Modelling Renewable Energy Integration Technologies in the EnergyPLAN Tool

This tutorial outlines how you can simulate various renewable energy integration technologies in the EnergyPLAN tool. In this first exercise, we will create a reference scenario, which is used as a starting point for analysing how renewable energy can be integrated into an energy system. Afterwards, this reference scenario will then be changed so it can integrate more intermittent renewable energy.

Based on previous research, approximately 6 key changes are necessary in existing energy systems to transition to renewable energy. In this tutorial the first three of these steps will be modelled and analysed in the EnergyPLAN tool after the reference 'starting point' is created. These are:

1. Regulating conventional power plants by varying their output to accommodate renewables. In other words, when the wind is blowing too much the power plants should shut down, and when the wind is not blowing enough then the power plants should produce more. This will enable a wind penetration up to **25%** of electricity production.
2. Power Plants are converted to Combined Heat and Power which are regulated according to wind production using Thermal Storage and the District Heating network. This will enable a wind penetration up to **25%** of electricity production, but it will be more efficient than in step 1.
3. Heat pumps and thermal storage in buildings and district heating networks. This will enable a wind penetration up to **40%** of electricity production.

This transition is illustrated graphically below. Figure 1 illustrates what today's energy system looks like: it is a very segregated energy system with separate supplies for electricity, heating and transport. This is what the energy system looks like in step 1.

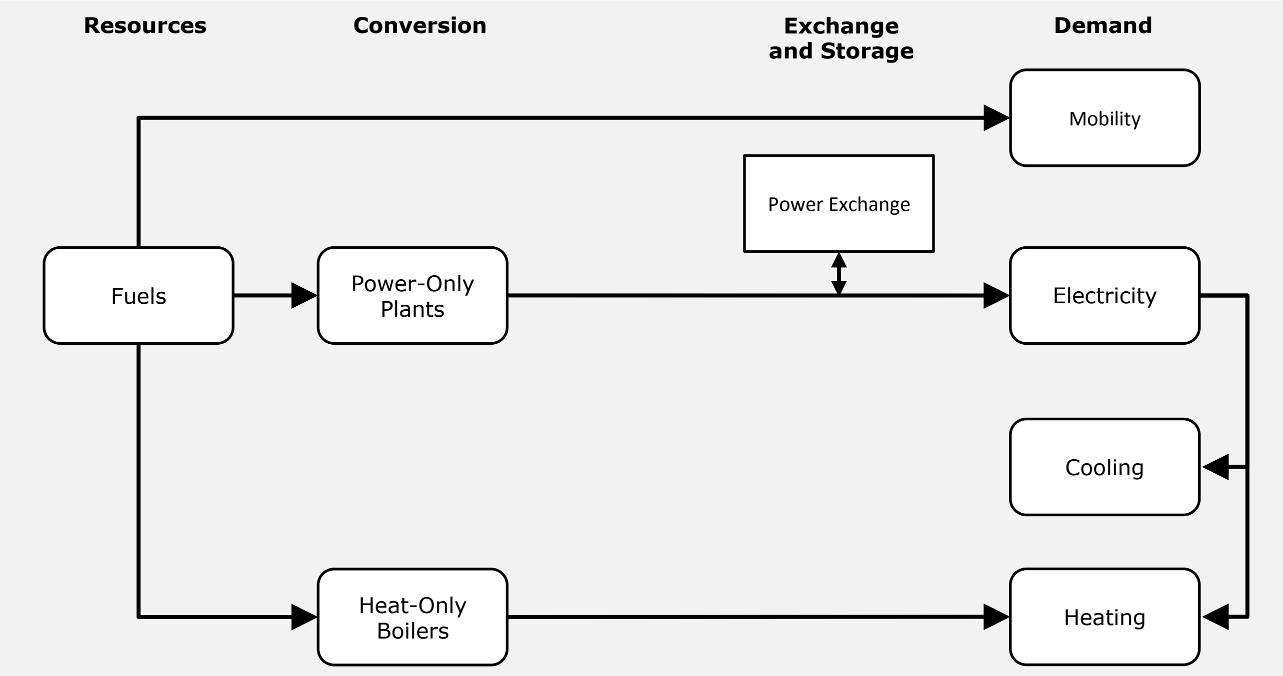


Figure 1: Interaction between sectors and technologies in today's typical energy system.

Figure 2 illustrates a smart energy system, where the electricity, heating, and transport sectors are interconnected with one another. This interconnection creates a lot of flexibility which enables the energy system to become dependent on intermittent renewable energy such as wind and solar. This is what the energy system looks like in step 3 here.

