

## **Guideline to EnergyPLAN Exercise 2: Make Simple Energy System Analyses.**

In exercise 2, you are asked to do a couple of energy system improvements of the energy system of exercise 1. Through the exercise and the guideline, you learn step by step how to analyse changes to the energy system.

Exercise 2 continues with the system defined in exercise 1, which is:

- Electricity demand of 49 TWh/year and “DK 2013 electricity demand”
- Condensing power plant: 9000 MW coal –fired
- 2000 MW wind power using “DK 2013 Wind onshore”
- Annual district heating demand of 39.18 TWh (distribution “hour\_distr\_heat”)
- Fuel demand for individual house heating of 23.07 TWh divided into 0.01 coal, 6.72 oil, 9.05 natural gas and 7.29 biomass.
- Industrial fuel demand of 53.66 TWh divided into 3.37 coal, 26.92 oil, 18.19 natural gas and 5.18 biomass (including fuel for district heating and electricity production).
- Industrial district heating production of 1.73 TWh and an electricity production of 2.41 TWh. Use the hour distribution file “const”.
- Fuel demand for transportation: 13.25 TWh Jet Petrol, 27.50 TWh Diesel and 28.45 TWh Petrol.

The system has a primary energy supply of 286.76 TWh/year and CO<sub>2</sub> emissions of 77.77 Mt.

### **Exercise 2.1: Energy conservation in house heating**

Open the EnergyPLAN model. Load the data of exercise 1. Assuming, that the district heating demand of 39.18 TWh/year is composed of 20% grid losses, 20% hot water and 60% space heating, implement energy conservation in house heating equal to 50% of the space heating demand. Do the same for the individual house heating demand of 19.70 TWh/year assuming that the demand is composed of 25% hot water and 75% space heating.

Consequently, the annual district heating demand will decrease by 50% of 60% from 39.18 to 27.43 TWh/year. And the heat demand for individual houses will decrease by 50% of 75% from 19.70 to 12.31 TWh/year.

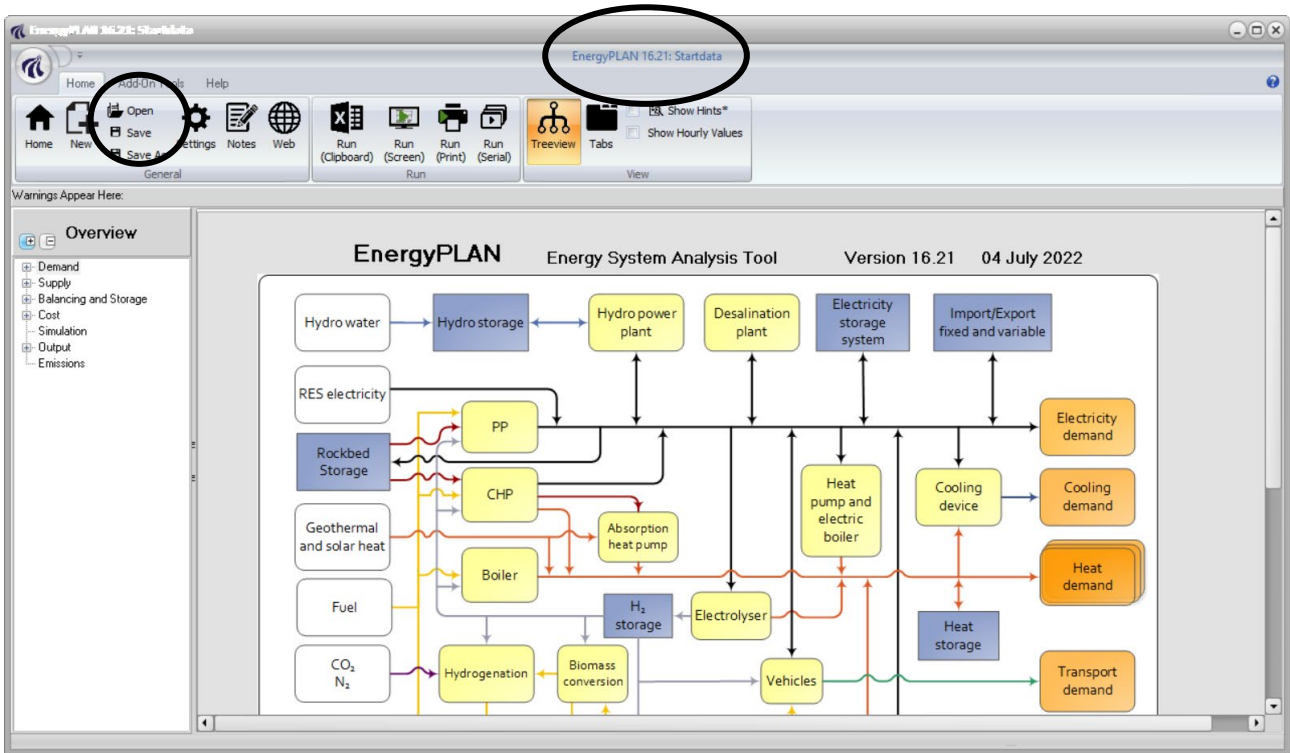
Note that such energy conservation measures change the duration curves and, consequently, the existing hour distribution curves must be replaced by “VpDkFjv50.txt” and Hour\_indv-heat-50percent.txt.

*Question 2.1.1: What is the peak hour district heating demand before and after implementing the energy conservation?*

*Question 2.1.2: What are the primary energy supply and the CO<sub>2</sub> emission of the system after implementing such energy conservation measures?*


## How to do exercise 2.1:

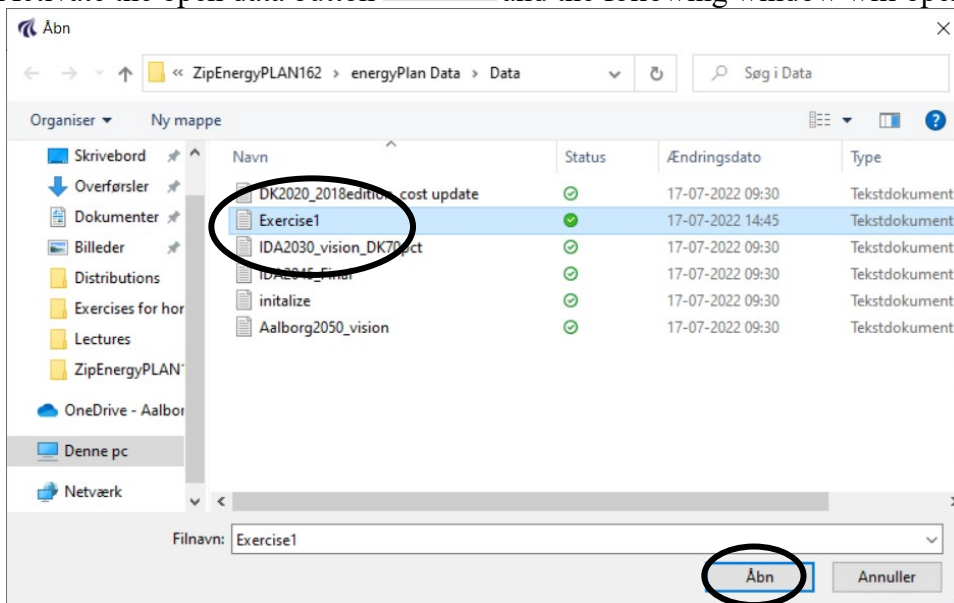
**Step 1: Open the EnergyPLAN model. You will see the following front page (version 16.21):**



Look at the top bar: The EnergyPLAN model is loaded with “Startdata”

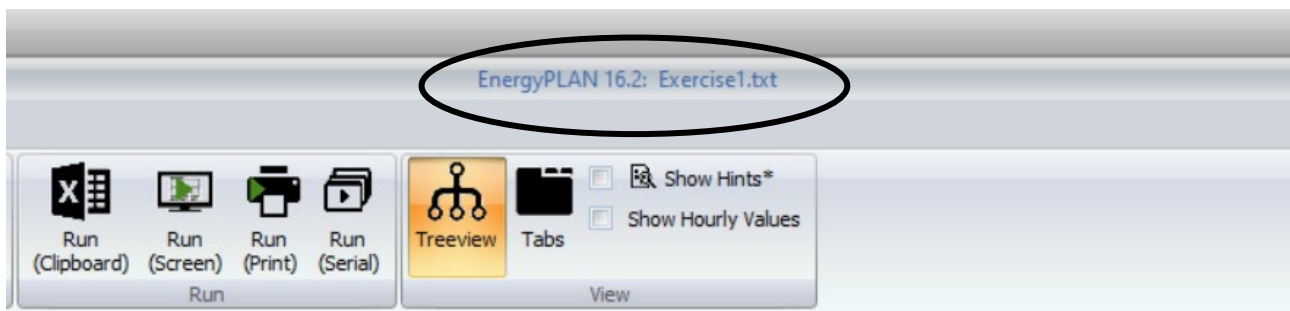
**Step 2: Load “Exercise 1” data.**

Activate the open data button  **Open** and the following window will open:



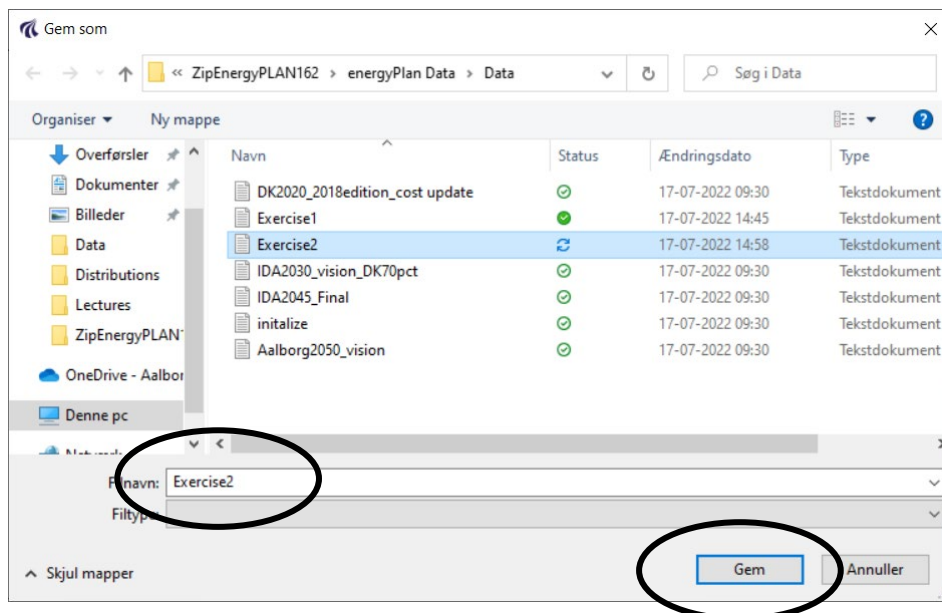
Choose “Exercise 1.txt” and activate the Open/Åbn button.

Look at the top bar: The EnergyPLAN model is loaded with “Exercise 1” data.



