7698	46,87	46,88	45,54
45	4270	8981	45,91	45,91	44,66
50	4270	10264	45,08	45,09	43,93



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 line capacity to zero ("External Electricity Market" window, under the "Cost" tab) when making both diagrams. And remember to set wind onshore power capacity at 4270 when doing the automatic calculations in the output window.

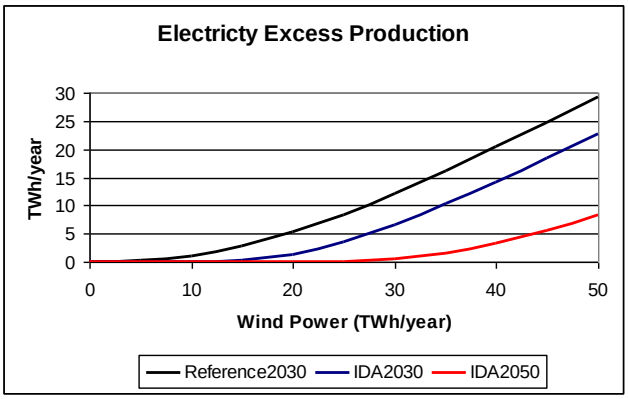
Moreover, remember to set CEEP regulation to zero ("Electricity" window under the "Balancing and Storage" tab) when making the Excess diagram.

How to do exercise 4.5:

Repeat the guideline for exercise 4.3 and 4.4 and achieve the following results:

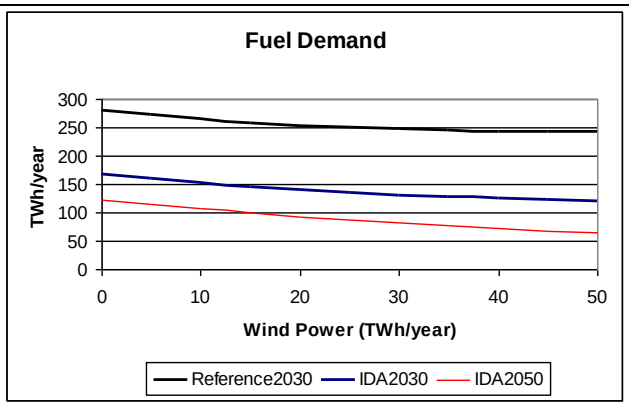
Critical Electricity Excess Production

Wind prod. TWh/year	Wind cap. MW	Offshore MW	Reference20 TWh/year	IDA2030 TWh/year	IDA2050 TWh/year
0	0	0	0	0	0
5	2135	0	0,13	0	0
10	4270	0	1,04	0	0
15	4270	1283	2,7	0,15	0
20	4270	2566	5,21	1,26	0
25	4270	3849	8,38	3,62	0,04
30	4270	5132	12,07	6,66	0,4
35	4270	6415	16,08	10,26	1,51
40	4270	7698	20,33	14,22	3,21
45	4270	8981	24,76	18,42	5,44
50	4270	10264	29,32	22,77	8,21



Fuel Demand

Wind prod. TWh/year	Wind cap. MW	Offshore MW	Reference20 TWh/year	IDA2030 TWh/year	IDA2050 TWh/year
0	0	0	280,91	167,58	122,57
5	2135	0	271,65	159,07	114,87
10	4270	0	263,86	151,94	107,49
15	4270	1283	257,51	145,3	100,47
20	4270	2566	252,76	139,34	93,75
25	4270	3849	249,26	134,16	87,38
30	4270	5132	246,75	130	81,46
35	4270	6415	244,86	126,82	76,45
40	4270	7698	243,42	124,39	72
45	4270	8981	242,34	122,46	68,28
50	4270	10264	241,5	120,91	65,14



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