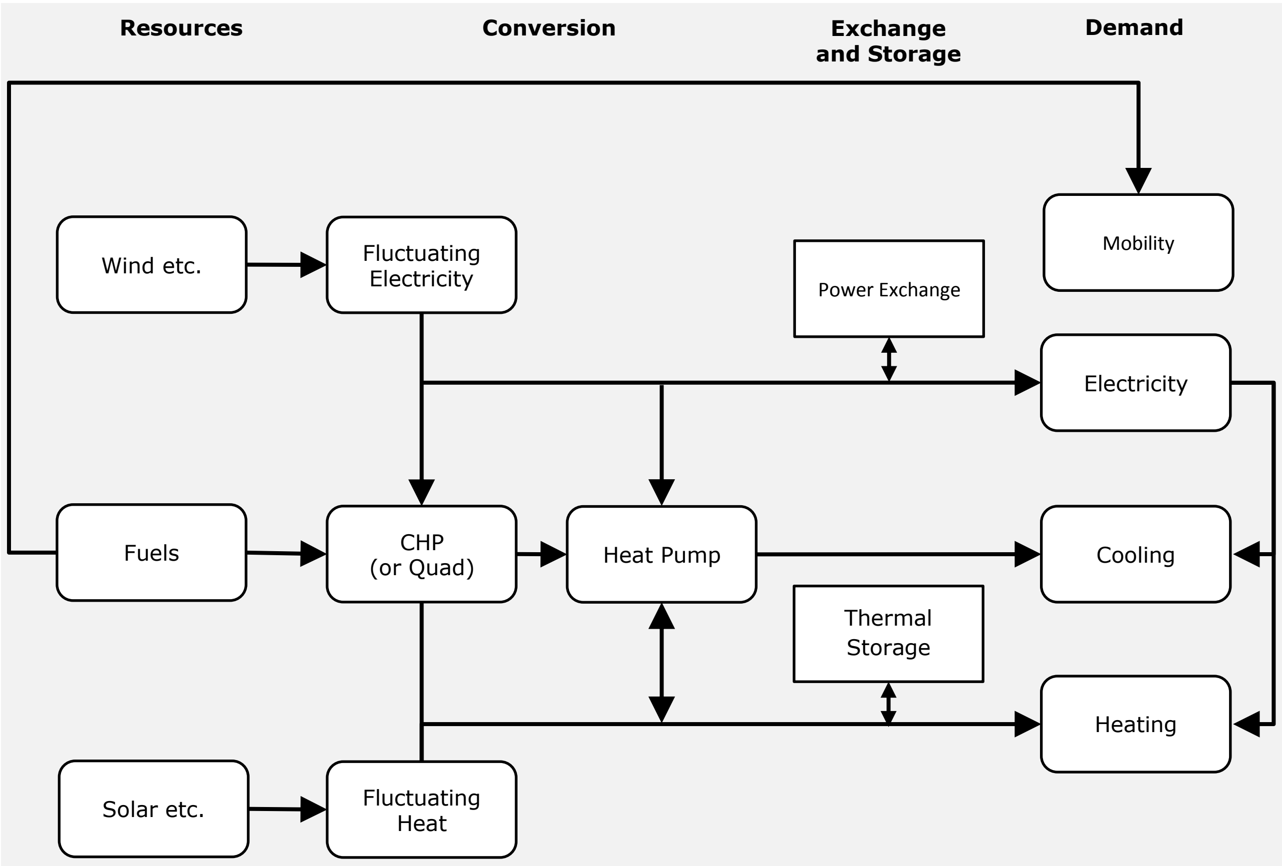


Figure 2: Interaction between sectors and technologies in an energy system with district heating and heat pumps.

Below is an overview of the costs you will need during these exercises.

- You can assume an Interest Rate of 3%

	Unit	Investment (Unit)	Lifetime (years)	Fixed Operation and Maintenance (% of investment)
Exercise A				
Gas Power Plant	M€/MW	0.9	25	2.0
Oil Boiler	€/boiler	6600	20	3.8
Conventional Car	€/vehicle	12000	16	7.7
Truck/Bus	€/vehicle	160000	8	1.2
Exercise B				
Wind Power	M€/MW	1.25	20	3.0
Exercise C				
Small CHP	M€/MWe	1.2	25	3.8
Large CHP	M€/MWe	0.8	25	3.6
Boiler	M€/MWth	0.1	35	3.7
Thermal Storage	M€/GWh	3.0	20	0.7
District Heating Pipes	M€/TWh	72	40	1.3
District Heating Heat Exchangers*	€/exchanger	5500	20	2.7
Exercise D				
Heat Pump	€/heat pump	14000	20	1.0
Centralised Heat Pumps	M€/MWe	3.5	25	2.0

*Includes the branch pipe.

(€/GJ)		Coal	Diesel	Petrol/Jet Fuel	Natural Gas
Fuel Price		3	16.5	17.5	10
Fuel Handling Costs	To Central Plant	0	-	-	0.4
	To Decentral Plant	1.5	-	-	2
	To Individual Households	2.5	2	-	3
	To Road Transportation	-	1.9	1.9	2
	To Air Transportation	-	-	0.5	-