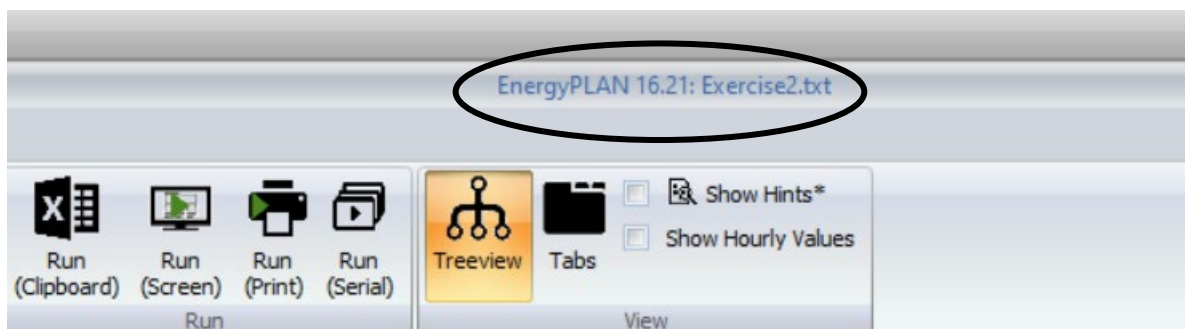
### Step 3: Save Data as Exercise 2 data

Activate **Save As** in the top left-hand corner and the following window will open:




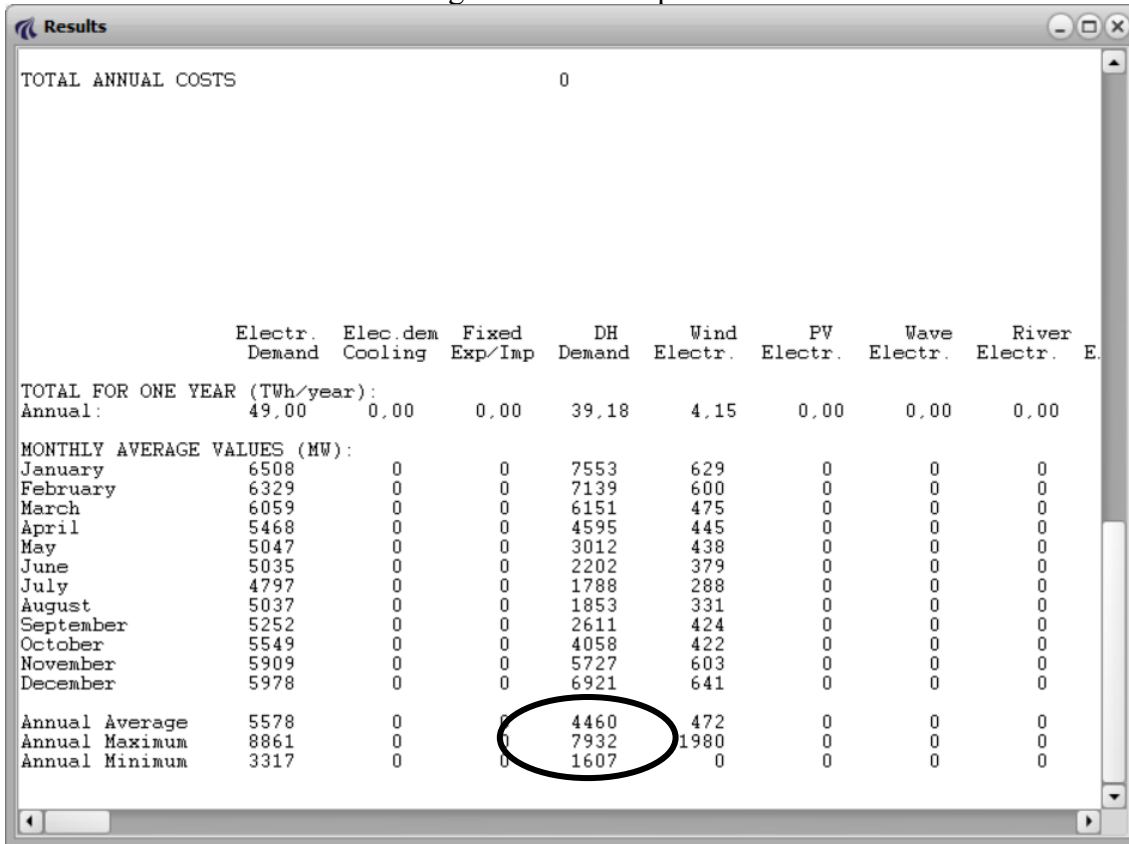
Choose a name and type in the name, e.g.: “Exercise2” and activate the Save/Gem button.

Look at the top left-hand corner: The EnergyPLAN model is loaded with “Exercise2” data.



**Step 4: Read the peak hour district heating demand BEFORE energy conservation.**

Activate the  button and the following window will open:

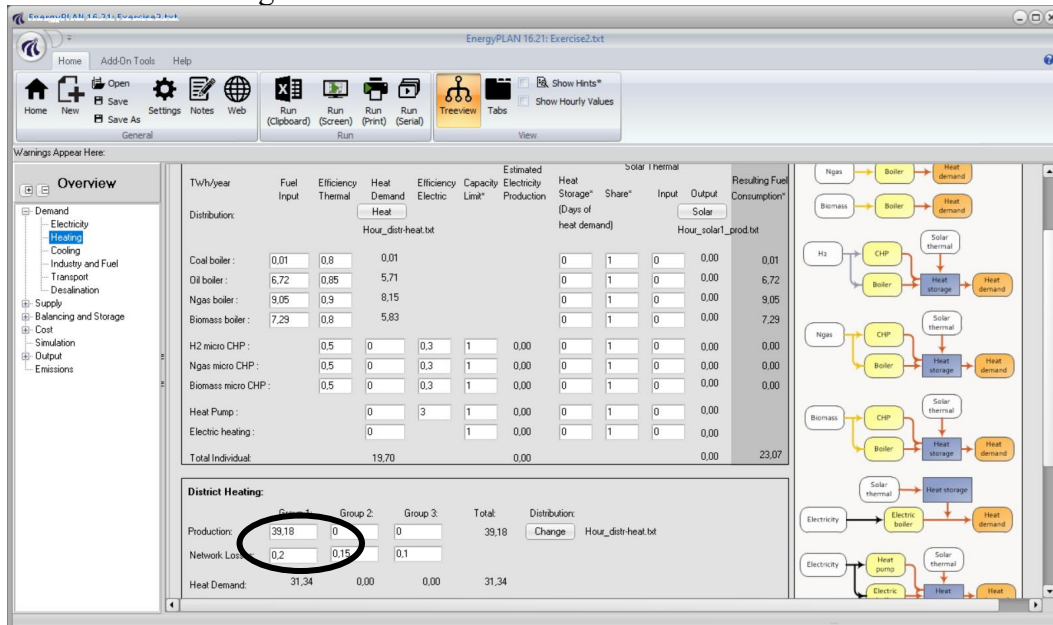


	Electr. Demand	Elec.dem Cooling	Fixed Exp/Imp	DH Demand	Wind Electr.	PV Electr.	Wave Electr.	River Electr.	E.
<b>TOTAL ANNUAL COSTS</b>									
	0								
<b>TOTAL FOR ONE YEAR (TWh/year):</b>									
Annual:	49,00	0,00	0,00	39,18	4,15	0,00	0,00	0,00	
<b>MONTHLY AVERAGE VALUES (MW):</b>									
January	6508	0	0	7553	629	0	0	0	
February	6329	0	0	7139	600	0	0	0	
March	6059	0	0	6151	475	0	0	0	
April	5468	0	0	4595	445	0	0	0	
May	5047	0	0	3012	438	0	0	0	
June	5035	0	0	2202	379	0	0	0	
July	4797	0	0	1788	288	0	0	0	
August	5037	0	0	1853	331	0	0	0	
September	5252	0	0	2611	424	0	0	0	
October	5549	0	0	4058	422	0	0	0	
November	5909	0	0	5727	603	0	0	0	
December	5978	0	0	6921	641	0	0	0	
Annual Average	5578	0	0	4460	472	0	0	0	
Annual Maximum	8861	0	0	7932	1980	0	0	0	
Annual Minimum	3317	0	0	1607	0	0	0	0	

Read the result: 7932 MW

**Step 5: Change district heating demand and hour distribution file.**

Open the “Demand > Heating” window:



EnergyPLAN 16.21: Exercise2.txt

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Warnings Appear Here:

**Overview**

	TWh/year	Fuel Input	Efficiency Thermal	Heat Demand	Efficiency Electric	Capacity Limit*	Estimated Electricity Production	Heat Storage* (Days of heat demand)	Share*	Input	Output	Resulting Fuel Consumption*
<b>Distribution:</b>												
				Hour_dist-heat.bt				Solar thermal				
Coal boiler:	0.01	0.8	0.01				0	1	0	0.00		0.01
Oil boiler:	6.72	0.85	5.71				0	1	0	0.00		6.72
Ngas boiler:	9.05	0.9	8.15				0	1	0	0.00		9.05
Biomass boiler:	7.29	0.8	5.83				0	1	0	0.00		7.29
H2 micro CHP:	0.5	0	0.3	1	0.00	0	1	0	0.00	0.00		0.00
Ngas micro CHP:	0.5	0	0.3	1	0.00	0	1	0	0.00	0.00		0.00
Biomass micro CHP:	0.5	0	0.3	1	0.00	0	1	0	0.00	0.00		0.00
Heat Pump:	0	3	1	0.00	0	1	0	0.00	0.00	0.00		0.00
Electric heating:	0		1	0.00	0	1	0	0.00	0.00	0.00		0.00
<b>Total Individual:</b>			19.70				0.00			0.00		23.07

**District Heating:**

	Group 1	Group 2	Group 3	Total	Distribution:
Production:	39.18	0	0	39.18	Change Hour_dist-heat.bt
Network Loss:	0.2	0.15	0.1		
Heat Demand:	31.34	0.00	0.00	31.34	

Place the cursor in the electricity input square and type in 27.43.

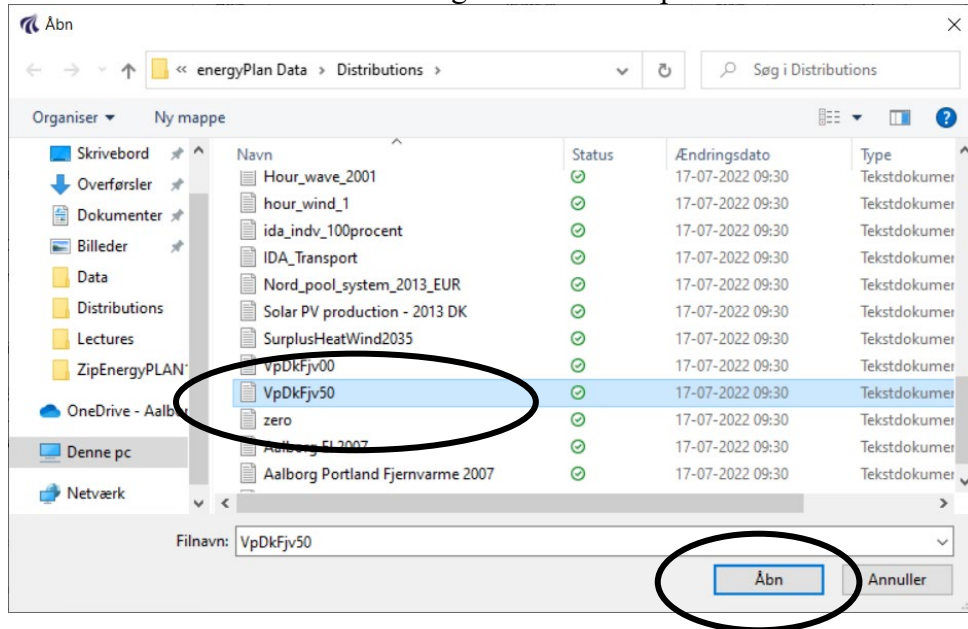
**District Heating:**

	Group 1:	Group 2:	Group 3:	Total:	Distribution:
Production:	<input type="text" value="27,43"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	27,43	<input type="button" value="Change"/> Hour_distr-heat.txt
Network Losses:	<input type="text" value="0,2"/>	<input type="text" value="0,15"/>	<input type="text" value="0,1"/>		
Heat Demand:	21,94	0,00	0,00	21,94	

Look at the Demand > Heating input window:

The model is loaded with “Hour-distr-heat.txt” distribution data.

Activate the  button and the following window will open:



Choose “VpDkFjv50” and activate the Open/Åbn button.


