

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 “hour-eldemand-eltra-2001”
- Condensing power plant: 9000 MW coal –fired
- 2000 MW on-shore wind power using “Hour_wind_eltra2001”
- 3000 MW off-shore wind power using “OffshoreHornsRef2003RAMSES.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 “Hour_distr-heat-2-50procent.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 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 201.57 TWh/year and CO₂ emissions of 47.14 Mt. and excess electricity production of 0.72 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%?

How to do exercise 3.1: Use Input data file from exercise 2

Step 1: Open the EnergyPLAN model and load data from exercise 2.

Step 2: Save as exercise 3.

Step 3: Open the "Waste" window under the "Supply" tab and add the input numbers:

EnergyPLAN 12.0: exercise3.bit

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Warnings Appear Here:

Overview

- Demand
- Supply
 - Heat and Electricity
 - Electricity Only
 - Heat Only
 - Waste
 - Plant Fuel Distribution
 - Oil and Gas Fuels
 - CO2
- Balancing and Storage
- Cost
- Simulation
- Output

Waste Incineration

Waste is defined geographical on the three district heating groups. Only one hour district heating production is utilised and given priority in the respective district heating groups. And biofuels for CHP and boilers is subtracted from the fuels in the respective district. The economic value is subtracted from the cost of the waste energy resource.

Distribution of Waste: const.bit

Unit:	Waste input	DH production	Electricity production
	TWh/year	Efficiency	TWh/year
Group 1:	1	0.8	0.80
Group 2:	2	0.8	1.60
Group 3:	3	0.8	2.40
Total:	6.00		4.80

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



Activate the **Run (Print)** button and read the results of question 3.1.1:

	Demand										Production										Consumption										Production										Balance					Payment	
	Distr. heating	Solar	Waste+	DHP	CHP	HP	ELT	Boiler	EH	MW	Ba-	Elec.	Flex.&	Transp.	Elec-	Hydro	Tur-	RES	Hy-	Geo-	Waste+	CHP	PP	Stab-	Imp	Exp	CEEP	EEP	Imp	Exp																	
January	4481	0	743	169	2265	591	0	725	0	-12	4348	0	197	0	0	0	0	2344	0	0	274	1857	136	100	0	67	67	0	0	0	9																
February	4564	0	743	174	3039	377	0	218	0	13	4349	0	126	0	0	0	0	1495	0	0	274	2492	227	100	0	14	14	0	0	0	2																
March	4021	0	743	142	2555	332	0	261	0	-14	4242	0	111	0	0	0	0	1705	0	0	274	2095	317	100	0	39	39	0	0	0	5																
April	3399	0	743	106	1939	393	0	206	0	11	3819	0	131	0	0	0	0	2009	0	0	274	1590	153	100	0	76	76	0	0	0	11																
May	2859	0	743	75	1843	163	0	33	0	3	3609	0	54	0	0	0	0	1285	0	0	274	1511	636	100	0	43	43	0	0	0	6																
June	1784	0	743	12	943	102	0	0	0	-17	3543	0	34	0	0	0	0	1533	0	0	274	773	1127	100	0	131	131	0	0	0	17																
July	1784	0	743	12	980	62	0	0	0	-14	3259	0	21	0	0	0	0	1187	0	0	274	803	1077	100	0	62	62	0	0	0	5																
August	1784	0	743	12	970	81	0	0	0	-24	3657	0	27	0	0	0	0	1547	0	0	274	796	1176	100	0	79	79	0	0	0	12																
September	2251	0	743	40	1319	139	0	13	0	6	3748	0	46	0	0	0	0	1499	0	0	274	1052	1001	100	0	62	62	0	0	0	10																
October	2530	0	743	79	1699	303	0	131	0	-15	3931	0	101	0	0	0	0	2047	0	0	274	1355	498	100	0	172	172	0	0	0	30																
November	3566	0	743	116	2002	438	0	260	0	7	4186	0	146	0	0	0	0	2342	0	0	274	1642	239	100	0	165	165	0	0	0	27																
December	4085	0	743	146	2294	432	0	459	0	10	4154	0	144	0	0	0	0	2051	0	0	274	1881	205	100	0	124	124	0	0	0	16																
Average	3123	0	743	90	1816	284	0	193	0	-4	3905	0	95	0	0	0	0	1755	0	0	274	1489	567	100	0	86	86	0	0	0	Average price																
Maximum	7161	0	743	324	4085	900	0	3410	0	1811	6111	0	300	0	0	0	0	4968	0	0	274	3350	3795	100	0	2526	2526	0	0	0	(DKK/MWh)																
Minimum	1673	0	743	6	549	0	0	0	0	-1969	0	0	0	0	0	0	0	1	0	0	274	450	0	100	0	0	0	0	0	0	214																
TWh/year	27,43	0,00	6,53	0,79	15,95	2,50	0,00	1,69	0,00	-0,03	34,30	0,00	0,83	0,00	0,00	0,00	0,00	15,42	0,00	0,00	2,41	13,08	4,98	0,00	0,76	0,76	0,00	0,00	0,00	0	151																
FUEL BALANCE (TWh/year):																																															
	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES	BioCon-	Synthetic	Wind	Offsh.	Wave	Hydro	Solar.Th.	Transp.	househ.	Various	Total	Imp/Exp	Corrected	CO2 emission (Mt):																							
Coal	-	-	20,65	0,08	0,39	11,07	-	-	-	-	-	-	-	-	-	-	-	-	0,01	3,37	35,58	-1,68	33,89	12,17	11,59																						
Oil	0,88	-	-	0,08	0,39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	69,20	4,20	26,92	101,67	27,08	27,08																						
N.Gas	-	11,25	-	0,08	0,39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5,66	18,19	35,57	0,00	35,57	7,26	7,26																					
Biomass	-	-	-	0,08	0,39	-	-	-	6,00	-	-	-	-	-	-	-	-	-	-	4,55	5,18	16,20	0,00	16,20	0,00	0,00																					
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	3,93	11,49	-	-	-	-	-	-	-	15,42	0,00	15,42	0,00	0,00																					
H2 etc.	-	-	-	0,00	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																					
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00																					
Total	0,88	11,25	20,65	0,31	1,57	11,07	-	-	6,00	-	-	-	3,93	11,49	-	-	-	-	-	69,20	14,42	53,66	204,43	-1,68	202,75	46,51	45,94																				

