## **Guideline to EnergyPLAN Exercise 3: More Simple Energy System Analyses.**

Exercise 3 continues from exercise 2 and here you are asked to implement more energy system improvements in the energy system. Through the exercise and the guideline, you learn step by step how to analyse more changes to the energy system.

Exercise 3 continues with the system defined in exercise 2, which is:

- Electricity demand of 34.3 TWh/year and "DK 2013 electricity demand"
- Condensing power plant: 9000 MW coal -fired
- 2000 MW on-shore wind power using "Hour\_wind\_1"
- 3000 MW off-shore wind power using "DK offshorewind 2013.txt"
- Annual district heating demand of total 27.43 TWh divided into 1.59 TWh district heating oil-boilers, 10 TWh small-scale CHP and 15.84 TWh large-scale CHP extraction plants (distribution "VpDkFjv50.txt").
- Decentralised CHP of total 1350 MW, eff-th = 50%, eff-el = 41% on natural gas, and Heat Pump of 300 MWe, COP=3.
- Large-scale CHP of total 2000 MW, eff-th = 50%, eff-el = 41% on coal.
- Fuel demand for individual house heating of total 14.42 TWh divided into 0.01 coal, 4.2 oil, 5.66 natural gas and 4.55 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 2.41 TWh and an electricity production of 1.73 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 200.64 TWh/year and CO2 emissions of 46.45 Mt. and excess electricity production of 0 TWh/year.

#### **Exercise 3.1: Add Waste Resources**

Open the EnergyPLAN model. Load the data of exercise 2. Add 6 TWh/year of waste resources to the system. Divide the resources geographically into

- 1 TWh in gr. 1,
- 2 TWh in gr. 2 and
- 3 TWh in gr. 3.

*Question 3.1.1: What are the excess production, the primary energy supply and the CO2 emission of the system, IF all waste resources are converted into heat with an efficiency of 80%?* 

Question 3.1.2: What are the excess production, the primary energy supply and the CO2 emission of the system, IF all waste resources are utilised in CHP with an electric efficiency of 30% and a heat efficiency of 50%?