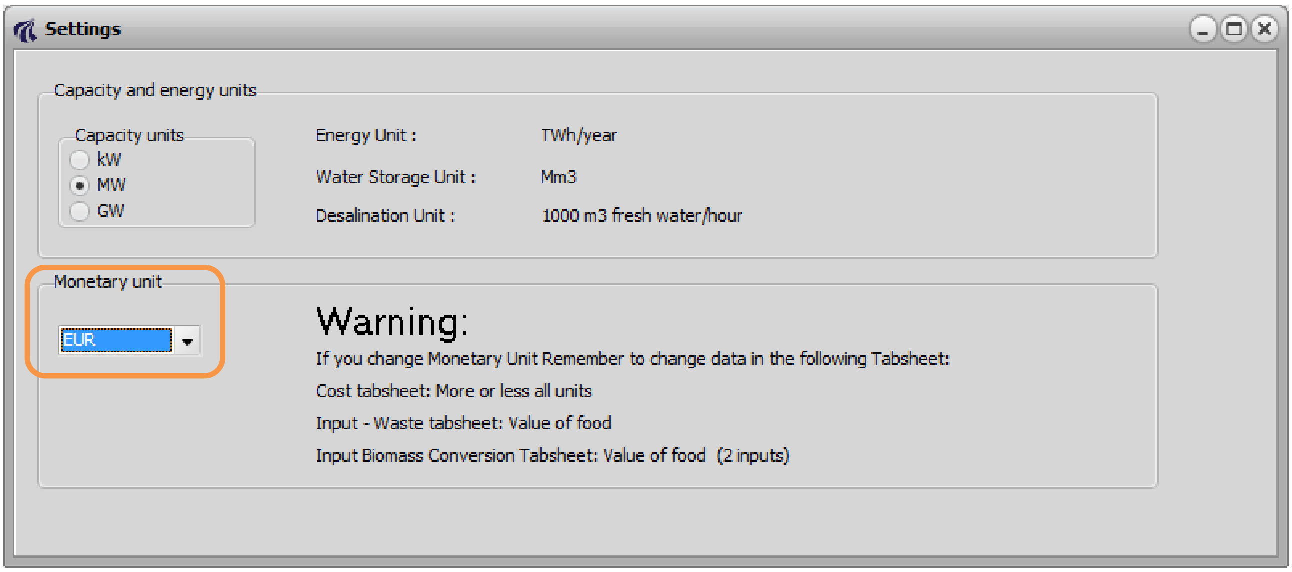
Exercise A: Creating the Reference Scenario

The name of our 'starting point' or 'case study' is Energyland. It is very similar to a typical country today. The only major difference is that there would be a greater variety of fuels and energy plants than utilised here. Below is an overview of the demand and supply for Energyland.

Sector	Demand (TWh)	Supply
Electricity	30	6000 MW of gas power plants
Heat	27	2 million individual oil boilers
Industry	25	Coal
Transport	70	Oil
Petrol	*35*	*2 million cars*
Diesel	*25*	*70,000 trucks*
Jet Fuel	*10*	

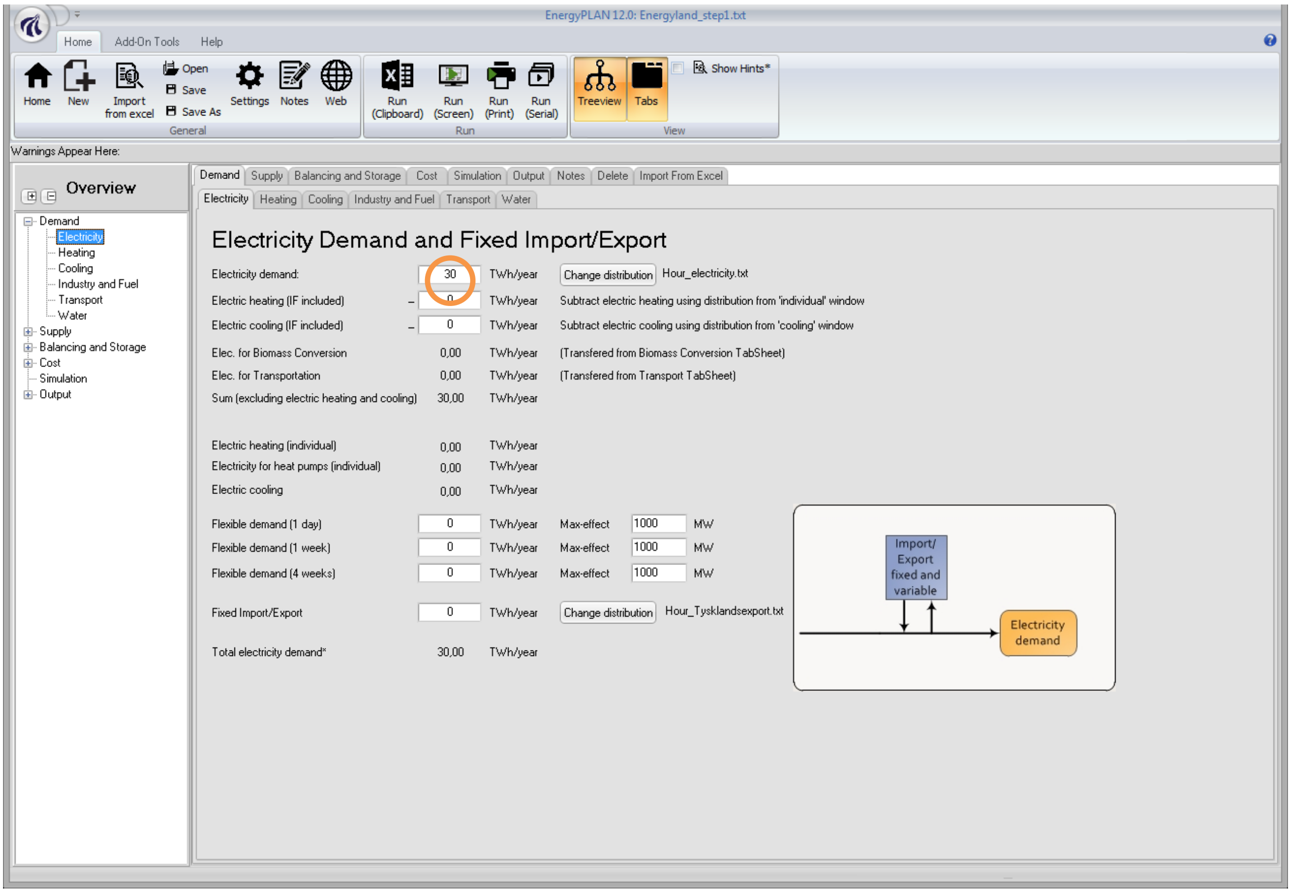
Try to model this in the EnergyPLAN tool. Before you do, make sure that you:

- Open the EnergyPLAN Tool
- Open the "initialize.txt" file. This will set all values in the tool to zero or for non-zero inputs such as efficiencies, to their default values.
- Go to "File->Save As" and save the file as "Energyland_step0_REF.txt"
- Go to the "Settings" tabsheet and change the "Monetary Unit" to "EUR" (euro).
- Save your file again.

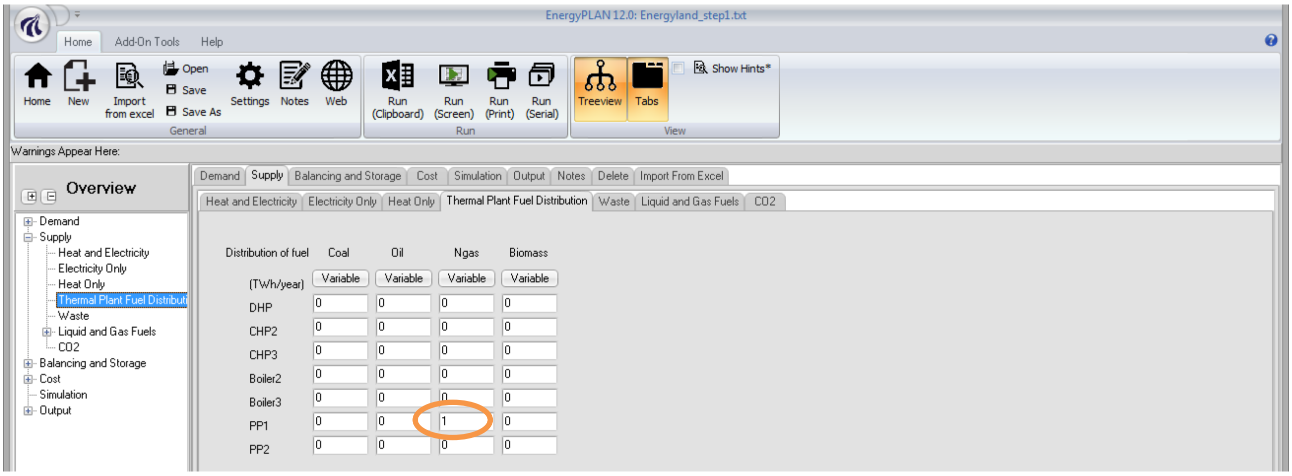


Electricity Sector

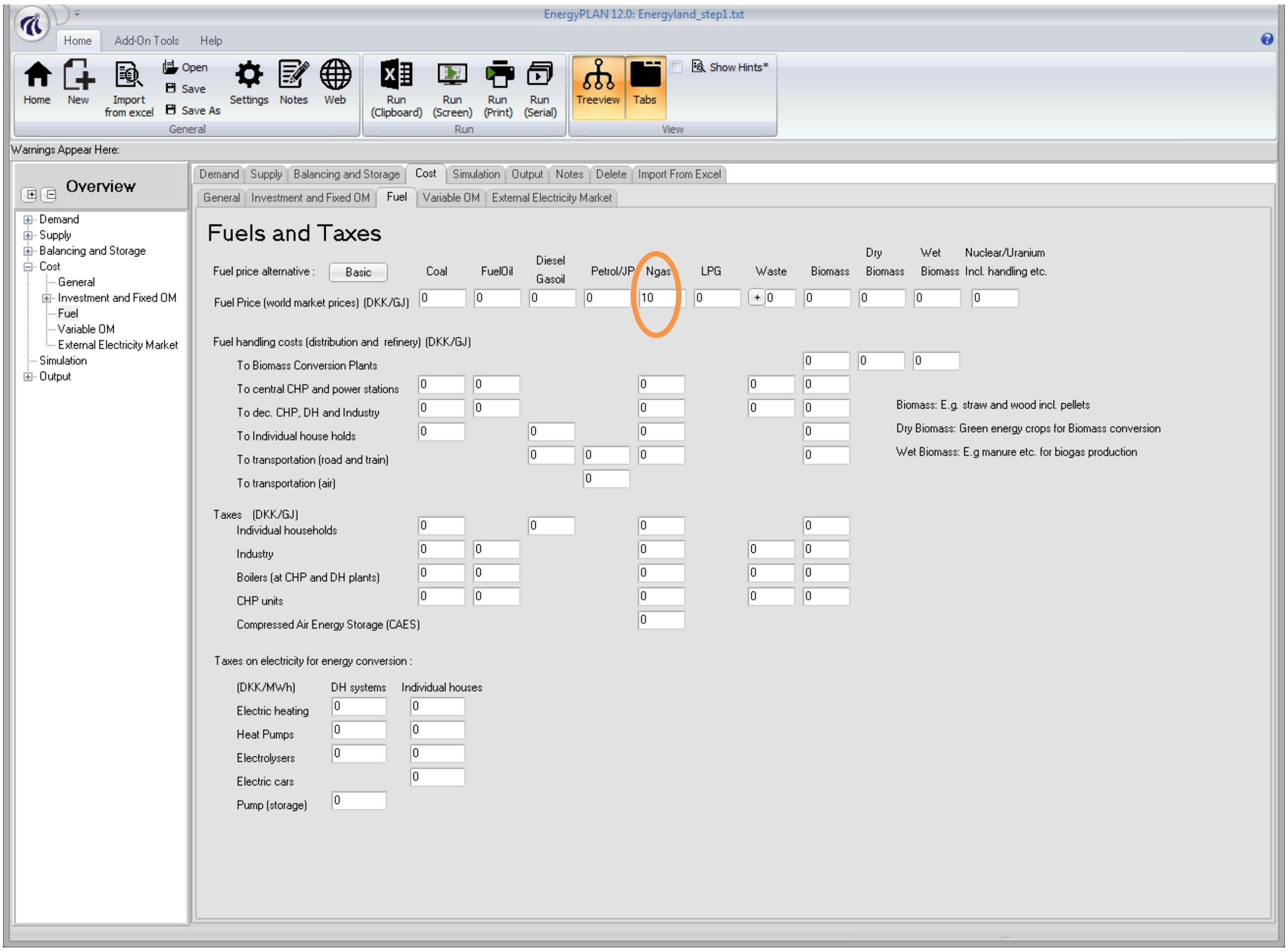
- Go to the ElectricityDemand tabsheet, and insert an electricity demand of 30 TWh.