Look at the Demand > Heating input window:

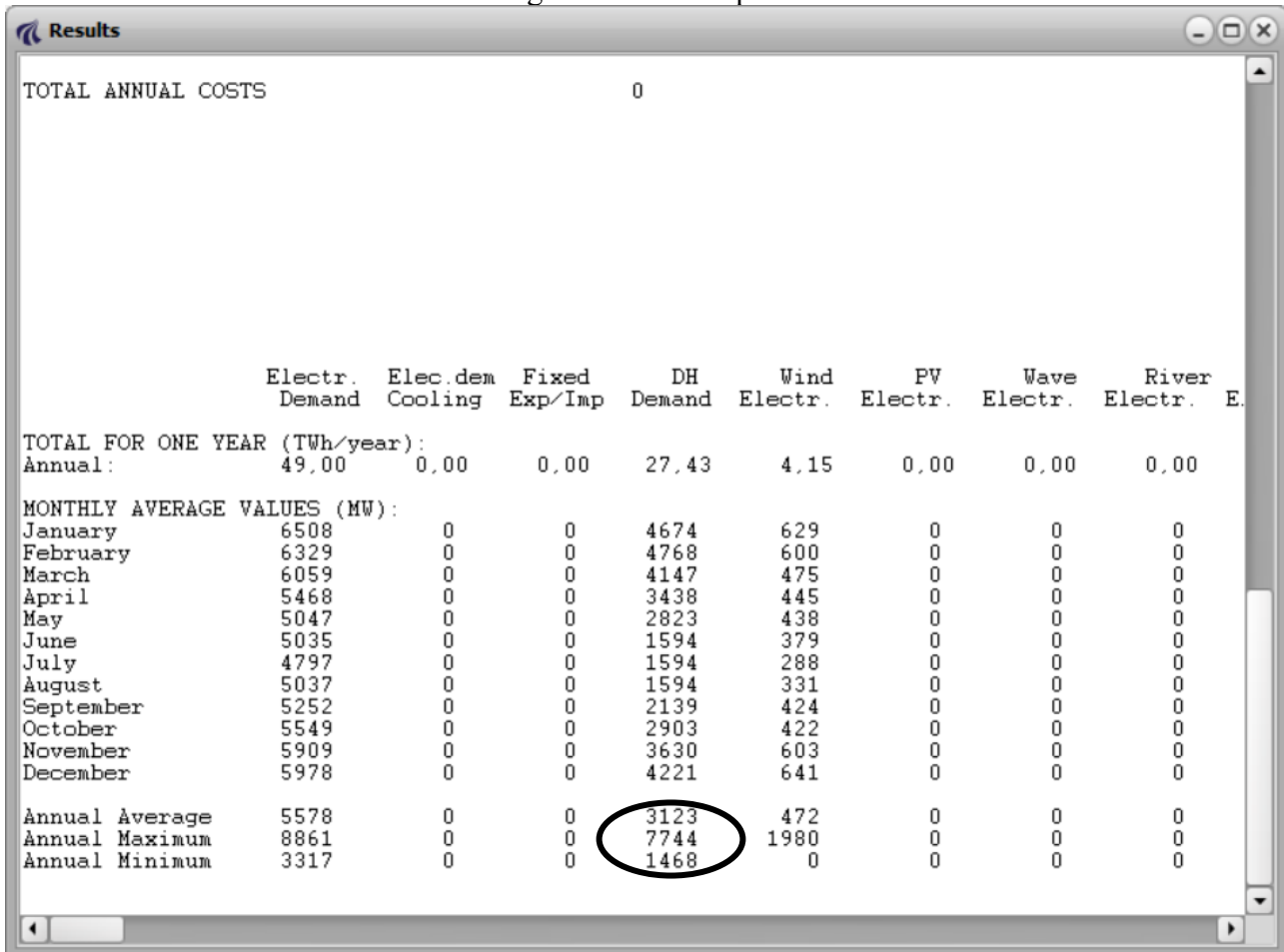
The model is loaded with “VpDkFjv50” distribution data.

**District Heating:**

	Group 1:	Group 2:	Group 3:	Total:	Distribution:
Production:	<input type="text" value="27,43"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	27,43	<input type="button" value="Change"/> VpDkFjv50.txt
Network Losses:	<input type="text" value="0,2"/>	<input type="text" value="0,15"/>	<input type="text" value="0,1"/>		
Heat Demand:	21,94	0,00	0,00	21,94	

**Step 6: Read the peak hour district heating demand AFTER energy conservation.**

Activate the  button and the following window will open:



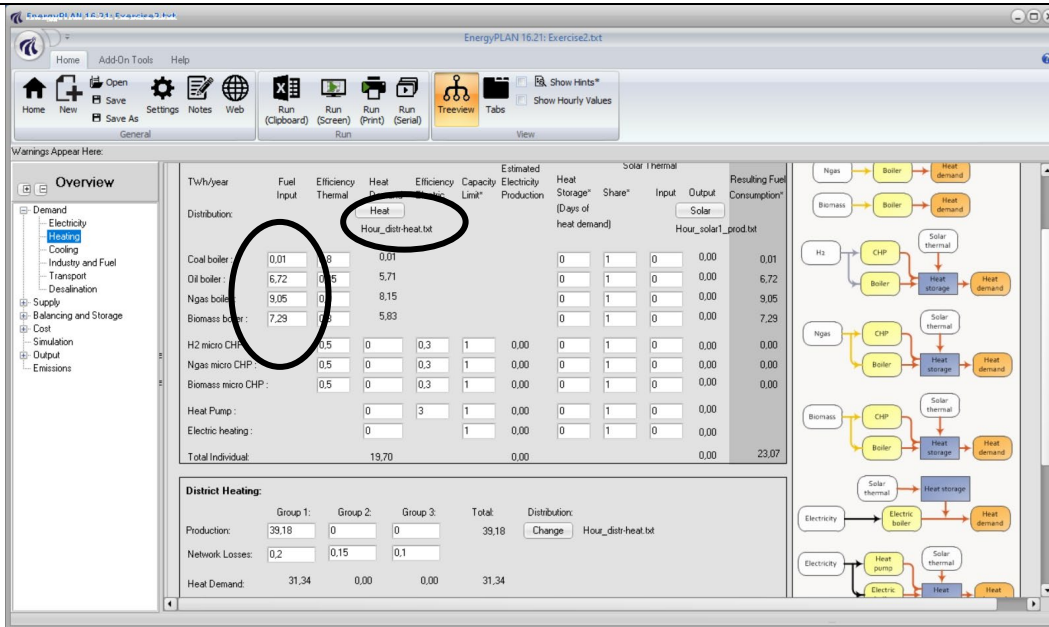
	Electr. Demand	Elec.dem Cooling	Fixed Exp/Imp	DH Demand	Wind Electr.	PV Electr.	Wave Electr.	River Electr.	E.
TOTAL ANNUAL COSTS	0								
TOTAL FOR ONE YEAR (TWh/year):									
Annual:	49,00	0,00	0,00	27,43	4,15	0,00	0,00	0,00	
MONTHLY AVERAGE VALUES (MW):									
January	6508	0	0	4674	629	0	0	0	
February	6329	0	0	4768	600	0	0	0	
March	6059	0	0	4147	475	0	0	0	
April	5468	0	0	3438	445	0	0	0	
May	5047	0	0	2823	438	0	0	0	
June	5035	0	0	1594	379	0	0	0	
July	4797	0	0	1594	288	0	0	0	
August	5037	0	0	1594	331	0	0	0	
September	5252	0	0	2139	424	0	0	0	
October	5549	0	0	2903	422	0	0	0	
November	5909	0	0	3630	603	0	0	0	
December	5978	0	0	4221	641	0	0	0	
Annual Average	5578	0	0	3123	472	0	0	0	
Annual Maximum	8861	0	0	7744	1980	0	0	0	
Annual Minimum	3317	0	0	1468	0	0	0	0	

Read the result: 7744 MW

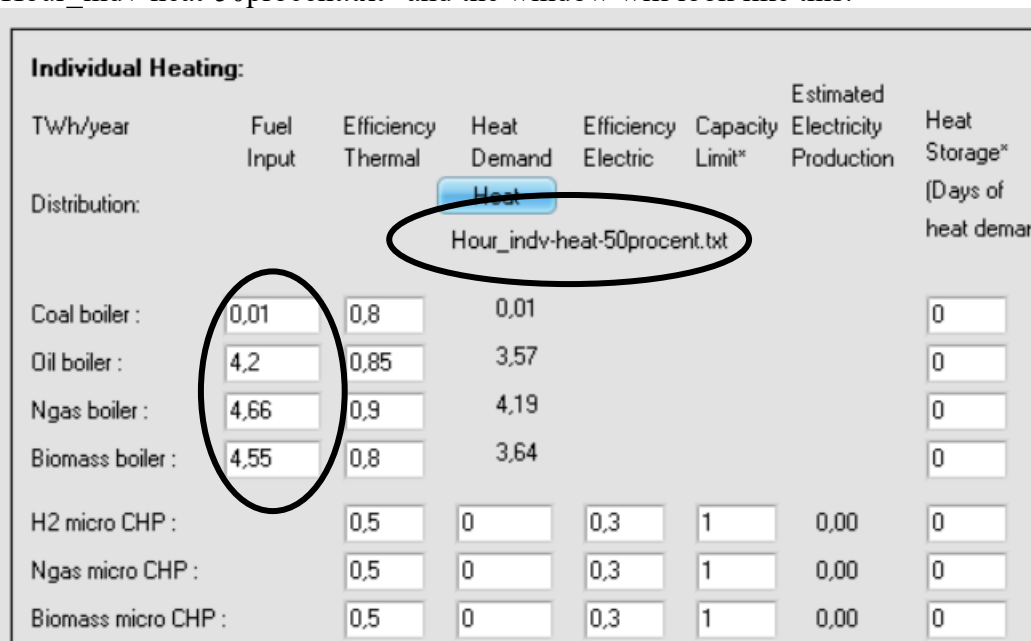
**Step 7: Change heat demand and distribution file for individual houses**

Open the “Demand > Heating” window :



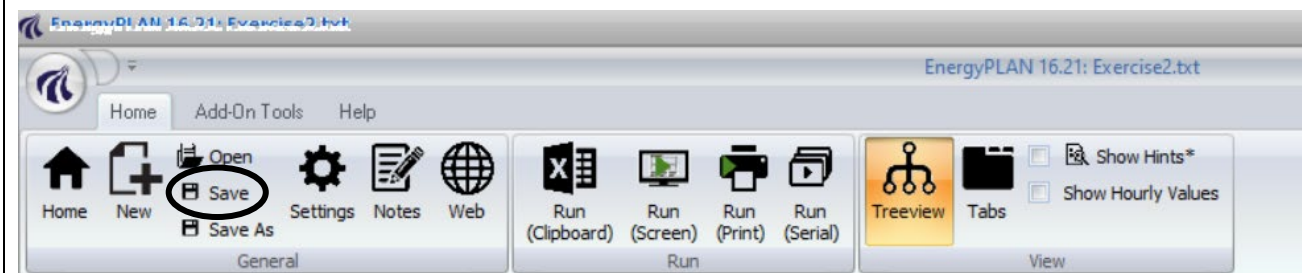


Change input fuel consumption to 62.5% of previous value. And change distribution file to “Hour\_indv-heat-50percent.txt” and the window will look like this:

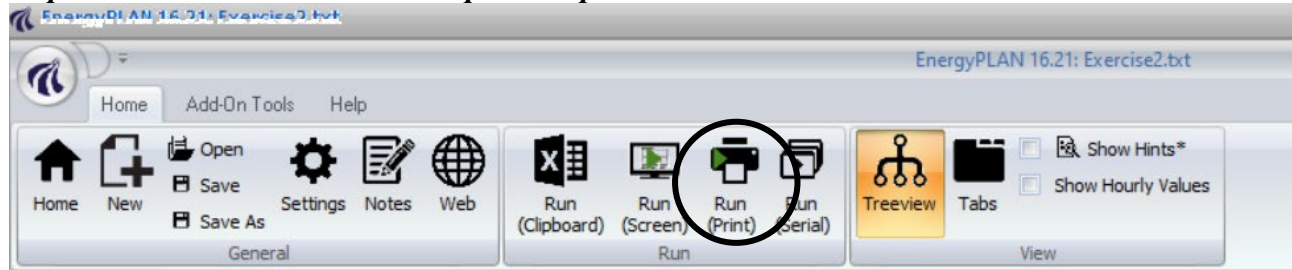


**Step 8: Save data:**

Activate the Save button.



