

## Guideline to EnergyPLAN Exercise 4:

### Advanced Energy System Analysis: Excess diagrams

In Exercise 4, you are asked to make Excess Electricity, CO<sub>2</sub> 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<sub>2</sub> emission and the Primary Energy Supply (PES), excluding the wind power RES.*

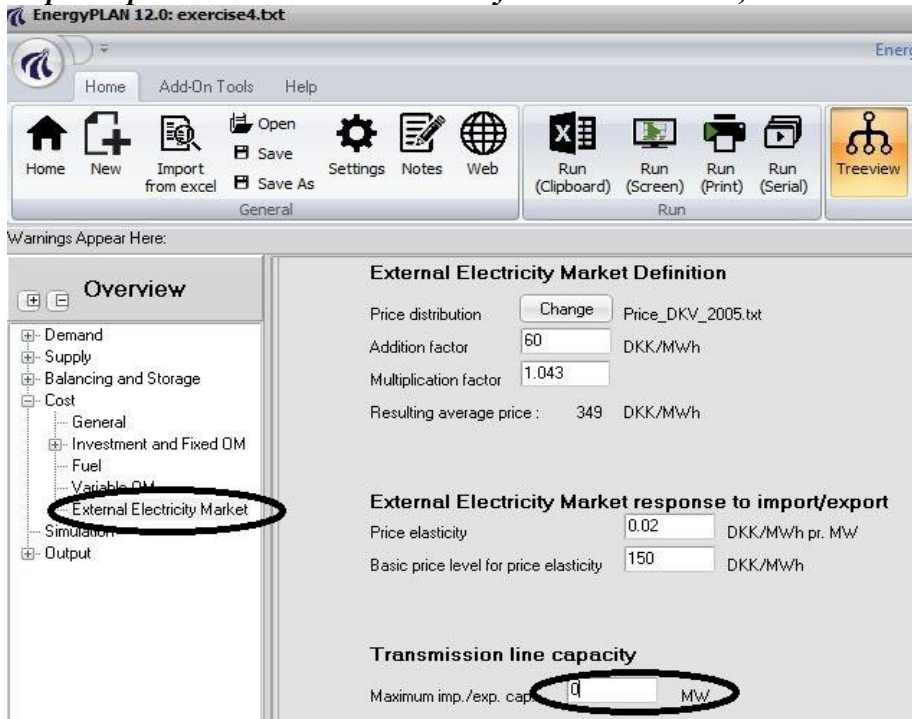
Wind prod. TWh/year	Wind cap. MW	Offshore MW	CEEP TWh/year	PES excl.RES TWh/year	CO <sub>2</sub> -emission Mt/year
0	0	0	0	280,91	60,57
5					
10					
15					
20					
25					
30					
35					
40					
45					
50					

## 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](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:**



The screenshot shows the EnergyPLAN 12.0 software interface. The title bar reads "EnergyPLAN 12.0: exercise4.txt". The menu bar includes "Home", "Add-On Tools", and "Help". The toolbar contains icons for Home, New, Import from excel, Save, Save As, Settings, Notes, Web, Run (Clipboard), Run (Screen), Run (Print), Run (Serial), and Treeview. The Overview pane on the left shows a tree view with "Cost" expanded, and "External Electricity Market" selected. The main window displays the "External Electricity Market Definition" section with the following parameters:

- Price distribution:  Price\_DKV\_2005.txt
- Addition factor:  DKK/MWh
- Multiplication factor:
- Resulting average price: 349 DKK/MWh

The "External Electricity Market response to import/export" section has the following parameters:

- Price elasticity:  DKK/MWh pr. MW
- Basic price level for price elasticity:  DKK/MWh

The "Transmission line capacity" section has the following parameter:

- Maximum imp./exp. cap:  MW

Set Transmission line capacity to zero

**Step 4: Open the “Simulation” window:**



The screenshot shows the EnergyPLAN 12.0 software interface. The title bar reads "EnergyPLAN 12.0: exercise4.txt". The menu bar includes "Home", "Add-On Tools", and "Help". The toolbar contains icons for Home, New, Import from excel, Save, Save As, Settings, Notes, Web, Run (Clipboard), Run (Screen), Run (Print), Run (Serial), Treeview, and Tabs. The Overview pane on the left shows a tree view with "Simulation" selected. The main window displays the "Chose Simulation Strategy:" section with the following options:

- Technical Simulation
- Individual Heat Pump Simulation

The "Technical Simulation Strategy" section has the following options:

- 1 Balancing heat demands
- 2 Balancing both heat and electricity demands
- 3 Balancing both heat and electricity demands (Reducing CHP also when partly needed for grid stabilisation)
- 4 Balancing heat demands using tripple tariff

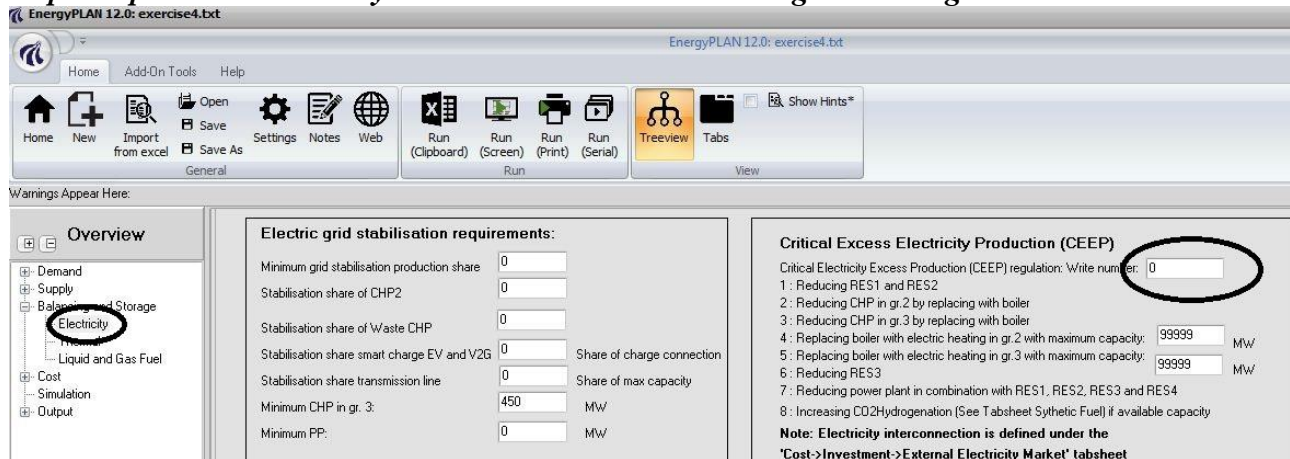
The "Individual Heat Pump Simulation" section has the following options:

- 1 Individual Heat Pumps and Electric Boilers seek to utilise only Critical Excess Production
- 2 Individual Heat Pumps and Electric Boilers seek to utilise all electricity export

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<sub>2</sub> 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<sub>2</sub> emission is 58.19 Mt/year,  
and the PES is 276,65 TWh/year including RES and 271.64 excluding RES (wind power).

EnergyPLAN 12.0: exercise4.txt

Home Add-On Tools Help

Home New Import from excel Open Save Save As Settings Notes Web Run (Clipboard) Run (Screen) Run (Print) Run (Serial) Treeview Tabs Show Hints\*

Warnings Appear Here: **WARNING!!: (1) Critical Excess:**

**Overview**

- ⊕ Demand
- ⊖ Supply
  - Heat and Electricity
  - Electricity Only
  - Heat Only
  - Thermal Plant Fuel Distributi
  - Waste
  - Liquid and Gas Fuels
  - CO2
- ⊕ Balancing and Storage
- ⊕ Cost
- Simulation
- ⊕ Output

Condensing PP2	0	0.45		n/a*		
Nuclear	0	0	1	0.00	Change	Hour_wind_1.txt
Geothermal	0	0	1	0.00	Change	Hour_wind_1.txt
Dammed Hydro Water supply*				0	Change	Hour_wind_1.txt
Dammed Hydro Power	0	0.33		0.00	(Estimated)*	

Renewable Energy Source	Capacity: MW	Stabilisation share	Distribution profile	Estimated Production TWh/year	Correction factor	Estimated Post Correction production
Wind	2135	0	Change hour_wind_eltra2	4.19	0.28	5.00
Offshore Wind	0	0	Change hour_wind_eltra2	0.00	0.77	0.00
Photo Voltaic	0	0	Change hour_PV_eltra200	0.00	0	0.00
Wave Power	0	0	Change Hour_wave_200	0.00	0	0.00
Tidal	0	0	Change hour_tidal_power	0.00	0	0.00
Wave Power	0	0	Change Hour_wave_200	0.00	0	0.00
CSP Solar Power	0	0	Change Hour_solar_prod1	0.00	0	0.00

**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<sub>2</sub> 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:**

EnergyPLAN 12.0: exercise4.txt

Home Add-On Tools Help

Home New Import from excel Open Save Save As Settings Notes Web Run (Clipboard) Run (Screen) Run (Print) Run (Serial) Treeview Tabs Show Hints\*

Warnings Appear Here: WARNING!!: (1) Critical Excess:

Additional print page: Yes

Overview

- Demand
- Supply
- Balancing and Storage
- Cost
- Simulation
- Output**

Graphics: To view results in graphic chose "Graphics" window.