Go to the Heating and Electricity tabsheet under "Supply" and insert 6000 MW of condensing power plants. Afterwards go to Thermal Plant Fuel Distribution tabsheet under "Supply" and chose natural gas as fuel for the condensing power plants.



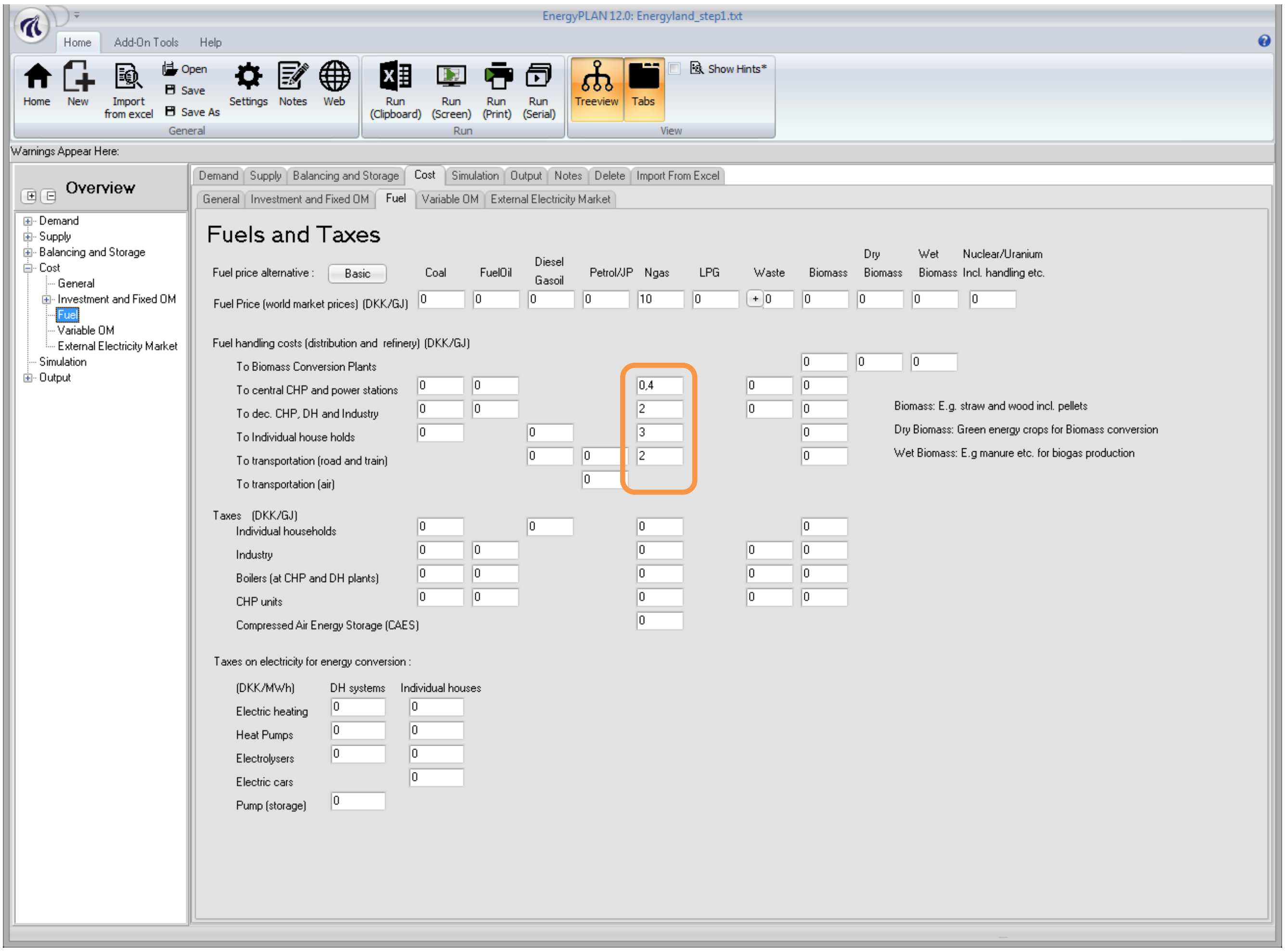
- Go to “Cost->Fuel” tabsheet and insert a natural gas price of 10 €/GJ. More cost data is available from the Danish Energy Agency, in the report “Forudsætninger for samfundsøkonomiske analyser på energiområdet (Assumptions for socio-economic analysis on energy)”, which is available from: http://www.ens.dk.