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Cutiva Outpu Guina anuary lebruary darch uly ugust beptember becember becember werage daximum Whyear FUEL BAL Coal Oli N.Gas Biomass Renewable	Ate t Ut Demand Distr. heating MW 4074 4708 4074 4708 4074 4708 4074 4708 4074 4708 4074 4708 4074 4074 4747 4074 4078 4074 40 40 40 40 40 40 40 40 40 4	he ; <u>Solar</u> <u>MW</u> 0 0 0 0 0 0 0 0 0 0 0 0 0	Waste+ CSHP U 821 821 821 821 821 821 821 821 821 821	RNING District Pr Pr Pr Chill C	GII: ( Heating doubtion HP HP W M 400 HP MP MW M400 HP MP MW M400 HP HP MW M400 HP HP HP HP M400 HP HP M400 HP HP HP HP M400 HP HP HP HP M400 HP H	)" b 1) Cr ELT MW 0 0 0 0 0 0 0 0 0 0 0 0 0	Boiler MW 553 414 434 37 5 0 0 0 0 0 113 198 732 208 4828 0 1.82	Lt in on a ll Ex ll Ex mw and and and and and and and and and and	Ba- lance of MW -3 -51 14 -77 0 9 -8 -55 -51 14 -17 0 9 -8 -55 -22 4 0 0 4203 -2233 0.000 Wass	TC244	Control of the contro	iumption Elec- trolyser El MW M 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Hydroffer Hydroffer Hydroffer General Hydroffer	pboa f que	RES MW 2121 1778 2034 1410 1583 1410 1583 1410 1583 1410 1583 2034 1451 2152 2152 2152 2152 2152 2152 215	Electron 3	.1.1 ttricity ttricity ttricity Construction Construction tricity tr	e+ P CHP MW 2153 2410 1928 1941 1509 561 606 567 1008 567 1008 1283 1500 1427 3360 0 12,53 househ	MW 272 192 242 177 460 1292 1579 1399 1057 368 298 264 635 3376 0 5,58 Industr Various 3,37 26,92	Stab- Load Ir % 100 100 100 100 100 100 100 100 100 100	Balar np Ex MW M 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	CEEF P CEEF W MW 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	MW 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Payment Imp E) Million DKK 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Ctiva Ctiva Output I I I I I I I I I I I I I	Ate t Ut Demand Distr. heating MW 4074 4708 4074 4708 4074 4708 4074 4708 4074 4708 4074 4708 4074 4074 4747 4074 4078 4074 40 40 40 40 40 40 40 40 40 4	he ; <u>Solar</u> <u>MW</u> 0 0 0 0 0 0 0 0 0 0 0 0 0	Waster ( CSHP ( 821 821 821 821 821 821 821 821 821 821	Image: Construct of the second seco	GII: ( Heating oduction HP HP doubtion HP MW MW W MW W MW HPW HPW HPW HPW HPW HPW HPW MW HPW HPW HPW HPW HPW HPW HPW HPW HPW HPW	)" b 1) Cr 1) Cr 0 0 0 0 0 0 0 0 0 0 0 0 0	Boiler MW 553 414 434 37 5 0 0 0 0 0 113 198 732 208 4828 0 1.82	Lt in on a ll Ex ll Ex mw and and and and and and and and and and	Ba- MW -15 -51 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -22 -2	TCA4	Control of the contro	sumption Elec- trolyser El WW M 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Hydroffer Hydroffer Hydroffer General Hydroffer	oboa f que	RES MW 2121 1778 2034 1410 1583 1410 1583 1410 1583 1410 1583 2034 1451 2152 2152 2152 2152 2152 2152 215	Electron 3	.1.1 ttricity ttricity ttricity Construction Construction tricity tr	e+ P CHP MW 2163 2410 1928 1941 1809 561 1809 561 1809 561 1809 561 1809 561 1809 561 1809 561 1283 1703 1500 0 12,53 1500 0 12,53 1427 3350 0 0 12,53	MW 272 192 242 192 247 167 1399 1057 368 298 284 635 3376 0 5,58 Industr Various 3,37 26,92 18,19	Stab- Load if 96 0 100 100 100 100 100 100 100 100 100 1	Balar np Ex 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	cce         CEEES           p         CEES         MW           0         0         0         0           0         0         0         0           0         0         0         0           0         0         0         0           0         0         0         0           1         1         1         1           8         962         0         0           0         0         0         0         0           10         0.01         0.01         10.71           73.63         0.00         0.00         0         0.00	MW 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Payment E Imp E Million DHK 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Cutiva Outpu Guina anuary lebruary darch uly ugust beptember becember becember werage daximum Whyear FUEL BAL Coal Oli N.Gas Biomass Renewable	Ate t Demand Distr. heating MW 4874 4778 4778 4778 4778 4778 2139 2003 3123 3830 4221 3123 3830 4221 3123 3123 31744 1594 2019 3123 3123 31744 1594 2019 3123 3123 3123 3123 3124 3124 3124 3125 3124 3125	he :	"Ru WASte* CSHP ( MW 821 821 821 821 821 821 821 821 821 821	Image: Construct of the second seco	GII: (( Heating oduction HP HP W MW 25 467 122 40 422 41 16 4 41 16 4 42 44 6 41 16 7 122 40 42 5 40 422 28 1,96 2 Boiler3 0 22 0,22 0,22 0,22 0,22 0,22 0,22 0,22	)" b 1) Cr LT MW 0 0 0 0 0 0 0 0 0 0 0 0 0	Boiler MW 553 414 434 37 5 0 0 0 0 0 113 198 732 208 4828 0 1.82	Lt in on a ll Ex ll Ex mw and and and and and and and and and and	CCESS Ba- lance of MW 3 3 -15 -51 -51 -51 -51 -51 -51 -51 -51 -2233 0,00 -2233 0,00 -2233 -2233 -2233 -0,00 	TC244 Elec. F Elec. F MWV N 4566 4430 4241 3652 4320 4241 3652 4320 4130 4130 4136 4130 4130 4130 4130 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	Control of the contro	sumption Elec- trolyser El WW M 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Hydri Hydri Hydri Hydri Hydri WW WW WW WW WW WW WW WW WW WW WW WW WW	oboa f que	RES MW 2121 1778 2034 1410 1583 1410 1583 1410 1583 1410 1583 2034 1451 2152 2152 2152 2152 2152 2152 215	Elec Produ Hy- Ged dro therm MW MV 0 0 0 0 0 0 0 0 0 0 0 0 0	.1.1 tricity trion → Wasta → Wasta	e+ P CHP 2153 2410 1928 1941 1909 561 608 1283 1703 1500 0 1427 3350 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 350 0 0 12,53 1	MW 272 192 242 177 177 1292 1579 1399 1399 1057 388 284 635 3376 0 5,58 10dustr Various 3,37 26,92 18,19 5,18 5,18	Stab- Load II 96 10 100 100 100 0.00	Balar np Ex MW M 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	CEEF P CEEF W MW 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	MW 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Imp         Ex           Million DHK         0           0         0           0         0           0         0           0         0           0         0           0         0           0         0           0         0           0         0           2         emission (M           Total         Net           123         11,23           7,63         7,63           0,00         0,00