Run serial calculations to clipboard:

To run series of calculations and save main results set the following button to "On" and chose input and output below.

Define input: RES2 Offshore Wind Chose number of calculations (maximum 11): 11

Input values: MW 0 0 0 1283 2566 3849 5132 6415 7698 8981 10264

Define output: CO2 Mt

Start calculations to: Clipbrd

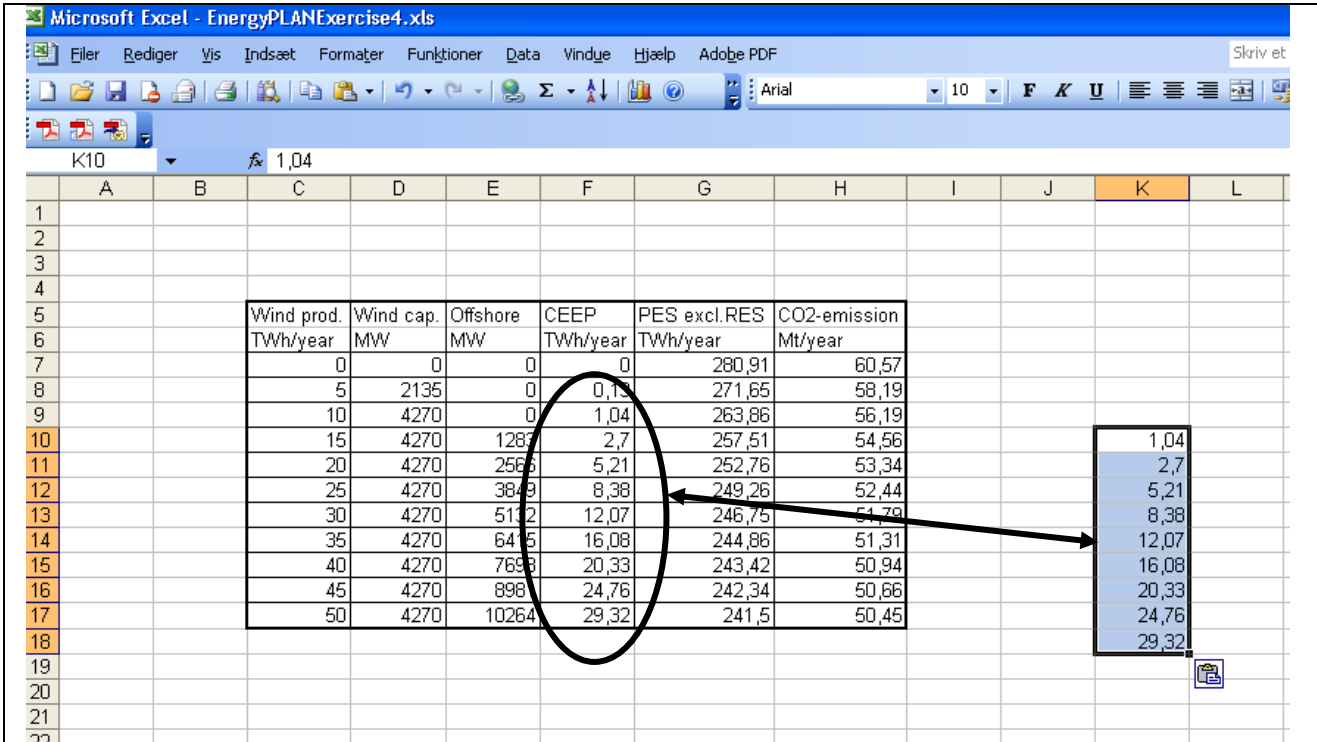
Start calculations to: Ascii

Calculation completed

1) Set Run serial calculation at “On”, 2) Define input as “RES2”, 3) Type in the offshore wind capacities, 4) Define output to CEEP, CO<sub>2</sub> 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.