**Step 9: Calculate and see result in print output**



Activate the "Run (print)" button and get the following print:

Input		Exercise2.txt		The EnergyPLAN model 16.2																															
Electricity demand (TWh/year):	Flexible demand	0,00		Group 2:	Capacities	Efficiencies	Regulation Strategy:	Technical regulation no. 1	Fuel Price level: Basic																										
Fixed demand	49,00	Fixed implexp.	0,00	CHP	MW-e	MJ/s	CEEP regulation	000000000	Capacities	Storage	Efficiencies																								
Electric heating + HP	0,00	Transportation	0,00	Heat Pump	0	0	Minimum Stabilisation share	0,00	Elec. Storage	MW-e	GWh	Elec. Ther.																							
Electric cooling	0,00	Total	49,00	Boiler	0	0	Stabilisation share of CHP	0,00	Charge 1:	0	0	0,80																							
District heating (TWh/year)				Gr.1	Gr.2	Gr.3	Sum	Minimum CHP gr 3 load	0	MW	Discharge 1:	0	0	0,80																					
District heating demand				27,43	0,00	0,00	27,43	Minimum PP	0	MW	Discharge 2:	0	0	0,80																					
Solar Thermal				0,00	0,00	0,00	0,00	Heat Pump maximum share	1,00	Discharge 2:	0	0	0,80																						
Industrial CHP (CSHP)				2,41	0,00	0,00	2,41	Maximum import/export	0	MW	Electrolysers:	0	0	0,80																					
Demand after solar and CSHP				25,02	0,00	0,00	25,02	Distr. Name :		Hour_nordpool.txt	CAES fuel ratio:	0	0	1,00																					
Wind				2000	MW	4,15	TWh/year	0,00	Grid	Addition factor	0,00	DKK/MWh																							
Photo Voltaic				0	MW	0	TWh/year	0,00	stabilisation	Multiplication factor	2,00	Dependency factor	0,00	DKK/MWh pr. MW																					
Wave Power				0	MW	0	TWh/year	0,00	satiation	Average Market Price	227	DKK/MWh																							
River Hydro				0	MW	0	TWh/year	0,00	share	Gas Storage	0	GWh																							
Hydro Power				0	MW	0	TWh/year	0,00		Syngas capacity	0	MW																							
Geothermal/Nuclear				0	MW	0	TWh/year	0,00		Biogas max to grid	0	MW																							
Heatsstorage: gr.2:				0	GWh	gr.3:	0	GWh																											
Fixed Boiler: gr.2:				0,0	Per cent	gr.3:	0,0	Per cent																											
Electricity prod. from				CSHP	Waste	(TWh/year)																													
Gr.1:				1,73	0,00																														
Gr.2:				0,00	0,00																														
Gr.3:				0,00	0,00																														
Output																																			
District Heating										Electricity										Exchange															
Demand					Production					Consumption					Production					Balance					Payment										
Distr. heating	Solar	Waste+	CHP	HP	ELT	Boiler	EH	Ba-	Elec. demand	Flex.& Transp.	HP	Electrolyser	EH	Hydro Pump	Tur-	RES	Hy-	Geo-	Waste+	CHP	PP	Stab-	Imp	Exp	CEEP	EEP	Imp	Exp							
MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	%	MW	MW	MW	MW	Million DKK	Million DKK						
January	4674	0	274	4399	0	0	0	0	0	0	0	0	0	0	0	629	0	0	197	0	5882	100	0	0	0	0	0	0	0						
February	4788	0	274	4494	0	0	0	0	0	0	0	0	0	0	0	600	0	0	197	0	5532	100	0	0	0	0	0	0	0	0					
March	4147	0	274	3873	0	0	0	0	0	0	0	0	0	0	0	475	0	0	197	0	5387	100	0	0	0	0	0	0	0	0	0				
April	3438	0	274	3164	0	0	0	0	0	0	0	0	0	0	0	445	0	0	197	0	4828	100	0	0	0	0	0	0	0	0	0				
May	2823	0	274	2548	0	0	0	0	0	0	0	0	0	0	0	438	0	0	197	0	4412	100	0	0	0	0	0	0	0	0	0	0			
June	1594	0	274	1319	0	0	0	0	0	0	0	0	0	0	0	379	0	0	197	0	4459	100	0	0	0	0	0	0	0	0	0	0	0		
July	1594	0	274	1319	0	0	0	0	0	0	0	0	0	0	0	288	0	0	197	0	4312	100	0	0	0	0	0	0	0	0	0	0	0		
August	1594	0	274	1319	0	0	0	0	0	0	0	0	0	0	0	331	0	0	197	0	4509	100	0	0	0	0	0	0	0	0	0	0	0	0	
September	2130	0	274	1854	0	0	0	0	0	0	0	0	0	0	0	424	0	0	197	0	4831	100	0	0	0	0	0	0	0	0	0	0	0	0	
October	2003	0	274	2029	0	0	0	0	0	0	0	0	0	0	0	422	0	0	197	0	4930	100	0	0	0	0	0	0	0	0	0	0	0	0	
November	3630	0	274	3356	0	0	0	0	0	0	0	0	0	0	0	603	0	0	197	0	5110	100	0	0	0	0	0	0	0	0	0	0	0	0	0
December	4221	0	274	3947	0	0	0	0	0	0	0	0	0	0	0	641	0	0	197	0	5141	100	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	3123	0	274	2848	0	0	0	0	0	0	0	0	0	0	0	472	0	0	197	0	4909	100	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	7744	0	274	7470	0	0	0	0	0	0	0	0	0	0	0	1980	0	0	197	0	8480	100	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	1488	0	274	1193	0	0	0	0	0	0	0	0	0	0	0	0	0	0	197	0	1960	100	0	0	0	0	0	0	0	0	0	0	0	0	0
TWh/year	27,43	0,00	2,41	25,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,15	0,00	0,00	1,73	0,00	43,12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
FUEL BALANCE (TWh/year):																				CO2 emission (Mt):															
DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste/ HTL	CAES	BioCon	Electro-	Wind	PV and CSP	Wind off	Industry	Imp/Exp	Corrected	CO2 emission (Mt):																	
Coal	-	-	-	-	-	95,83	-	-	-	-	-	-	-	-	-	0,01	3,37	99,21	0,00	99,21	33,93	33,93													
Oil	27,80	-	-	-	-	-	-	-	-	-	-	-	-	-	69,20	4,20	26,92	128,12	0,00	128,12	34,13	34,13													
N.Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,66	18,19	22,85	0,00	22,85	4,66	4,66														
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,55	5,18	9,73	0,00	9,73	0,00	0,00														
Renewable	-	-	-	-	-	-	-	-	-	-	4,15	-	-	-	-	4,15	0,00	4,15	0,00	4,15	0,00	0,00													
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00														
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00														
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00														
Total	27,80	-	-	-	-	95,83	-	-	-	-	-	4,15	-	-	69,20	13,42	3,66	264,05	0,00	264,05	72,72	72,72													

Read the results of question 1.2.2:

The Primary energy supply has been reduced from 286.76 to 264.05 TWh/year.

The CO2 emission has been reduced from 77.77 to 72.72 Mt/year.



## Exercise 2.2: Replace district heating boilers by CHP

Replace the 27.43 TWh of district heating boilers by:

- 1.59 TWh of district heating boilers
- 10.00 TWh of small-scale CHP: 1350 MW, eff-th = 50%, eff-el = 41% on natural gas
- 15.84 TWh of large-scale CHP: 2000 MW, eff-th = 50%, eff-el = 41% on coal.
- Add boiler capacities of 5000 MJ/s in gr. 2 and gr. 3
- Add thermal storage capacity of 10 GWh in gr. 2 and gr. 3.
- Identify a 450 MW minimum production on the large-scale CHP units.
- Move 1.73 TWh of industrial excess heat production (2.41 of electricity) to gr. 3
- Chose simulation strategy “balancing both heat and electricity demands”

*Question 2.2.1: What are the primary energy supply and the CO2 emission of the system?*

**How to do exercise 2.2:** Use input data file from exercise 2.1.

**Step 1: Change district heating demand to three groups**

Choose “Demand” and “Heating”:

	Group 1	Group 2	Group 3	Total	Distribution:
Production:	1.59	10	15.84	27.43	VpDkFv50.txt
Network Losses:	0.2	0.15	0.08	0.43	
Heat Demand:	1.27	8.50	14.26	24.03	

Write the three new values...

## Chose “Supply” and “Heat and Electricity”

EnergyPLAN 16.21: Exercise2.txt

Warnings: Appear Here:

**Overview**

- Demand
  - Electricity
  - Heating
  - Cooling
  - Industry and Fuel
  - Transport
  - Desalination
- Supply
  - Heat and Electricity
  - Central Power Production
  - Variable Renewable Electric
  - Heat Only
  - Fuel Distribution
  - Waste
  - Liquid and Gas Fuels
  - CD2
  - Balancing and Storage
  - Cost
  - Simulation
  - Output
  - Emissions

**Boilers**

Thermal Capacity	3000	5000	MJ/s
Boiler Efficiency	0.9	0.9	Percent
Fixed Boiler share	0	0	

**Combined Heat and Power (CHP)**

CHP Condensing Mode Operation:

Electric Capacity (PP1)	9000	MW-e
Electric Efficiency (PP1)	0.45	

CHP Back Pressure Mode Operation:

Electric Capacity	1350	2000	MW-e
Thermal Capacity	1646	2439	MJ/s
Electric Efficiency	0.41	0.41	
Thermal Efficiency	0.5	0.5	

**Industrial CHP**

CHP Electricity	0	0	1.73	1.73	TWh/year
CHP Heat Produced	0	0	2.41	2.41	TWh/year
CHP Heat Demand	0	0	0	0.00	TWh/year
CHP Heat Delivered*	0.00	0.00	2.41	2.41	TWh/year

CHP plants are modelled as a combination of CHP back pressure and condensing plants so the Max CHP3 is the PP1 Capacity, which is:

## Chose “Supply” and “Fuel Distribution”

**Overview**

- Demand
  - Electricity
  - Heating
  - Cooling
  - Industry and Fuel
  - Transport
  - Desalination
- Supply
  - Heat and Electricity
  - Central Power Production
  - Variable Renewable Electric
  - Heat Only
  - Fuel Distribution
  - Waste
  - Liquid and Gas Fuels
  - CD2
  - Balancing and Storage

**Distribution of fuel**

	Coal	Oil	Ngas	Biomass	Electrofuels(Oil) *	Hydrogen **	
(TWh/year)	Variable	Variable	Variable	Variable	Fixed **)	Fixed **)	
DHP	0	1	0	0	0	0	DHP: Boilers in district
CHP2	0	0	1	0	0	0	CHP2: Combined heat
CHP3	1	0	0	0	0	0	CHP3: Combined heat
Boiler2	0	0	0	0	0	0	Boiler2: Boilers in distri
Boiler3	0	0	0	0	0	0	Boiler3: Boilers in distri
PP1	1	0	0	0	0	0	PP1: Condensing mod
PP2	0	0	0	0	0	0	PP2: Condensing pow

Reg1 Allow for import/export

\*) Replace only Oil - will be adjusted if the Oil demand is not big enough

## Chose “Balancing and Storage” and “Thermal”

**Overview**

- Demand
  - Electricity
  - Heating
  - Cooling
  - Industry and Fuel
  - Transport
  - Desalination
- Supply
  - Heat and Electricity
  - Central Power Production
  - Variable Renewable Electric
  - Heat Only
  - Fuel Distribution
  - Waste
  - Liquid and Gas Fuels
  - CD2
  - Balancing and Storage
    - Electricity
    - Thermal
    - Liquid and Gas Fuel

**Thermal Storage**

Group 1:	Group 2:	Group 3:	Total:	Unit:
10	10			GWh

For Solar Thermal Storage, go to Supply -> Heat Only

**Individual Heat Pump Regulation**

Not active When active the Heat Pump heat storage is only used for space heating and not hot water (defined by min distr. value)

Place the cursor in the input squares and type in the various input values.

## Step 2: Define a minimum operation on large-scale CHP

Chose “Balancing and Storage” and “Thermal”

Place the cursor in the input square and type in the 450 MW value.

The screenshot shows the EnergyPLAN 16.21: Exercise2.txt software interface. The 'Overview' panel on the left is expanded to 'Balancing and Storage'. The main configuration area is divided into several sections:

- Electric grid stabilisation requirements:** A table of input fields for grid stability parameters. The 'Minimum CHP in gr. 3' field is circled in red and contains the value '450'.
- Critical Excess Electricity Production (CEEP):** A list of 9 strategies for managing excess production, with a 'Note: Electricity interconnection is defined under the Supply -> Electricity only tabsheet'.
- Rockbed Storage:** Configuration for storage capacity and loss rate.
- Electricity Storage 1 and 2:** Configuration for two different storage units, including capacity, efficiency, and fuel ratio.