The Primary energy supply has been raised from 200,64 to 203.64 TWh/year.

The CO2 emission has been reduced from 46.45 to 45.95 Mt/year.

The Critical Excess Electricity Production (CEEP) is raised from 0 to 0.01 TWh/year.

Step 5: Open the Supply > Waste window and add new input values:
File Edit Tools Help
Frontpage Input Cost Regulation Output Settings
ElectricityDemand DistrictHeating RenewableEnergy ElecStorage Cooling Individual Industry Transport Waste Biomass Conversion Synthetic Fuel Desalination CCS Nuclear
Waste: Heat, electricity and biofuel from energy conversion of waste
Waste is defined geograhical on the three district heating groups. Only one hour distribution can be defined and storage of waste is not considered an option. Heat production is utilised and given priority in the respective district heating groups. Electricity production is fed into the grid.
Heat production is unised and given priority in the respective district heating groups. Electricity production is real into the grid. Biofuel production for transportation is transfered to the transportation window. And biofuels for CHP and boliers is substracted from the fuels in the respective district heating group.
"Various" represent non energy products such as food. The economic value is substrated from the cost of the waste energy recource.
Distribution of Waste: Change distribution const.txt
Waste input DH production Elementicity production Biofuel transportation Biofuel CHP-Boiler Various (Food etc.) Strategy CHP-Boiler
TWh/year         Efficiency         TWh/year         Efficiency         TWh/year         Efficiency         TWh/year         Efficiency         TWh/year         MDKK/TWh         fuel substitution           DLC.1.         1         0.5         0.50         0.3         0.30         0         0,00         0         0,00         1         0,00
Total: 6,00 V 3,00 V 1,80 0,00 0,00 0,00 0,00 MDKK
Step 6: Calculate and see result in print output (or clipboard)
Activate the "Run (print)" button and read the results of question 3.1.2:
Activate the Run (print) button and read the results of question 5.1.2.
The Driver of an energy suggesting has been reduced from 202 (4 to 201 (5 TWI) (see r
The Primary energy supply has been reduced from 203.64 to 201.65 TWh/year.
The CO2 emission has been reduced from 45,95 to 45.12 Mt/year.
The Critical Excess Electricity Production (CEEP) is still 0.01 TWh/year.

### **Exercise 3.2: Waste Resources used for producing biogas for transportation**

Use the waste resources for producing biogas and heat instead of CHP with a biogas output of 50% and a heat output of 30%. Let the biogas replace diesel in cars by 1 to 1.

Question 3.2.1: What are the excess production, the primary energy supply and the CO2 emission of the system?