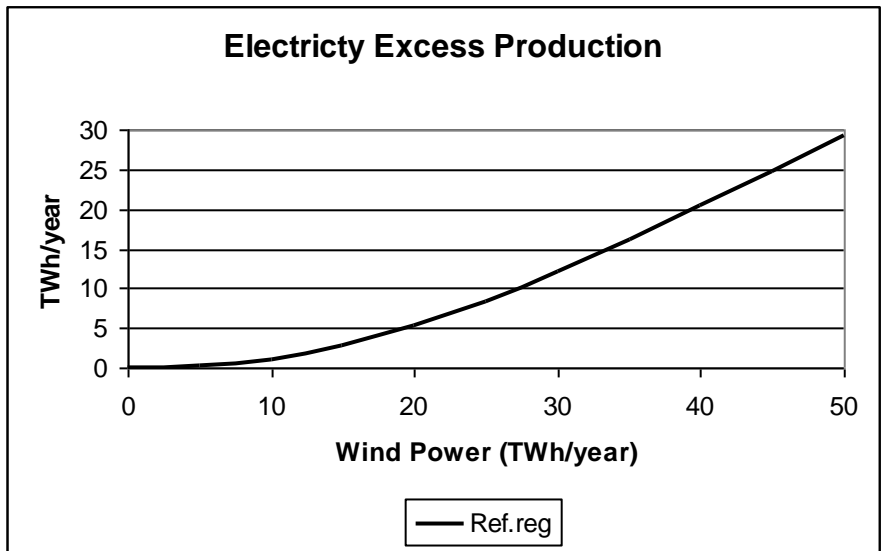
**Step 3: Open Excel spreadsheet and load the data:**



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.

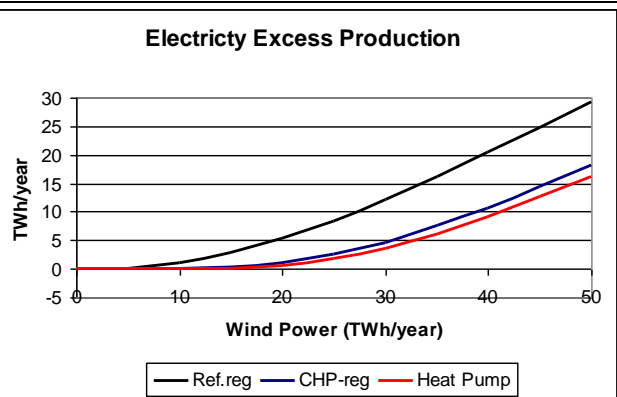
Discuss the results.

#### 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:

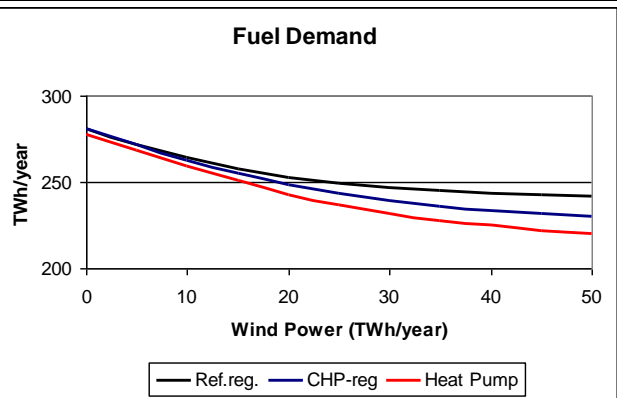
##### Critical Electricity Excess Production

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



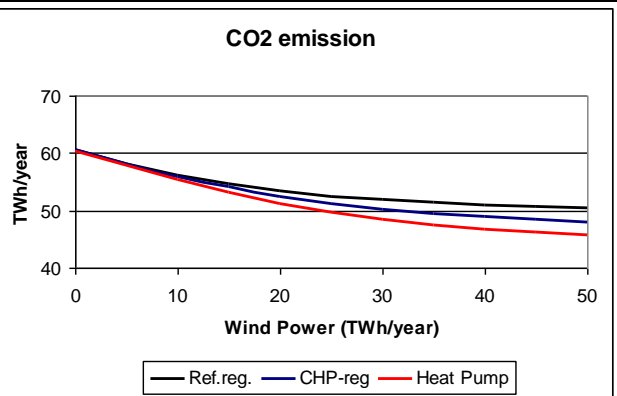
##### Fuel Demand

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.