The Primary energy supply has been raised from 201.57 to 204.43 TWh/year.

The CO2 emission has been reduced from 47.14 to 46.51 Mt/year.

The Critical Excess Electricity Production (CEEP) is raised from 0.72 to 0.76 TWh/year.

Step 5: Open the Input Waste window and add new input values:

EnergyPLAN 12.0: exercise3.txt

EnergyPLAN 12.0: exercise3.b

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Warnings Appear Here:

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

Waste Incineration

Waste is defined geographical on the three district heating groups. Only one hour distribution can be defined and Heat production is utilised and given priority in the respective district heating groups. Electricity production is fed And biofuels for CHP and boilers is substracted from the fuels in the respective district heating group. "Various" The economic value is substracted from the cost of the waste energy recourse.

Distribution of Waste: const.txt

Unit:	Waste input	DH production		Electricity production		Biofuel transportation	
	TWh/year	Efficiency	TWh/year	Efficiency	TWh/year	Efficiency	TWh/year
Group 1:	1	0.5	0.50	0.3	0.30	0	0.00
Group 2:	2	0.5	1.00	0.3	0.60	0	0.00
Group 3:	3	0.5	1.50	0.3	0.90	0	0.00
Total:	6.00		3.00		1.80		0.00

Step 6: Calculate and see result in print output (or clipboard)



Activate the  button and read the results of question 3.1.2:

The Primary energy supply has been reduced from 204.43 to 202.72 TWh/year.

The CO₂ emission has been reduced from 46.51 to 45.81 Mt/year.

The Critical Excess Electricity Production (CEEP) has raised from 0.76 to 1.03 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 exercise 3.2: Use Input data file from exercise 3.1

Step 1: Open the "Waste" window under the "Supply" tab and change the input numbers:

Waste Incineration

Waste is defined geographical on the three district heating groups. Only one hour distribution can be defined and storage of waste is not considered. Heat production is utilised and given priority in the respective district heating groups. Electricity production is fed into the grid. Biofuel production for CHP and boilers is subtracted from the fuels in the respective district heating group. "Various" represent non energy products such as wood chips. The economic value is subtracted from the cost of the waste energy resource.

Distribution of Waste: const.txt

Unit:	Waste input TW/h/year	Heat production Efficiency	Electricity production TW/h/year	Efficiency	Biofuel transportation TW/h/year	Efficiency	Biofuel CHP-Boiler TW/h/year	Efficiency
Group 1:	<input type="text" value="1"/>	<input type="text" value="0.3"/>	<input type="text" value="0.30"/>	<input type="text" value="0"/>	<input type="text" value="0.50"/>	<input type="text" value="0.50"/>	<input type="text" value="0"/>	<input type="text" value="0.00"/>
Group 2:	<input type="text" value="2"/>	<input type="text" value="0.3"/>	<input type="text" value="0.60"/>	<input type="text" value="0"/>	<input type="text" value="0.5"/>	<input type="text" value="1.00"/>	<input type="text" value="0"/>	<input type="text" value="0.00"/>
Group 3:	<input type="text" value="3"/>	<input type="text" value="0.3"/>	<input type="text" value="0.90"/>	<input type="text" value="0"/>	<input type="text" value="0.5"/>	<input type="text" value="1.50"/>	<input type="text" value="0"/>	<input type="text" value="0.00"/>
Total:	6.00		1.80		0.00	3.00		0.00