## Step 3: Define regulations strategy

Chose “Simulation”

The screenshot shows the EnergyPLAN 16.21: Exercise2.txt software interface. The 'Overview' panel on the left is expanded to 'Simulation'. The main configuration area is titled 'Chose Simulation Strategy:' and contains several radio button options:

- Technical Simulation:** Selected. Sub-options include:
  - Technical Simulation Strategy:
    - 1 Balancing heat demands
    - 2 Balancing both heat and electricity demands (circled in red)
  - Individual Heat Pump Simulation:
    - 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
  - V2G Regulation:
    - 1 V2G seek to balance only Critical Excess and Power Plant Production
    - 2 V2G seek to balance Power Plants and all electricity import and export
  - Rock bed regulation:
    - 1 Rock bed storage seek to balance only Critical Excess and Power Plant Production
    - 2 Rock bed storage seek to balance Power Plants and all electricity import and export
  - Prioritization in balancing of electricity:
    - Electricity balancing priority: 123
    - 1 Pumped Hydro
    - 2 Vehicle to Grid
    - 3 Rock bed storage
- Market Economic Simulation:** Unselected. Sub-options include:
  - V2G Simulation Strategy:
    - 1 No limitations
    - 2 Limitation: Smart Charge/V2G charge ( $\leftarrow$  PowerPlant-cap + import-max - electricity demand)
    - 3 V2G seeks to minimise PP max
  - Transmission capacity's effect on system price:
    - Transmission capacity does not limit the effect on the system price
    - Transmission capacity limits the effect on system price
  - RES influence on system electricity prices:
    - Zero bidding price (RES can stop)
    - Negative bidding price (RES cannot stop)

Chose simulation strategy ”2 Balancing both heat and electricity demands”

**Step 4: Calculate and see result in print output (or clipboard)**  
 Activate the "Run (print)" button and get the following print:

Input		Exercise2.txt		The EnergyPLAN model 16.2																	
Electricity demand (TWh/year):		Flexible demand 0,00		Group 2:			Capacities			Efficiencies			Regulation Strategy:			Technical regulation no. 2			Fuel Price level: Basic		
Fixed demand 49,00		Fixed imp/exp. 0,00		CHP			MW-e			elec.			CEEP regulation			00000000			Elec. Storage		
Electric heating + HP 0,00		Total 49,00		Heat Pump			MJ/s			Ther			Minimum Stabilisation share			0,00			MW-e		
Electric cooling 0,00				Boiler			0			COP			Stabilisation share of CHP			0,00			Storage		
District heating (TWh/year)		Gr.1		Gr.2		Gr.3		Sum		Group 3:			Minimum CHP gr 3 load			450 MW			Efficiencies		
District heating demand		1,59		10,00		15,84		27,43		CHP			Minimum PP			0 MW			Elec. Ther.		
Solar Thermal		0,00		0,00		0,00		0,00		Heat Pump			Heat Pump maximum share			1,00			Discharge 1:		
Industrial CHP (CSHP)		0,00		0,00		2,41		2,41		Boiler			Maximum import/export			0 MW			Discharge 2:		
Demand after solar and CSHP		1,59		10,00		13,43		25,02		Condensing			Distr. Name :			Hour_nordpool.txt			Electrolysers:		
Wind		2000 MW		4,15 TWh/year		0,00 Grid		0,00		Heatstorage: gr:2: 10 GWh			Addition factor			0,00			DKK/MWh		
Photo Voltaic		0 MW		0 TWh/year		0,00 stabili-		0,00		Fixed Boiler: gr:2: 0,0 Per cent			Multiplication factor			2,00			Dependency factor		
Wave Power		0 MW		0 TWh/year		0,00 sation		0,00		Electricity prod. from CSHP			Average Market Price			227 DKK/MWh			(TWh/year)		
River Hydro		0 MW		0 TWh/year		0,00 share		0,00		Gr:1:			Gas Storage			0 GWh			Coal		
Hydro Power		0 MW		0 TWh/year		0,00		0,00		Gr:2:			Syngas capacity			0 MW			Oil		
Geothermal/Nuclear		0 MW		0 TWh/year		0,00		0,00		Gr:3:			Biogas max to grid			0 MW			Ngas		
																			Biomass		

Output		The EnergyPLAN model 16.2																												
Demand		Production								Consumption								Electricity							Exchange					
Distr. heating	MW	Waste+							Balance	Elec. demand	Flex. Transp.	HP	Elec. trollyser	EH	Hydro Pump	Tur- bine	RES	Hy- dro	Geo- thermal	Waste+ CSHP	CHP	PP	Stab- Load %	Imp	Exp	CEEP	EEP	Payment Imp	Exp	
		Solar	CSHP	DHP	CHP	HP	ELT	Boiler																						EH
January	4674	0	274	271	3943	0	0	186	0	-1	6508	0	0	0	0	0	629	0	0	197	3234	2448	100	0	0	0	0	0	0	0
February	4788	0	274	278	3963	0	0	280	0	5	6329	0	0	0	0	0	600	0	0	197	3241	2291	100	0	0	0	0	0	0	0
March	4147	0	274	240	3660	0	0	10	0	-27	6069	0	0	0	0	0	475	0	0	197	2993	2394	100	0	0	0	0	0	0	0
April	3438	0	274	199	2964	0	0	0	0	0	5488	0	0	0	0	0	445	0	0	197	2431	2395	100	0	0	0	0	0	0	0
May	2823	0	274	164	2385	0	0	0	0	0	5047	0	0	0	0	0	438	0	0	197	1955	2457	100	0	0	0	0	0	0	0
June	1594	0	274	92	1227	0	0	0	0	0	5035	0	0	0	0	0	379	0	0	197	1006	3453	100	0	0	0	0	0	0	0
July	1594	0	274	92	1227	0	0	0	0	0	4797	0	0	0	0	0	288	0	0	197	1006	3306	100	0	0	0	0	0	0	0
August	1594	0	274	92	1227	0	0	0	0	0	5037	0	0	0	0	0	331	0	0	197	1006	3502	100	0	0	0	0	0	0	0
September	2190	0	274	124	1740	0	0	0	0	0	5252	0	0	0	0	0	424	0	0	197	1427	3204	100	0	0	0	0	0	0	0
October	2903	0	274	168	2481	0	0	0	0	0	5549	0	0	0	0	0	422	0	0	197	2016	2912	100	0	0	0	0	0	0	0
November	3630	0	274	210	3145	0	0	0	0	0	5909	0	0	0	0	0	603	0	0	197	2579	2531	100	0	0	0	0	0	0	0
December	4221	0	274	245	3553	0	0	126	0	24	5978	0	0	0	0	0	641	0	0	197	2913	2227	100	0	0	0	0	0	0	0
Average	3123	0	274	181	2620	0	0	48	0	0	5578	0	0	0	0	0	472	0	0	197	2148	2761	100	0	0	0	0	0	0	0
Maximum	7744	0	274	449	4085	0	0	2936	0	1920	8881	0	0	0	0	0	1980	0	0	197	3350	5861	100	0	0	0	0	0	0	0
Minimum	1488	0	274	85	1108	0	0	0	0	-1212	3317	0	0	0	0	0	0	0	0	197	909	0	100	0	0	0	0	0	0	0
TWh/year	27,43	0,00	2,41	1,59	23,01	0,00	0,00	0,42	0,00	0,00	49,00	0,00	0,00	0,00	0,00	0,00	4,15	0,00	0,00	1,73	18,87	24,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

FUEL BALANCE (TWh/year):															Industry			Total			Imp/Exp Corrected		CO2 emission (Mt):			
DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste/ HTL	CAES	BioCon-	Electro-	Wind	PV and CSP	Wind off	Solar.Th.	Transp.	househ.	Various	Total	Imp/Exp	Corrected	CO2 Total	Net			
Coal	-	-	28,36	0,05	0,07	53,90	-	-	-	-	-	-	-	-	-	-	-	-	0,01	3,37	83,75	0,00	83,75	28,64	28,64	
Oil	1,77	-	-	0,05	0,07	-	-	-	-	-	-	-	-	-	-	-	-	-	69,20	4,20	26,62	102,20	0,00	102,20	27,23	27,23
N.Gas	-	19,66	-	0,05	0,07	-	-	-	-	-	-	-	-	-	-	-	-	-	4,66	18,19	42,63	0,00	42,63	8,70	8,70	
Biomass	-	-	-	0,05	0,07	-	-	-	-	-	-	-	-	-	-	-	-	-	4,55	5,18	9,85	0,00	9,85	0,00	0,00	
Renewable	-	-	-	-	-	-	-	-	-	-	-	4,15	-	-	-	-	-	-	-	4,15	0,00	4,15	0,00	0,00	0,00	0,00
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total	1,77	19,66	28,36	0,19	0,28	53,90	-	-	-	-	-	4,15	-	-	-	-	-	-	69,20	13,42	53,66	242,58	0,00	242,58	64,57	64,57

Read the results of question 2.2.1:  
 The Primary energy supply has been reduced from 264.05 to 242.58 TWh/year.  
 The CO2 emission has been reduced from 72.72 to 64.57 Mt/year.

## Exercise 2.3: Add 3000 MW off-shore wind power

Add 3000 MW off-shore wind power.

Use the hour distribution file “DK offshorewind 2013.txt”

The electricity production from CHP in combination with wind power may lead to hours in which the production exceeds the demand, known as excess electricity production. The energy system analysis will identify and quantify this excess production. However, such balancing problems depend on the regulation of the electricity production units. Basically, the model differs between operating CHP units 1) to meet solely heat demand or 2) to meet both heat and electricity demands (Regulation strategy 1 and 2).

*Question 2.3.1: What is 1) the excess electricity production, 2) the primary energy supply and 3) the CO2 emission of the system if the CHP units are regulated solely according to the heat demand?*

*Question 2.3.2: What is the answer if the CHP units are regulated according to both the heat and the electricity demand?*

### How to do exercise 2.3: Use input data file from exercise 2.2.

#### Step 1: Add wind power input

Choose “Supply” and “Variable Renewable Electricity” and the following window will open:

The screenshot shows the EnergyPLAN 16.22 software interface. The 'Variable Renewable Electricity' window is open, displaying a table of energy sources. The 'Offshore Wind' entry is highlighted with a red circle, and its 'Distribution profile' is set to 'DK offshorewind', also circled in red. The 'Capacity' is set to 3000 MW. Below the table, the 'Concentrated Solar Power' section is visible.

Renewable Energy Source	Capacity: MW	Stabilisation share	Distribution profile*	Estimated Production TWh/year	Correction factor	Estimated Post Correction production	Estimated capacity factor
Wind	2000	0	Change Hour_wind_1.txt	4.15	0	4.15	0.24
<b>Offshore Wind</b>	<b>3000</b>	0	<b>Change DK offshorewind</b>	11.34	0	11.34	0.43
Wind	0	0	Change Hour_wind_prod1	0.00	0	0.00	0.00
Offshore Wind	0	0	Change Hour_wind_prod1	0.00	0	0.00	0.00
Photo Voltaic	0	0	Change Hour_solar_prod1	0.00	0	0.00	0.00
Wave Power	0	0	Change hour_tidal_power	0.00	0	0.00	0.00
River Hydro	0	0	Change Hour_wave_200'	0.00	0	0.00	0.00
Tidal	0	0	Change Hour_solar_prod1	0.00	0	0.00	0.00
CSP Solar Power	0	0	Change Hour_solar_prod1	0.00	0	0.00	0.00
Wave Power	0	0	Change Hour_solar_prod1	0.00	0	0.00	0.00
CSP Solar Power	0	0	Change Hour_solar_prod1	0.00	0	0.00	0.00

**Concentrated Solar Power**

Annual solar thermal input: 0 TWh/year Change hour\_solar\_prod1.txt

Storage capacity: 0 GWh

Storage efficiency (losses): 0.5 Percent pr. hour

Power capacity: 0 MW-e

Power efficiency: 0.3

Stabilisation Share: 0

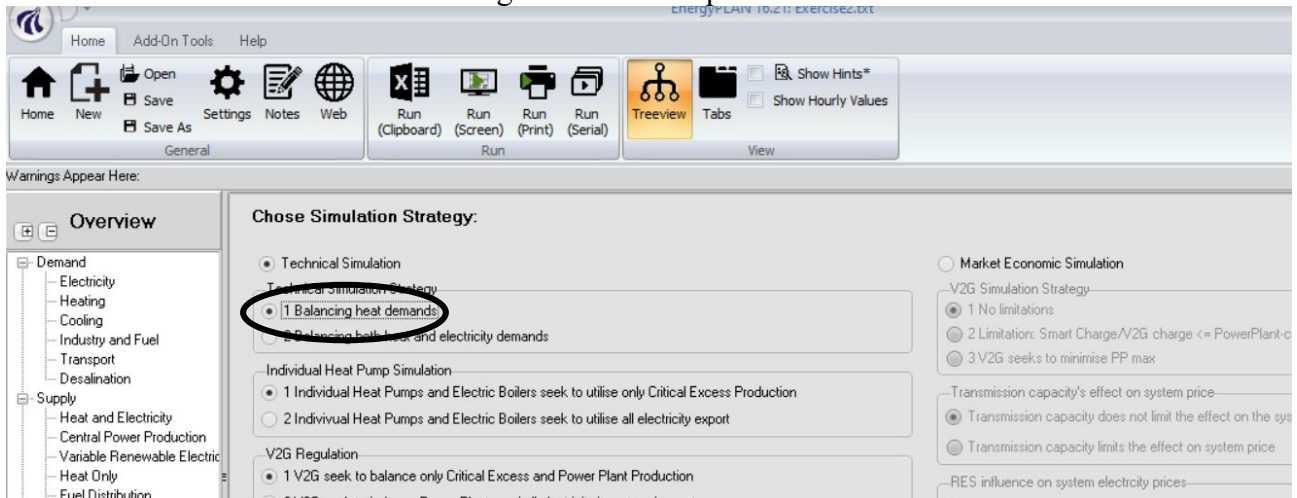
Estimated Production TWh/year: 0.00

Estimated Storage loss TWh/year: 0.00

Place the cursor in the input squares and type in the various input values and choose distribution file “DK 2013 Wind offshore”



Choose "Simulation" and the following window will open:



Make sure that the technical regulation strategy is 1.