<b>How to do exercise 4.4:</b> Use the input file from exercise 4.3																																																																															
Add CEEP regulation 23457 and repeat the guideline for exercise 4.3. Achieve the following results:																																																																															
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="6" style="text-align: center;">Critical Electricity Excess Production</th> </tr> <tr> <th>Wind prod. TWh/year</th> <th>Wind cap. MW</th> <th>Offshore MW</th> <th>Ref.reg TWh/year</th> <th>CHP-reg TWh/year</th> <th>Heat Pump TWh/year</th> </tr> </thead> <tbody> <tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>5</td><td>2135</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>10</td><td>4270</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>15</td><td>4270</td><td>1283</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>20</td><td>4270</td><td>2566</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>25</td><td>4270</td><td>3849</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>30</td><td>4270</td><td>5132</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>35</td><td>4270</td><td>6415</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>40</td><td>4270</td><td>7698</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>45</td><td>4270</td><td>8981</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>50</td><td>4270</td><td>10264</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table>	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	<div style="text-align: center;"> <h4>Electricity Excess Production</h4> </div>
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<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="6" style="text-align: center;">CO2 emissions</th> </tr> <tr> <th>Wind prod. TWh/year</th> <th>Wind cap. MW</th> <th>Offshore MW</th> <th>Ref.reg Mt/year</th> <th>CHP-reg Mt/year</th> <th>Heat Pump Mt/year</th> </tr> </thead> <tbody> <tr><td>0</td><td>0</td><td>0</td><td>60,57</td><td>60,57</td><td>60,27</td></tr> <tr><td>5</td><td>2135</td><td>0</td><td>58,16</td><td>58,16</td><td>57,82</td></tr> <tr><td>10</td><td>4270</td><td>0</td><td>55,96</td><td>55,97</td><td>55,38</td></tr> <tr><td>15</td><td>4270</td><td>1283</td><td>53,97</td><td>53,96</td><td>53,06</td></tr> <tr><td>20</td><td>4270</td><td>2566</td><td>52,2</td><td>52,2</td><td>51,02</td></tr> <tr><td>25</td><td>4270</td><td>3849</td><td>50,63</td><td>50,64</td><td>49,3</td></tr> <tr><td>30</td><td>4270</td><td>5132</td><td>49,24</td><td>49,24</td><td>47,85</td></tr> <tr><td>35</td><td>4270</td><td>6415</td><td>47,98</td><td>47,99</td><td>46,6</td></tr> <tr><td>40</td><td>4270</td><td>7698</td><td>46,87</td><td>46,88</td><td>45,54</td></tr> <tr><td>45</td><td>4270</td><td>8981</td><td>45,91</td><td>45,91</td><td>44,66</td></tr> <tr><td>50</td><td>4270</td><td>10264</td><td>45,08</td><td>45,09</td><td>43,93</td></tr> </tbody> </table>	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	<div style="text-align: center;"> <h4>CO2 emission</h4> </div>
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### 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.

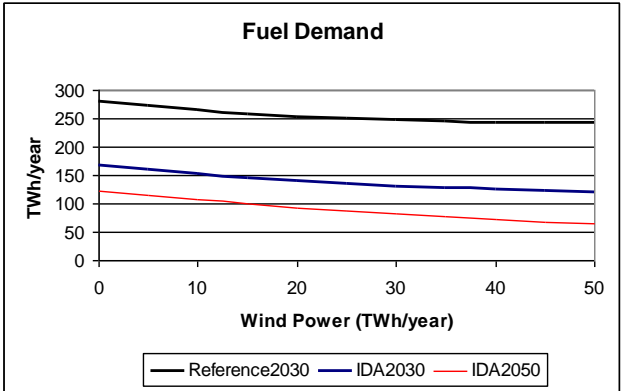
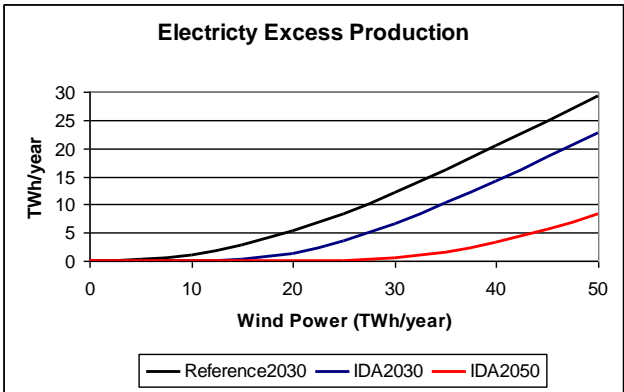
Remember to set import export transmission line capacity to zero ("External Electricity Market" window, under the "Cost" tab) when making both diagrams. And remember to set wind onshore power capacity at 4270 when doing the automatic calculations in the output window.

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

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.**