Step 2: Open the "Transport" window under the "Demand" tab:

Demand

TWh/year	Fossil	Biofuel	Waste*	Synthetic Fuel	Total
JP (Jet Fuel)	<input type="text" value="13.25"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	13.25
Diesel	<input type="text" value="24.5"/>	<input type="text" value="0"/>	<input type="text" value="3.00"/>	<input type="text" value="0"/>	27.50
Petrol	<input type="text" value="28.45"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	28.45
Ngas* (Grid Gas)	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	0.00
LPG	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	0.00

Note: The biofuels from waste have already been transferred.
Change diesel from 27.5 to 24.5

Step 3: Calculate and see result in print output (or clipboard)



Activate the  button and read the results of question 3.2.1:

The Primary energy supply has increased from 202.72 to 203.32 TWh/year.

The CO₂ emission has increased from 45.81 to 46.08 Mt/year.

The Critical Excess Electricity Production (CEEP) has decreased from 1.03 to 0.74 TWh/year.

Exercise 3.3: Wind and hydrogen for transportation

Add 2000 MW wind power producing 3.93 TWh electricity in combination with electrolyzers producing 2.55 TWh hydrogen for transportation with an efficiency of 65%. 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 “Electricity Only” window under the “Supply” tab and increase wind power from 2000 to 4000 MW:

Step 2: Open the “Transport” window under the “Demand” tab:

Warnings Appear Here: Transport Electrolyser is too small. Must be app.: 726 MW

	TWh/year	Fossil	Biofuel	Waste*	Synthetic Fuel	Total	Distribution	Help to design inputs
JP (Jet Fuel)		13.25	0		0	13.25		km/kWh Billion km/year
Diesel		24.5	0	3.00	0	27.50		1.5 41
Petrol		23.35	0		0	23.35		1.5 35
Ngas* (Grid Gas)		0				0.00	Gas const.txt	1.5 0
LPG		0				0.00		1.5 0
H2 (Produced by Electrolyzers)					2.55		H2 Hour_transport.txt	3 8
Electricity (Dump Charge)					0		Dump Hour_transport.txt	5 0
Electricity (Smart Charge)					0		Smart Hour_transport.txt	5 0
								84

Activate the button and receive assistance for the calculation of km transportation.

Add 2.55 TWh Hydrogen leading to 7.65 billion km/year.

Subtract 7.65 billion km/year on petrol cars equal to 5.1 TWh petrol.

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

Step 3: Open the “Hydrogen window under the “Liquid and Gas Fuels” tab under the “Supply” tab and add electrolyzers.

The screenshot shows the EnergyPLAN 12.0 interface. The 'Hydrogen' window is active under the 'Liquid and Gas Fuels' tab. The 'Electrolysers' table is visible with the following data:

Electrolysers	Capacities		Efficiencies			Hydrogen Storage	
	MW-e	MJ/s	fuel	DH gr2	DH gr3		GWh
CHP and Boilers in Group 2	0	0	0.8	0.1		0	GWh
CHP and Boilers in Group 3	0	0	0.8		0.1	0	GWh
Transport and Syntetic Fuel	900		0.65	0	0	0	GWh
Micro CHP	0		0.8			0	GWh

Add efficiency input = 65% and capacity = 900 MW.

NOTE that the remark on missing electrolyzers disappears

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



Activate the  button and read the results of question 3.3.1:

The Primary energy supply has decreased from 203.32 to 202.8 TWh/year.

The CO₂ emission has decreased from 46.08 to 44.94 Mt/year.

The Critical Excess Electricity Production (CEEP) has increased from 0.74 to 0.95 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. 10% of heat demand) to individual houses with natural gas boilers. Use the hour distribution “Hour_SolarThermal_IndvDK.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?

How to do exercise 3.4: Use Input data file from exercise 3.3

Step 1: Open the “Heating” window under the “Demand” tab:

The screenshot shows the EnergyPLAN 12.0 software interface. The 'Demand' tab is active, and the 'Heating' window is open. The 'Solar Thermal' section is visible, with a dropdown menu set to 'Solar' and a file path 'Hour_SolarThermal_IndvDK.txt' selected. The 'Output' column for the 'Solar' row shows a value of 0.72. The 'Total Heat Demand' is 39.74 TWh/year.