Step 2: Calculate and see result in print output (or clipboard)

Activate the "Run (print)" button and get the following print:

Input		Exercise2.txt		The EnergyPLAN model 16.22																														
Electricity demand (TWh/year):	Flexible demand	0,00		Group 2:	Capacities	Efficiencies	Regulation Strategy:						Technical regulation no. 1						Fuel Price level:															
Fixed demand	49,00	Fixed implep.	0,00	CHP	MW-e	MJ/s	elec.	Ther	COP	CEEP regulation	00000000	Capacities			Storage			Efficiencies																
Electric heating + HP	0,00	Transportation	0,00	Heat Pump	0	0	0,41	0,50	3,00	Minimum Stabilisation share	0,00	Elec. Storage	MW-e	GWh	Elec. Ther.																			
Electric cooling	0,00	Total	49,00	Boiler	5000			0,90		Stabilisation share of CHP	0,00	Charge 1:	0	0	0,80																			
District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum	Group 3:	Capacities	Efficiencies	Regulation Strategy:						Technical regulation no. 1						Fuel Price level:														
District heating demand	1,59	10,00	15,84	27,43	CHP	2000	2439	0,41	0,50	Minimum CHP gr 3 load	450	Minimum PP	0	0	0,90																			
Solar Thermal	0,00	0,00	0,00	0,00	Heat Pump	0	0		3,00	Heat Pump maximum share	1,00	Maximum import/export	0	0	0,90																			
Industrial CHP (CSHP)	0,00	0,00	2,41	2,41	Boiler	5000			0,90	Maximum import/export	0	0	0	0	0,80	0,00																		
Demand after solar and CSHP	1,59	10,00	13,43	25,02	Condensing	9000			0,45	Distr. Name :	Hour_nordpool.txt	Addition factor	0,00	DKK/MWh	Rockbed Storage:	0	0	1,00																
Wind	2000	MW	4,15	TWh/year	0,00	Grid	stabilisation	Heatstorage: gr.2: 10 GWh gr.3: 10 GWh						CAES fuel ratio: 0,000																				
Offshore Wind	3000	MW	11,34	TWh/year	0,00	stabilisation	share	Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent						(TWh/year) Coal Oil Ngas Biomass																				
Wave Power	0	MW	0	TWh/year	0,00	share		Electricity prod. from CSHP Waste (TWh/year)						Transport 0,00 69,20 0,00 0,00																				
River Hydro	0	MW	0	TWh/year	0,00	share		Gr.1: 0,00 0,00						Household 0,01 4,20 4,86 4,65																				
Hydro Power	0	MW	0	TWh/year	0,00	share		Gr.2: 0,00 0,00						Industry 3,37 26,92 18,19 5,18																				
Geothermal/Nuclear	0	MW	0	TWh/year	0,00	share		Gr.3: 1,73 0,00						Various 0,00 0,00 0,00 0,00																				
Output		WARNING!!!: (1) Critical Excess;																																
Demand		District Heating										Electricity										Exchange												
Distr. heating	Production	Consumption										Production										Balance		Payment	Exp									
MW	MW	Solar	Waste+	CSHP	DHP	CHP	HP	ELT	Boiler	EH	Ba-	Elec.	Flex.&	Transp.	HP	Electro-	Hydro	Tur-	Hy-	Geo-	Waste+	Stab-	Imp	Exp	CEEP	EEW	Exp	Million DKK						
January	4674	0	274	271	3898	0	0	234	0	-3	8508	0	0	0	0	0	0	0	2121	0	0	197	3196	1232	100	0	239	239	0	0	33			
February	4788	0	274	276	3934	0	0	280	0	3	8329	0	0	0	0	0	0	0	1778	0	0	197	3226	1267	100	0	139	139	0	0	17			
March	4147	0	274	240	3622	0	0	37	0	-27	8059	0	0	0	0	0	0	0	2034	0	0	197	2970	1058	100	0	200	200	0	0	30			
April	3438	0	274	199	2964	0	0	0	0	0	5488	0	0	0	0	0	0	0	1583	0	0	197	2431	1270	100	0	13	13	0	0	2			
May	2823	0	274	184	2384	0	0	0	0	0	5047	0	0	0	0	0	0	0	1410	0	0	197	1955	1499	100	0	13	13	0	0	2			
June	1594	0	274	92	1228	0	0	0	0	0	5035	0	0	0	0	0	0	0	1548	0	0	197	1007	2301	100	0	19	19	0	0	2			
July	1594	0	274	92	1227	0	0	0	0	0	4797	0	0	0	0	0	0	0	994	0	0	197	1006	2802	100	0	3	3	0	0	0			
August	1594	0	274	92	1227	0	0	0	0	0	5037	0	0	0	0	0	0	0	1406	0	0	197	1006	2428	100	0	1	1	0	0	0			
September	2139	0	274	124	1740	0	0	0	0	0	5252	0	0	0	0	0	0	0	1451	0	0	197	1427	2181	100	0	4	4	0	0	1			
October	2903	0	274	188	2454	0	0	0	0	0	5549	0	0	0	0	0	0	0	2152	0	0	197	2012	1197	100	0	9	9	0	0	2			
November	3630	0	274	210	3121	0	0	9	0	14	5909	0	0	0	0	0	0	0	2128	0	0	197	2560	1132	100	0	107	107	0	0	17			
December	4221	0	274	245	3572	0	0	123	0	7	5978	0	0	0	0	0	0	0	2547	0	0	197	2929	795	100	0	490	490	0	0	78			
Average	3123	0	274	181	2611	0	0	56	0	0	5578	0	0	0	0	0	0	0	1764	0	0	197	2141	1580	100	0	103	103	0	0	Average price			
Maximum	7744	0	274	449	4085	0	0	2936	0	2902	8861	0	0	0	0	0	0	0	4868	0	0	197	3350	5295	100	0	3683	3683	0	0	(DKK/MWh)			
Minimum	1488	0	274	85	1084	0	0	0	0	-1742	3317	0	0	0	0	0	0	0	30	0	0	197	889	0	100	0	0	0	0	0	231	201		
TWh/year	27,43	0,00	2,74	1,59	22,93	0,00	0,00	0,50	0,00	0,00	49,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	15,49	0,00	0,00	1,73	18,81	13,88		0,00	0,91	0,91	0,00	0	183			
FUEL BALANCE (TWh/year):		Waste/ CAES BioCon- Electro- PV and Wind off										Industry										Imp/Exp Corrected		CO2 emission (Mt):										
DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	HTL	Elc.ly.	ersion	Fuel	Wind	CSP	Wave	Hydro	Solar.Th	Transp.	househ.	Various	Total	Imp/Exp	Corrected	Net	Total	Net									
Coal	-	-	26,31	0,08	0,08	30,85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Oil	1,77	-	-	0,08	0,08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
N.Gas	-	-	19,56	-	0,08	0,08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Biomass	-	-	-	0,08	0,08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1,77	19,56	26,31	0,24	0,31	30,85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Read the results of question 2.3.1:

The Primary energy supply has been reduced from 242.58 to 230.80 TWh/year.

The CO2 emission has been reduced from 64.57 to 56.67 Mt/year.

Critical Excess Electricity Production (CEEP) = 0.91 TWh/year



### Step 3: Change regulation strategy)

Choose "Simulation" and the following window will open:

Change the technical regulation strategy to 2 by activating the **Change technical regulation strategy** button.

### Step 4: Calculate and see result in print output (or clipboard)

Activate the "Run (print)" button and get the following print:

Input		Exercise2.txt		The EnergyPLAN model 16.22	
Electricity demand (TWh/year):	Flexible demand 0,00	Fixed demand 48,00	Fixed Imp/exp. 0,00	Electric heating + HP 0,00	Electric cooling 0,00
District heating (TWh/year)	Gr.1 1,59	Gr.2 10,00	Gr.3 15,84	Sum 27,43	
Wind	2000 MW	4,15 TWh/year	0,00 Grid		
Offshore Wind	3000 MW	11,34 TWh/year	0,00 stabilisation		
Wave Power	0 MW	0 TWh/year	0,00 share		
River Hydro	0 MW	0 TWh/year	0,00 share		
Hydro Power	0 MW	0 TWh/year			
Geothermal/Nuclear	0 MW	0 TWh/year			

Output	
Demand	Production
Distr. heating MW	Solar MW
January 4674	0
February 4788	0
March 4147	0
April 3438	0
May 2823	0
June 1594	0
July 1594	0
August 1594	0
September 2139	0
October 2903	0
November 3630	0
December 4221	0
Average 3123	0
Maximum 7744	0
Minimum 1488	0
TWh/year 27,43	0,00

Consumption		Production		Balance		Exchange	
Elec. demand MW	Flex.& Transp. MW	Waste+ CHP MW	HP MW	ELT MW	Boiler MW	Exp MW	Imp MW
January 8508	0	0	0	0	0	0	0
February 8329	0	0	0	0	0	0	0
March 8059	0	0	0	0	0	0	0
April 5408	0	0	0	0	0	0	0
May 5047	0	0	0	0	0	0	0
June 5035	0	0	0	0	0	0	0
July 4797	0	0	0	0	0	0	0
August 5037	0	0	0	0	0	0	0
September 5252	0	0	0	0	0	0	0
October 5549	0	0	0	0	0	0	0
November 5909	0	0	0	0	0	0	0
December 5978	0	0	0	0	0	0	0
Average 5578	0	0	0	0	0	0	0
Maximum 8861	0	0	0	0	0	0	0
Minimum 3317	0	0	0	0	0	0	0
TWh/year 49,00	0,00	0,00	0,04	0,00	0,00	0,00	0,00

FUEL BALANCE (TWh/year):		Waste/ HTL		CAES		BioCon-		Electro-		PV and Wind off CSP		Industry		Corrected		CO2 emission (Mt):	
DHP	CHP2	CHP3	Boiler2	Boiler3	PP	GeoNu.	Hydro	HTL	CAES	Electro-	Wind	Solar.Th	Transp. househ.	Various	Total	Total	Total
Coal	24,30	0,09	0,36	31,00	-	-	-	-	-	-	-	-	0,01	3,37	59,13	0,00	59,13
Oil	1,77	-	0,09	0,36	-	-	-	-	-	-	-	-	69,20	4,20	26,92	102,53	27,31
N.Gas	19,27	-	0,09	0,36	-	-	-	-	-	-	-	-	4,66	18,19	42,57	0,00	42,57
Biomass	-	-	0,09	0,36	-	-	-	-	-	-	-	-	4,55	5,18	10,18	0,00	10,18
Renewable	-	-	-	-	-	-	-	-	-	4,15	11,34	-	-	-	15,49	0,00	15,49
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00
Total	1,77	19,27	24,30	0,36	1,42	31,00	-	-	-	4,15	11,34	-	69,20	13,42	56,68	229,90	56,23

Read the results of question 2.3.2:

The Primary energy supply has been reduced from 230.80 to 229.90 TWh/year.