How to do exercis	se 3.2: Use I	nput da	ta file f	rom e	xercise	e 3.1				
Step 1: Open the Sup	nh > Wasta	nindou	and ak		tha in	nut uu	mhans	•		
Step 1. Open the Sup	ply > waste	vinaon	anu ch	unge	ine in	ригпи	mbers	•		
Distribution of Waste: Change	e distribution const.tx	t								
Waste input TWh/yearDH pro EfficiencyDH Gr.1:1DH Gr.2:2DH Gr.3:3Total:6,00			Biofuel trans Fiftsjency 0.5 0.5 0.5		Biofuel CH Efficiency 0 0		Various (F Efficiency 0 0		MDKK/TWh 1 0,00 1 0,00 1 0,00 0,00	MDKK
Step 2: Open the Den	nand > Trans	sport w	indow:							
Warnings Appear Here:										
• • Overview	TWh/year	Fossil	Biofuel	HTL, Py and Wa	rolysis iste* Eleci	trofuel T	otal	Distribution		
- Demand	JP (Jet Fuel)	13,25	0	0,00		D 1	3,25			
Electricity Heating	Diesel / DME	24,5		3,00		) 2	27,50			
Cooling	Petrol / Methanol	28,45	0	0,00		2 2	28,45			
Industry and Fuel Transport	Ngas* (Grid Gas)	0			,		0,00	Gas	const.txt	
Desalination	LPG	0					0,00			
- Supply - Heat and Electricity										
Central Power Production	Ammonia (NH3)					)	0,00			
Wariable Renewable Electric     Heat Only	H2 (Produced by Elec	trolysers)					0	H2	Hour_transport.txt	
- Fuel Distribution	Electricity (Dump Char	ge)					0	Dump	Hour_transport.txt	
Waste     Equid and Gas Fuels     CO2     Balancing and Storage	Electricity (Smart Char	ge)					0	Smart	Hour_transport.txt	
Note: The biofuels fro Change diesel from 2	7.5 to 24.5.		2			4)				
Step 3: Calculate and		-	- '	-		,	) 1.			
Activate the "Run (pr										
The Primary energy s							vn/yea	ır.		
The CO2 emission ha					•					
The Critical Excess E	lectricity Pro	duction	I (CEEP	) has (	lecrea	sed fro	om 0.0	1 to 0 T	Wh/vear.	

The Critical Excess Electricity Production (CEEP) has decreased from 0,01 to 0 TWh/year.

#### **Exercise 3.3: Wind and hydrogen for transportation**

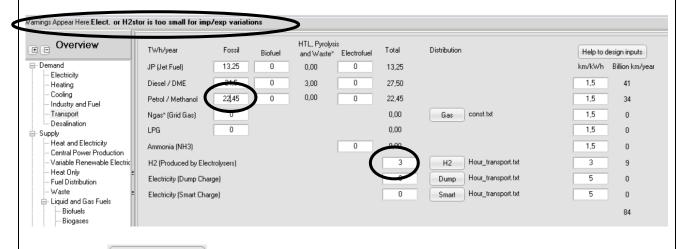
Add 2000 MW wind power producing 4,15 TWh electricity in combination with electrolysers producing 3.00 TWh hydrogen for transportation with an efficiency of 72,3% and a capacity of 500 MW. Let the hydrogen replace petrol cars (1.5 km/kWh) with HFCV (3.0 km/kWh).

*Question 3.3.1: What are the excess production, the primary energy supply and the CO2 emission* of the system?

How to do exercise 3.3: Use Input data file from exercise 3.2

Step 1: Open the Supply > Variable Renewable Energy window and increase wind power from 2000 to 4000 MW.