Distribution:	Fuel Consumption		Efficiency Thermal	Heat Demand	Efficiency Electric	Capacity Limit*	Estimated Electricity Production	Heat Storage*	Share*	Solar Thermal	
	Input	Output								Input	Output
Coal boiler :	0.01	0.01	0.8	0.01				0	1	0	0.00
Oil boiler :	4.2	4.20	0.85	3.57				0	1	0	0.00
Ngas boiler :	5.66	4.86	0.9	5.09				0	1	1	0.72
Biomass boiler :	4.55	4.55	0.8	3.64				0	1	0	0.00
H2 micro CHP :		0.00	0.5	0	0.3	1	0.00	0	1	0	0.00

Change hour distribution to “Hour_SolarThermal_IndvDK.txt”;

Add 1 TWh of solar thermal to Ngas Boilers;

Read the result of question 3.4.1: 0.72 TWh of solar thermal production are utilised.

Step 2: Add storage capacity:

EnergyPLAN 12.0: exercise3.txt

Warnings Appear Here:

Overview

Total Heat Demand (Individual plus District Heating) **39.74**

Individual Heating:

TWh/year	Fuel Consumption		Efficiency Thermal	Heat Demand	Efficiency Electric	Capacity Limit*	Estimated Electricity Production	Solar Thermal		
	Input	Output						Heat Storage*	Share*	Input
Distribution: <input type="button" value="Heat"/> Hour_indv-heat-50percent.txt										
Coal boiler :	0.01	0.01	0.8	0.01			0	1	0	0.00
Oil boiler :	4.2	4.20	0.85	3.57			0	1	0	0.00
Ngas boiler :	5.66	4.55	0.9	5.09			0.3	1	1	1.00
Biomass boiler :	4.55	4.55	0.8	3.64			0	1	0	0.00

The answer to question 3.4.2 is found by adding heat storage capacity to the system. All solar thermal production can be utilised when the storage capacity is equal to 0.3 days of average heat demand.

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 202.8 to 202.69 TWh/year.
 The CO₂ emission has decreased from 44.94 to 44.72 Mt/year.
 The Critical Excess Electricity Production (CEEP) is still 0.95 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?

How to do exercise 3.5: Use Input data file from exercise 3.4

Step 1: Open the “Heat Only” window under the “Supply” tab:

The screenshot shows the EnergyPLAN 12.0 software interface. The 'Overview' window is open, displaying the 'Solar Thermal' configuration. The 'Production' row shows 0 for Group 1, 2 for Group 2, and 0 for Group 3. The 'Storage' row shows 0 for all groups. The 'Loss*' row shows 0 for all groups. The 'Share*' row shows 1 for all groups. The 'Result' row shows 0.00 for Group 1, 1.43 for Group 2, and 0.00 for Group 3, with a total of 1.43 TWh/year. The 'Annual accumulated heat in solar thermal storage' is 0.00 TWh/year. The 'Distribution' field is set to 'Hour_SolarThermal_CenDK.txt'.

	Group 1:	Group 2:	Group 3:	Total:	Unit	Distribution:
Solar Thermal						
Production	0	2	0		TWh/year	Change Hour_SolarThermal_CenDK.txt
Storage	0	0	0		GWh	
Loss*	0	0	0		Percent	
Share*	1	1	1		Percent	
Result	0.00	1.43	0.00	1.43	TWh/year	
Annual accumulated heat in solar thermal storage:				0.00	TWh/year	

Change hour distribution to “Hour_SolarThermal_CenDK.txt”;

Add 2 TWh of solar thermal to District Heating Group 2;

Read the result of question 3.5.1: 1.43 TWh of solar thermal production are utilised.

Step 2: Add storage capacity:

EnergyPLAN 12.0: exercise3.txt

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
 - Biofuels
 - Biogases
 - Hydrogen
 - Electrofuels
 - Gas to Liquid
 - CO2
- Balancing and Storage
- Cost
- Simulation

	Group 1:	Group 2:	Group 3:	Total:	Unit	Distribution:
Solar Thermal						
Production	0	2	0		TWh/year	Change Hour_SolarThermal_CenDK.txt
Storage	0	9	0		GWh	
Loss*	0	0	0		Percent	
Share*	1	1	1		Percent	
Result	0.00	2.00	0.00	2.00	TWh/year	
Annual accumulated heat in solar thermal storage:				0.00	TWh/year	

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 202.69 to 204.02 TWh/year.

The CO₂ emission has increased from 44.72 to 44.88 Mt/year.

The Critical Excess Electricity Production (CEEP) has increased from 0.95 to 1.00 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.