The CO2 emission has been reduced from 56.67 to 56.23 Mt/year.

Critical Excess Electricity Production (CEEP) is reduced from 0.91 to 0 TWh/year

## Exercise 2.4: Implement electricity-saving measures

Decrease the electricity demand by 30% from 49 to 34.3 TWh/year.

*Question 2.4.1: What is 1) the excess electricity production, 2) the primary energy supply and 3) the CO<sub>2</sub> emission of the system if the CHP units are regulated solely according to the heat demand?*

*Question 2.4.2: What is the answer if the CHP units are regulated according to both the heat and the electricity demands?*

**How to do exercise 2.4:** Use input data file from exercise 2.3.

### Step 1: Change electricity demand

Choose “Demand” and “Electricity” and the following window will open:

Parameter	Value	Unit	Action
Electricity demand*	34.3	TWh/year	Change distribution DK 2013 Electricity demand.tx
Additional electricity demand	0	TWh/year	Change distribution const.txt
Electric heating (IF included)	0	TWh/year	Subtract electric heating using distribution from 'indiv
Electric cooling (IF included)	0	TWh/year	Subtract electric cooling using distribution from 'cooli
Elec. for Biomass Conversion	0,00	TWh/year	(Transferred from Biomass Conversion TabSheet)
Elec. for Transportation	0,00	TWh/year	(Transferred from Transport TabSheet)

Place the cursor in the input squares and type in the various input values.

Choose “Simulation”:

Chose Simulation Strategy:

- Technical Simulation
  - 1 Balancing heat demands
  - 2 Balancing both heat and electricity demands
- Individual Heat Pump Simulation
  - 1 Individual Heat Pumps and Electric Boilers seek to utilise only Critical Ex
  - 2 Individual Heat Pumps and Electric Boilers seek to utilise all electricity exp

Make sure that the technical regulation strategy is 1.

**Step 2: Calculate and see result in print output (or clipboard)**  
 Activate the "Run (print)" button and get the following print:

Input      Exercise2.txt      The EnergyPLAN model 16.22

Electricity demand (TWh/year):      Flexible demand    0,00 Fixed demand                            34,30      Fixed imp/exp.    0,00 Electric heating + HP                    0,00      Transportation    0,00 Electric cooling                            0,00      Total                34,30	Capabilities      Efficiencies MW-e    MJ/s    elec.    Ther    COP Group 2: CHP        1350    1646    0,41    0,50 Heat Pump      0        0        -        -        3,00 Boiler                5000                    0,90 Group 3: CHP        2000    2439    0,41    0,50 Heat Pump      0        0        -        -        3,00 Boiler                5000                    0,90 Condensing        9000                    0,45	Regulation Strategy:      Technical regulation no. 1 CEEP regulation            000000000 Minimum Stabilisation share    0,00 Stabilisation share of CHP        0,00 Minimum CHP gr 3 load            450    MW Minimum PP                            0        MW Heat Pump maximum share        1,00 Maximum import/export            0        MW Distr. Name :                    Hour_nordpool.txt Addition factor                    0,00    DKK/MWh Multiplication factor                2,00 Dependency factor                    0,00    DKK/MWh pr. MW Average Market Price                227    DKK/MWh Gas Storage                            0        GWh Syngas capacity                        0        MW Biogas max to grid                    0        MW
---	--	---

District heating (TWh/year)      Gr.1    Gr.2    Gr.3    Sum District heating demand            1,59    10,00    15,84    27,43 Solar Thermal                        0,00    0,00    0,00    0,00 Industrial CHP (CSHP)                0,00    0,00    2,41    2,41 Demand after solar and CSHP        1,59    10,00    13,43    25,02	Fuels      TWh/year      Grid      stabil- Offshore Wind      2000    MW    4,15    TWh/year      0,00    Grid Onshore Wind      3000    MW    11,34    TWh/year      0,00    stabil- Wave Power            0        MW    0        TWh/year      0,00    station River Hydro            0        MW    0        TWh/year      0,00    share Hydro Power            0        MW    0        TWh/year Geothermal/Nuclear    0        MW    0        TWh/year	Heatstorage: gr.2: 10 GWh      gr.3: 10 GWh Fixed Boiler: gr.2: 0,0 Per cent      gr.3: 0,0 Per cent Electricity prod. from      CSHP      Waste (TWh/year) Gr.1:                            0,00    0,00 Gr.2:                            0,00    0,00 Gr.3:                            1,73    0,00
--	---	--

Fuel Price level: Basic Capacities      Storage      Efficiencies MW-e      GWh      Elec.      Ther. Elec. Storage      0      0      0,80 Charge 1:            0      0      0,90 Discharge 1:        0      0      0,80 Charge 2:            0      0      0,80 Discharge 2:        0      0      0,90 Electrolysers:      0      0      0,80    0,00 Rockbed Storage:    0      0      1,00 CAES fuel ratio:    0,000	(TWh/year)      Coal      Oil      Ngas      Biomass Transport      0,00    69,20    0,00    0,00 Household      0,01    4,20    4,66    4,55 Industry        3,37    26,92    18,19    5,18 Various          0,00    0,00    0,00    0,00	CAES fuel ratio:    0,000
---	--	---------------------------

**Output      WARNING!:(1) Critical Excess;**

	District Heating										Electricity														Exchange					
	Demand heating MW	Production								Bal- ance MW	Consumption						Production						Balance				Payment Imp    Exp Million DKK			
		Solar	CSHP	DHP	CHP	HP	ELT	Boiler	EH		Elec. demand	Flex.& Transp.	Elec. trolleyser	Hydro Pump	Tur- bine	RES	Hy- dro	Geo- thermal	Waste+	CSHP	CHP	PP	Stab- Load %	Imp	Exp	CEEP		EEP		
January	4874	0	274	271	3881	0	0	248	0	0	4556	0	0	0	0	0	0	2121	0	0	197	3162	207	100	0	1152	1152	0	0	178
February	4768	0	274	276	3893	0	0	335	0	0	4430	0	0	0	0	0	0	1778	0	0	197	3184	155	100	0	884	884	0	0	113
March	4147	0	274	240	3568	0	0	65	0	0	4241	0	0	0	0	0	0	2034	0	0	197	2926	143	100	0	1058	1058	0	0	172
April	3438	0	274	199	2982	0	0	3	0	-21	3827	0	0	0	0	0	0	1583	0	0	197	2446	89	100	0	487	487	0	0	73
May	2823	0	274	164	2368	0	0	0	0	17	3533	0	0	0	0	0	0	1410	0	0	197	1942	218	100	0	234	234	0	0	37
June	1594	0	274	92	1251	0	0	0	0	-24	3524	0	0	0	0	0	0	1548	0	0	197	1026	919	100	0	165	165	0	0	24
July	1594	0	274	92	1227	0	0	0	0	0	3358	0	0	0	0	0	0	984	0	0	197	1006	1211	100	0	50	50	0	0	4
August	1594	0	274	92	1221	0	0	0	0	6	3526	0	0	0	0	0	0	1406	0	0	197	1001	1035	100	0	114	114	0	0	18
September	2136	0	274	124	1743	0	0	0	0	-3	3676	0	0	0	0	0	0	1451	0	0	197	1429	726	100	0	127	127	0	0	22
October	2903	0	274	168	2437	0	0	0	0	24	3884	0	0	0	0	0	0	2152	0	0	197	1998	183	100	0	646	646	0	0	111
November	3630	0	274	210	3132	0	0	13	0	0	4136	0	0	0	0	0	0	2128	0	0	197	2569	163	100	0	919	919	0	0	145
December	4221	0	274	245	3567	0	0	135	0	0	4185	0	0	0	0	0	0	2547	0	0	197	2625	105	100	0	1589	1589	0	0	268
Average	3123	0	274	181	2602	0	0	66	0	0	3905	0	0	0	0	0	0	1764	0	0	197	2133	429	100	0	618	618	0	0	Average price
Maximum	7744	0	274	449	4085	0	0	2936	0	2319	6203	0	0	0	0	0	0	4968	0	0	197	3350	3002	100	0	4911	4911	0	0	(DKK/MWh)
Minimum	1488	0	274	85	1084	0	0	0	0	-1918	2322	0	0	0	0	0	0	30	0	0	197	889	0	100	0	0	0	0	228	214
TWh/year	27,43	0,00	2,41	1,59	22,85	0,00	0,00	0,58	0,00	0,00	34,30	0,00	0,00	0,00	0,00	0,00	0,00	15,49	0,00	0,00	1,73	18,74	3,77	0,00	5,43	5,43	0,00	0,00	0	1162

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	HTL	Waste/CAES	BioCon-	Electro-	Fuel	Wind	PV and CSP	Wind off	Wave	Hydro	Solar.Th	Transp.	househ.	Industry	Various	Total	Imp/Exp Corrected		CO2 emission (Mt):		
																									Imp/Exp	Net	Total	Net	
Coal	-	-	26,23	0,07	0,09	8,37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,01	3,37	38,14	-12,06	26,08	13,04	8,92		
Oil	1,77	-	-	0,07	0,09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	69,20	4,20	26,92	102,25	0,00	102,25	27,24	27,24	
N.Gas	-	19,47	-	0,07	0,09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,66	18,19	42,48	0,00	42,48	8,87	8,87	
Biomass	-	-	-	0,07	0,09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,55	5,18	9,89	0,00	9,89	0,00	0,00	
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	4,15	-	11,34	-	-	-	-	-	-	-	15,49	0,00	15,49	0,00	0,00	0,00	0,00
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total	1,77	19,47	26,23	0,29	0,35	8,37	-	-	-	-	-	-	4,15	-	11,34	-	-	-	-	-	69,20	13,42	53,66	208,25	-12,06	196,20	48,96	44,83	

22-juli-2022 [14:05]

Read the results of question 2.4.1:  
 The Primary energy supply has been reduced from 229.90 to 208.25 TWh/year.  
 The CO2 emission has been reduced from 56.23 to 48.96 Mt/year.  
 Critical Excess Electricity Production (CEEP) is raised from 0 to 5.43 TWh/year

**Step 3: Change regulation strategy, calculate and read results.**

Repeat steps 1 and 2.  
 Change the technical regulation strategy to 2 in the simulation window.

Activate the "Run (print)" button and read the results of question 2.4.2 on the print:  
 The Primary energy supply has been reduced from 208.25 to 202.89 TWh/year.  
 The CO2 emission has been reduced from 48.96 to 46.70 Mt/year.  
 Critical Excess Electricity Production (CEEP) is reduced from 5.43 to 0 TWh/year

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## Exercise 2.5: Add heat pump and heat storage capacity to CHP plants

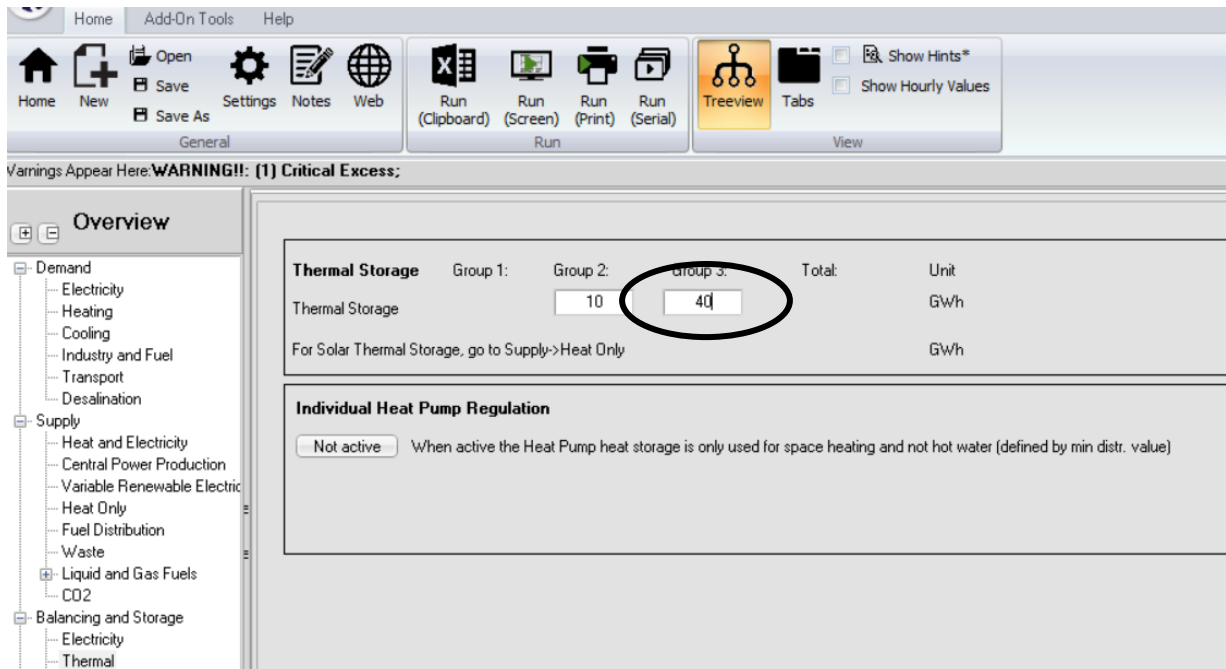
Add heat storage capacity of 40 GWh to gr 2 together with a 300 MW heat pump with a COP=3.