Under the same tabsheet, you must enter the price of transport this fuel to the final consumer (i.e. fuel handling costs). There are three different types of consumers for natural gas:

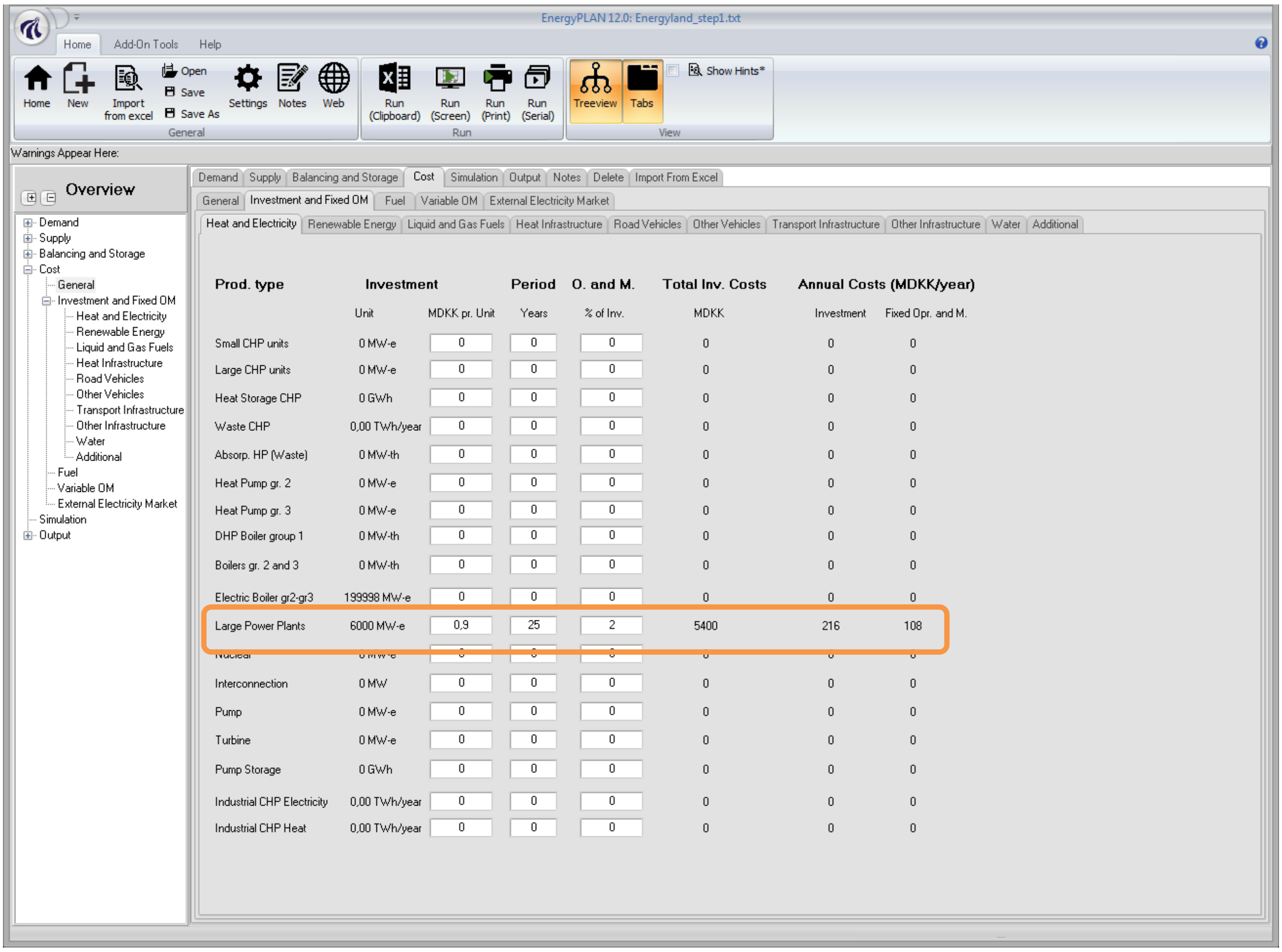
- The centralised plants
- The decentralised plants
- The final consumer (i.e. an individual building)

These prices reflect the cost of transporting the natural gas from the international market to these final consumers. In other words it is the cost of the natural gas grid in this case.