*Step 2: Open the Demand > Transport window:* 



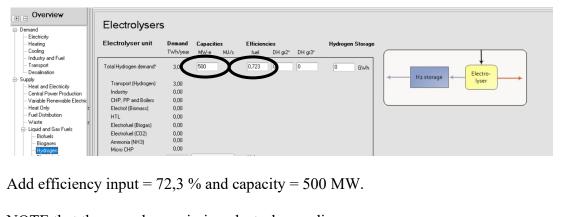
Activate the

Help to design inputs button and receive assistance for the calculation of km transportation. Add 3 TWh Hydrogen leading to 9 billion km/year.

Subtract 9 billion km/year on petrol cars equal to 6 TWh petrol.

NOTE that you have to add electrolysers in order to produce the hydrogen.

Step 3: Open the Supply > Liquid and Gas Fuels > Hydrogen window and add electrolysers.



NOTE that the remark on missing electrolysers disappears

*Step 4: Calculate and see result in print output (or clipboard)* Activate the "Run (print)" button and read the results of question 3.3.1:

The Primary energy supply has decreased from 202.45 to 201.75 TWh/year. The CO2 emission has decreased from 45.44 to 44.32 Mt/year. The Critical Excess Electricity Production (CEEP) has increased from 0.01 to 0.02 TWh/year.

# *Note: If you have got a different result, check if you remembered to change the wind power from 2000 to 4000 MW..!*

#### **Exercise 3.4: Add Solar Thermal in Individual houses**

Add 1 TWh solar thermal (equal to app. 20% of heat demand) to individual houses with natural gas boilers. Use the hour distribution "Hour\_SolarThermal\_CenDK.txt".

*Question 3.4.1: How much of the solar thermal can be utilised?* 

*Question 3.4.2: How much storage capacity is needed in order to utilise all solar thermal production?* 

Question 3.4.3: What are the excess production, the primary energy supply and the CO2 emission of the system?

Overview													
9	Total Heat Dema	35,44	Demand	Per Buildi	ng*: 15	000 kWh	/year <b>Ind</b>	v. heated	househo	olds: 76	1 1000-Units		
mand -Electricity													
	Individual Heati	ng:								r Thermal			
- Industry and Fuel - Transport	TWh/year	Fuel	Efficiency	Heat	Efficiency	Canacitu	Estimated Electricity	Heat	50ia	rnema		Resulting Fuel	
Desalination	1 Will your	Input	Thermal	Demand	Electric	Limit*	Production	Storage*	Share*	Input	Output	Consumption*	
pply	Distribution:		(	Heat				(Days of		6	Solar		
Heat and Electricity     Central Power Production				Hour_indv-h	eat-50proce	nt.txt		heat dema	nd)	н	lour_SolarTi	hermal_CenDK.t	
Variable Renewable Electric											_		
Heat Only =	Coal boiler :	0,01	0,8	0,01				0	1	0	0,00	0,01	
Fuel Distribution	Oil boiler :	4,2	0,85	3,57				0	1	0	0,00	4,20	
Waste = Liquid and Gas Fuels	Ngas boiler :	4,66	0,9	4,19				0	1		0,61	3,98	
Biofuels	-			3,64					-		$\bigcirc$		
Biogases	Biomass boiler :	4,55	0,8	3,04				0	1	U	0,00	4,55	
- Hydrogen	H2 micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00	
- Electrofuels HTL and Pyrolysis	Ngas micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00	
CO2	-					-			-		0,00		
ncing and Storage	Biomass micro CHP	:	0,5	0	0,3	1	0,00	0		0	0,00	0,00	
	Heat Pump :			0	3	1	0,00	0	1	0	0,00		
ulation	Electric heating :			0		1	0.00	0	1	0	0,00		
sions	Elocato fiedality.			•			0,00	•	·		0,00		
	Total Individual:			11,41			0,00				0,61	12,74	

Read the result of question 3.4.1: 0.61 TWh of solar thermal production are utilised.