*Question 2.5.1: What is 1) the excess electricity production, 2) the primary energy supply and 3) the CO<sub>2</sub> emission of the system if the CHP units are regulated according to both the heat and the electricity demands?*

**How to do exercise 2.5:** Use input data file from exercise 2.4.

### Step 1: Add heat pump and heat storage

Choose “Balancing and Storage” and “Thermal” and change storage to 40 GWh.

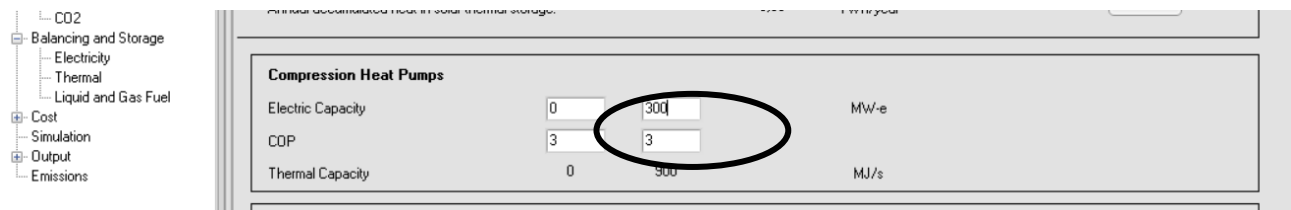


The screenshot shows the software interface with the following details:

- Menu bar: Home, Add-On Tools, Help
- General toolbar: Home, New, Open, Save, Save As, Settings, Notes, Web, Run (Clipboard), Run (Screen), Run (Print), Run (Serial), Treeview, Tabs, Show Hints\*, Show Hourly Values
- Warnings: Appear Here: **WARNING!!: (1) Critical Excess;**
- Overview panel (left):
  - Demand
    - Electricity
    - Heating
    - Cooling
    - Industry and Fuel
    - Transport
    - Desalination
  - Supply
    - Heat and Electricity
    - Central Power Production
    - Variable Renewable Electric
    - Heat Only
    - Fuel Distribution
    - Waste
    - Liquid and Gas Fuels
    - CO<sub>2</sub>
  - Balancing and Storage
    - Electricity
    - Thermal
- Thermal Storage table:

Thermal Storage	Group 1:	Group 2:	Group 3:	Total:	Unit
Thermal Storage		10	40		GWh
For Solar Thermal Storage, go to Supply->Heat Only					GWh
- Individual Heat Pump Regulation:
  - Not active
  - When active the Heat Pump heat storage is only used for space heating and not hot water (defined by min distr. value)

Choose “Supply” and “Heat Only” and input 300 MW heat pump and COP=3.



The screenshot shows the software interface with the following details:

- Overview panel (left):
  - CO<sub>2</sub>
  - Balancing and Storage
    - Electricity
    - Thermal
    - Liquid and Gas Fuel
  - Cost
  - Simulation
  - Output
  - Emissions
- Compression Heat Pumps table:

Electric Capacity	0	300	MW-e
COP	3	3	
Thermal Capacity	0	300	MJ/s

Place the cursor in the input squares and type in the various input values.

**Step 2: Calculate and see result in print output (or clipboard)**

Activate the  button and look at the following print output:

Input		Exercise2.txt	The EnergyPLAN model 16.22																																			
Electricity demand (TWh/year): Flexible demand 0,00 Fixed demand 34,30 Fixed imp/exp. 0,00 Electric heating + HP 0,00 Transportation 0,00 Electric cooling 0,00 Total 34,30			Group 2: Capacities Efficiencies MW-e MJ/s elec. Ther COP CHP 1350 1846 0,41 0,50 Heat Pump 0 0 0,90 3,00 Boiler 5000				Regulation Strategy: Technical regulation no. 2 CEEP regulation 000000000 Minimum Stabilisation share 0,00 Stabilisation share of CHP 0,00 Minimum CHP gr 3 load 450 MW Minimum PP 0 MW Heat Pump maximum share 1,00 Maximum import/export 0 MW				Fuel Price level: Basic Capacities Storage Efficiencies Elec. Storage MW-e GWh Elec. Ther. Charge 1: 0 0 0,80 Discharge 1: 0 0 0,90 Charge 2: 0 0 0,80 Discharge 2: 0 0 0,90 Electrolysers: 0 0 0,80 0,00 Rockbed Storage: 0 0 1,00 CAES fuel ratio: 0,000				District heating (TWh/year) Gr.1 Gr.2 Gr.3 Sum District heating demand 1,59 10,00 15,84 27,43 Solar Thermal 0,00 0,00 0,00 0,00 Industrial CHP (CSHP) 0,00 0,00 2,41 2,41 Demand after solar and CSHP 1,59 10,00 13,43 25,02				Group 3: Capacities Efficiencies MW-e MJ/s elec. Ther COP CHP 2000 2439 0,41 0,50 Heat Pump 300 600 0,90 3,00 Boiler 5000 Condensing 9000 0,45				Heatsstorage: gr:2: 10 GWh gr:3: 40 GWh Fixed Boiler: gr:2: 0,0 Per cent gr:3: 0,0 Per cent Electricity prod. from CSHP Waste (TWh/year) Gr.1: 0,00 0,00 Gr.2: 0,00 0,00 Gr.3: 1,73 0,00				Distr. Name : Hour_nordpool.txt Addition factor 0,00 DKK/MWh Multiplication factor 2,00 Dependency factor 0,00 DKK/MWh pr. MW Average Market Price 227 DKK/MWh Gas Storage 0 GWh Syngas capacity 0 MW Biogas max to grid 0 MW				Wind 2000 MW 4,15 TWh/year 0,00 Grid Offshore Wind 3000 MW 11,34 TWh/year 0,00 stabili- Wave Power 0 MW 0 TWh/year 0,00 sation River Hydro 0 MW 0 TWh/year 0,00 share Hydro Power 0 MW 0 TWh/year Geothermal/Nuclear 0 MW 0 TWh/year				(TWh/year) Coal Oil Ngas Biomass Transport 0,00 66,20 0,00 0,00 Household 0,01 4,20 4,66 4,55 Industry 3,37 26,62 18,19 5,18 Various 0,00 0,00 0,00 0,00			
<b>Output WARNING!!: (1) Critical Excess;</b>																																						
District Heating										Electricity										Exchange																		
Demand										Consumption										Balance		Payment																
Production										Production										Imp Exp		Imp Exp																
Distr. heating	Solar	Waste+	DHP	CHP	HP	ELT	Boiler	EH	Ba-	Elec.	Flex.&	HP	Electro-	EH	Hydro	Tur-	RES	Hy-	Geo-	Waste+	CHP	PP	Stab-	Imp	Exp	CEEP	EEP	Imp	Exp									
MW	MW	MW	MW	MW	MW	MW	MW	MW	lance	demand	Transp.	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	Load	MW	MW	MW	MW	Million DKK	Million DKK									
January	4074	0	274	271	2690	559	0	849	31	0	4566	0	186	0	31	0	0	2121	0	0	197	2206	249	100	0	0	0	0	0	0								
February	4768	0	274	276	2698	504	0	869	16	0	4430	0	168	0	16	0	0	1778	0	0	197	2458	182	100	0	0	0	0	0	0								
March	4147	0	274	240	2477	501	0	832	36	-13	4241	0	167	0	36	0	0	2034	0	0	197	2031	183	100	0	0	0	0	0	0								
April	3438	0	274	199	2542	287	0	126	28	-18	3827	0	96	0	28	0	0	1583	0	0	197	2084	87	100	0	0	0	0	0	0								
May	2823	0	274	164	2228	105	0	26	29	-4	3533	0	35	0	29	0	0	1410	0	0	197	1827	162	100	0	0	0	0	0	0								
June	1594	0	274	92	1123	95	0	4	39	-33	3524	0	32	0	39	0	0	1548	0	0	197	920	935	100	0	5	5	0	0	1								
July	1594	0	274	92	1198	29	0	0	13	0	3358	0	10	0	13	0	0	994	0	0	197	972	1217	100	0	0	0	0	0	0								
August	1594	0	274	92	1104	80	0	11	17	16	3528	0	27	0	17	0	0	1406	0	0	197	905	1061	100	0	0	0	0	0	0								
September	2139	0	274	124	1659	53	0	20	21	-13	3676	0	18	0	21	0	0	1451	0	0	197	1390	707	100	0	0	0	0	0	0								
October	2903	0	274	168	1765	329	0	231	42	64	3884	0	110	0	42	0	0	2152	0	0	197	1472	215	100	0	0	0	0	0	0								
November	3630	0	274	210	2243	442	0	387	75	-2	4196	0	147	0	75	0	0	2128	0	0	197	1839	195	100	0	0	0	0	0	0								
December	4221	0	274	245	1893	616	0	1047	144	2	4185	0	205	0	144	0	0	2547	0	0	197	1552	238	100	0	0	0	0	0	0								
Average	3123	0	274	181	1990	300	0	336	41	0	3605	0	100	0	41	0	0	1764	0	0	197	1632	454	100	0	0	0	0	0	0	Average price							
Maximum	7744	0	274	449	4085	900	0	5283	1930	4363	6203	0	300	0	1930	0	0	4868	0	0	197	3350	3002	100	0	725	725	0	0	0	(DKK/MWh)							
Minimum	1468	0	274	85	0	0	0	0	0	-1991	2322	0	0	0	0	0	0	30	0	0	197	0	0	100	0	0	0	0	0	0	222	160						
TWh/year	27,43	0,00	2,41	1,59	17,48	2,63	0,00	2,95	0,36	0,00	34,30	0,00	0,88	0,00	0,36	0,00	0,00	15,49	0,00	0,00	1,73	14,34	3,98	0,00	0,00	0,00	0,00	0,00	0,00	0	1							
FUEL BALANCE (TWh/year):										Waste/ CAES BioCon- Electro- PV and Wind off										Industry		Imp/Exp		CO2 emission (Mt):														
DHP CHP2 CHP3 Boiler2 Boiler3 PP Geo/Nu. Hydro HTL										Elec. version Fuel Wind CSP Wave Hydro Solar.Th. Transp. househ. Various Total										Imp/Exp		Total Net																
Coal	-	-	18,85	0,44	0,38	8,86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,01	3,37	31,61	-0,01	31,60	10,91	10,91	-	-									
Oil	1,77	-	-	0,44	0,38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	66,20	4,20	26,92	102,91	0,00	102,91	27,41	27,41	-	-								
N Gas	-	16,11	-	0,44	0,38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,66	19,19	36,78	0,00	36,78	6,12	6,12	-	-									
Biomass	-	-	-	0,44	0,38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,55	5,18	10,55	0,00	10,55	0,00	0,00	-	-									
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	4,15	-	11,34	-	-	-	-	-	-	-	-	15,49	0,00	15,49	0,00	0,00	-	-								
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	-	-									
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	-	-									
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00	-	-									
Total	1,77	16,11	18,85	1,76	1,52	8,86	-	-	-	-	-	-	-	4,15	-	11,34	-	-	-	-	66,20	13,42	53,65	200,64	-0,01	200,63	46,45	46,44	-	-								

Read the results of question 2.5.1:

The Primary energy supply has been reduced from 202.89 to 200.64 TWh/year.

The CO2 emission has been reduced from 46.70 to 46.45 Mt/year.

Critical Excess Electricity Production (CEEP) is still 0 TWh/year

**REMEMBER to save exercise 2. You will need it when doing exercise 3.**