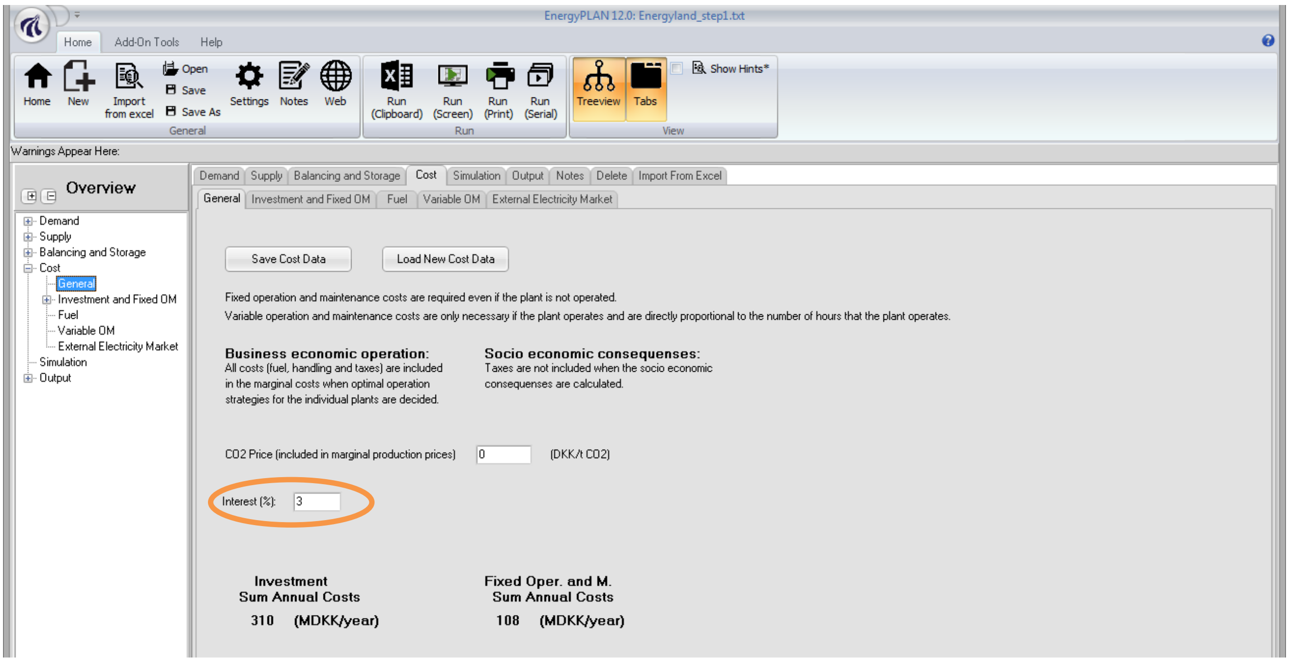


- Go to the "Cost->Investment" tabsheet and insert the following prices for the natural gas power plants:
  - Investment: 0.9 M€/MW
  - Lifetime: 25 years
  - Operation and maintenance: 2%

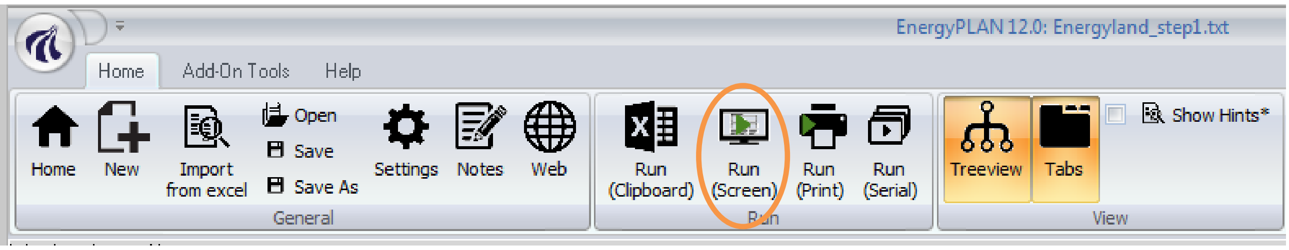
  More investment cost data is available