Individual Heati	ng:					Estimated		Sola			
[Wh/year	Fuel Input	Efficiency Thermal	Heat Demand	Efficiency Electric	Capacity Limit*	Electricity Production	Heat Storage <sup>×</sup>	Share*	Input	Output	Resulting Fue Consumption <sup>®</sup>
Distribution:			Heat Hour_indv-h	eat-50proce	nt.txt		(Days of heat demand)		E H	) [hermal_CenDK	
Coal boiler :	0,01	0,8	0,01				0	1	0	0,00	0,01
Oil boiler :	4,2	0,85	3,57				0	1	0	0,00	4,20
Ngas boiler :	4,66	0,9	4,19				1,1	1	1	1,00	3,55
Biomass boiler :	4,55	0,8	3,64					1	0	0,00	4,55
H2 micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00
Ngas micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00
Biomass micro CHF	P:	0,5	0	0,3	1	0,00	0	1	0	0,00	0,00
Heat Pump :			0	3	1	0,00	0	1	0	0,00	
Electric heating :			0		1	0,00	0	1	0	0,00	
Total Individual:			11.41			0.00				1,00	12,31
Electric heating : Total Individual: e answer to rmal produce nand.	-		11,41	•	-	0,00 at storage	e capaci	ty to th	ne syste	1,00 em. All	solar

**Step 3: Calculate and see result in print output (or clipboard)** Activate the "Run (print)" button and read the results of question 3.4.3: The Primary energy supply has decreased from 201.75 to 201,64 TWh/year. The CO2 emission has decreased from 44.32 to 44.1 Mt/year. The Critical Excess Electricity Production (CEEP) is still 0.02 TWh/year.

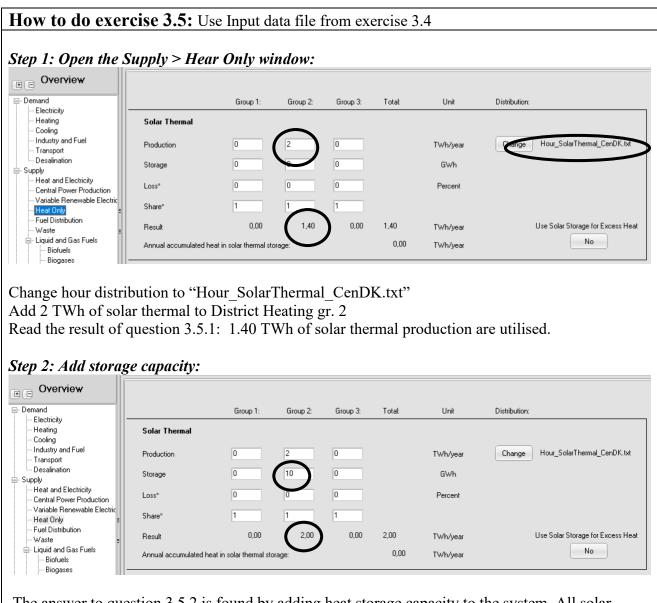
#### Exercise 3.5: Add Solar Thermal to the district heating system

Add 2 TWh solar thermal (equal to app. 20% of district heating demand) to district heating group 2. Use the hour distribution "Hour\_SolarThermal\_CenDK.txt".

Question 3.5.1: How much of the solar thermal can be utilised?

*Question 3.5.2: How much storage capacity is needed in order to utilise all solar thermal production?* 

*Question 3.5.3: What are the excess production, the primary energy supply and the CO2 emission of the system?* 



The answer to question 3.5.2 is found by adding heat storage capacity to the system. All solar thermal production can be utilised when the storage capacity is equal to 9 GWh.

*Step 3: Calculate and see result in print output (or clipboard)* Activate the "Run (print)" button and read the results of question 3.5.3:

The Primary energy supply has increased from 201,64 to 202.86 TWh/year. The CO2 emission has increased from 44.1 to 44.3 Mt/year. The Critical Excess Electricity Production (CEEP) has increased from 0.02 to 0.05 TWh/year.

Remark: The reason for the increase in PES and CO2 is partly based on the fact that not all solar thermal and heat produced on waste can be utilised, and partly on the fact that solar thermal to some extent hinders the heat pump from utilising CEEP.

**REMEMBER** to save exercise 3.