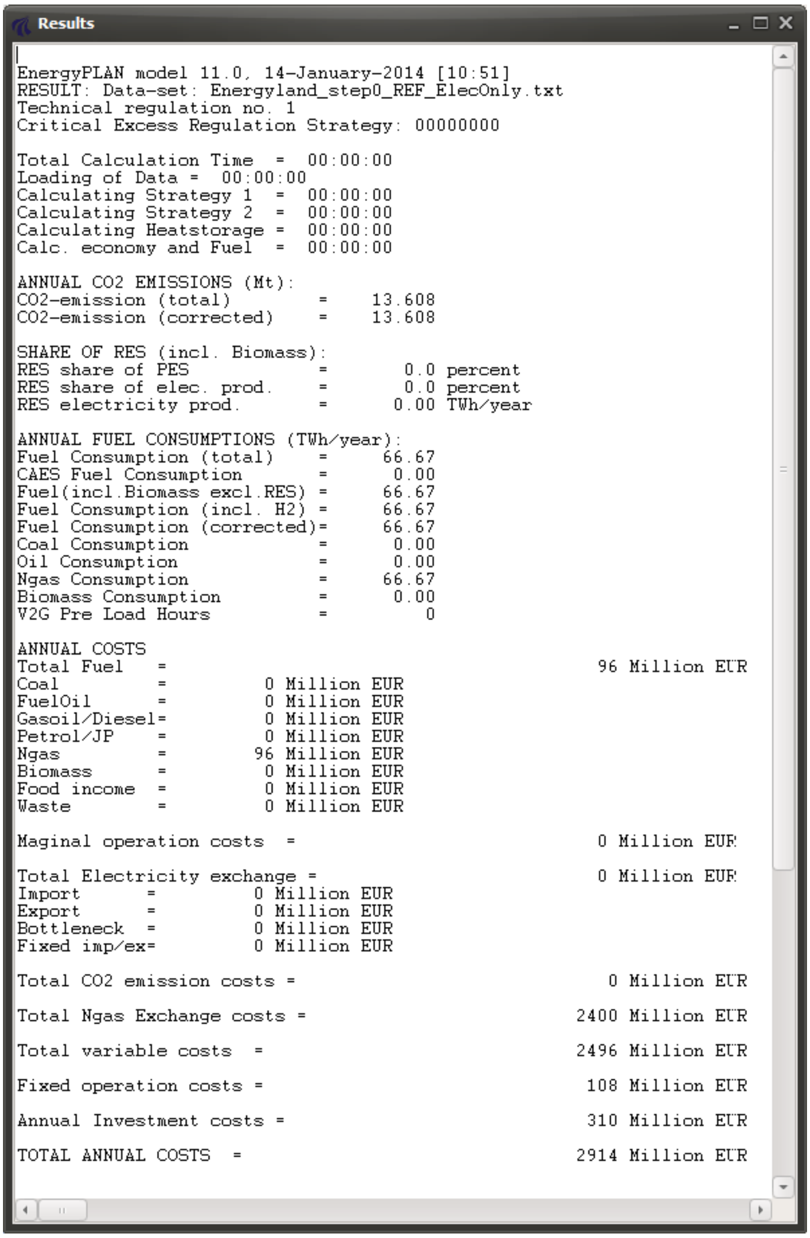


Go to the “General” tabsheet under “Cost” and insert the interest rate of 3%



You have now created an electricity system that uses 6000 MW of gas power plants to supply 30 TWh of electricity each year. Run the results on the internal screen by pressing the print preview button with the green arrow, see below.





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Results

EnergyPLAN model 11.0, 14-January-2014 [10:51]
RESULT: Data-set: Energyland_step0_REF_ElecOnly.txt
Technical regulation no. 1
Critical Excess Regulation Strategy: 00000000

Total Calculation Time  =  00:00:00
Loading of Data =  00:00:00
Calculating Strategy 1  =  00:00:00
Calculating Strategy 2  =  00:00:00
Calculating Heatstorage =  00:00:00
Calc. economy and Fuel  =  00:00:00

ANNUAL CO2 EMISSIONS (Mt):
CO2-emission (total)        =     13.608
CO2-emission (corrected)    =     13.608

SHARE OF RES (incl. Biomass):
RES share of PES            =        0.0 percent
RES share of elec. prod.    =        0.0 percent
RES electricity prod.       =       0.00 TWh/year

ANNUAL FUEL CONSUMPTIONS (TWh/year):
Fuel Consumption (total)    =      66.67
CAES Fuel Consumption       =       0.00
Fuel(incl.Biomass excl.RES) =      66.67
Fuel Consumption (incl. H2) =      66.67
Fuel Consumption (corrected)=      66.67
Coal Consumption            =       0.00
Oil Consumption             =       0.00
Ngas Consumption            =      66.67
Biomass Consumption         =       0.00
V2G Pre Load Hours          =          0

ANNUAL COSTS
Total Fuel    =                                     96 Million EUR
Coal          =          0 Million EUR
FuelOil       =          0 Million EUR
Gasoil/Diesel=           0 Million EUR
Petrol/JP     =          0 Million EUR
Ngas          =         96 Million EUR
Biomass       =          0 Million EUR
Food income   =          0 Million EUR
Waste         =          0 Million EUR

Maginal operation costs  =                          0 Million EUR

Total Electricity exchange =                        0 Million EUR
Import       =          0 Million EUR
Export       =          0 Million EUR
Bottleneck   =          0 Million EUR
Fixed imp/ex=           0 Million EUR

Total CO2 emission costs =                          0 Million EUR

Total Ngas Exchange costs =                      2400 Million EUR

Total variable costs  =                          2496 Million EUR

Fixed operation costs =                           108 Million EUR

Annual Investment costs =                         310 Million EUR

TOTAL ANNUAL COSTS  =                            2914 Million EUR
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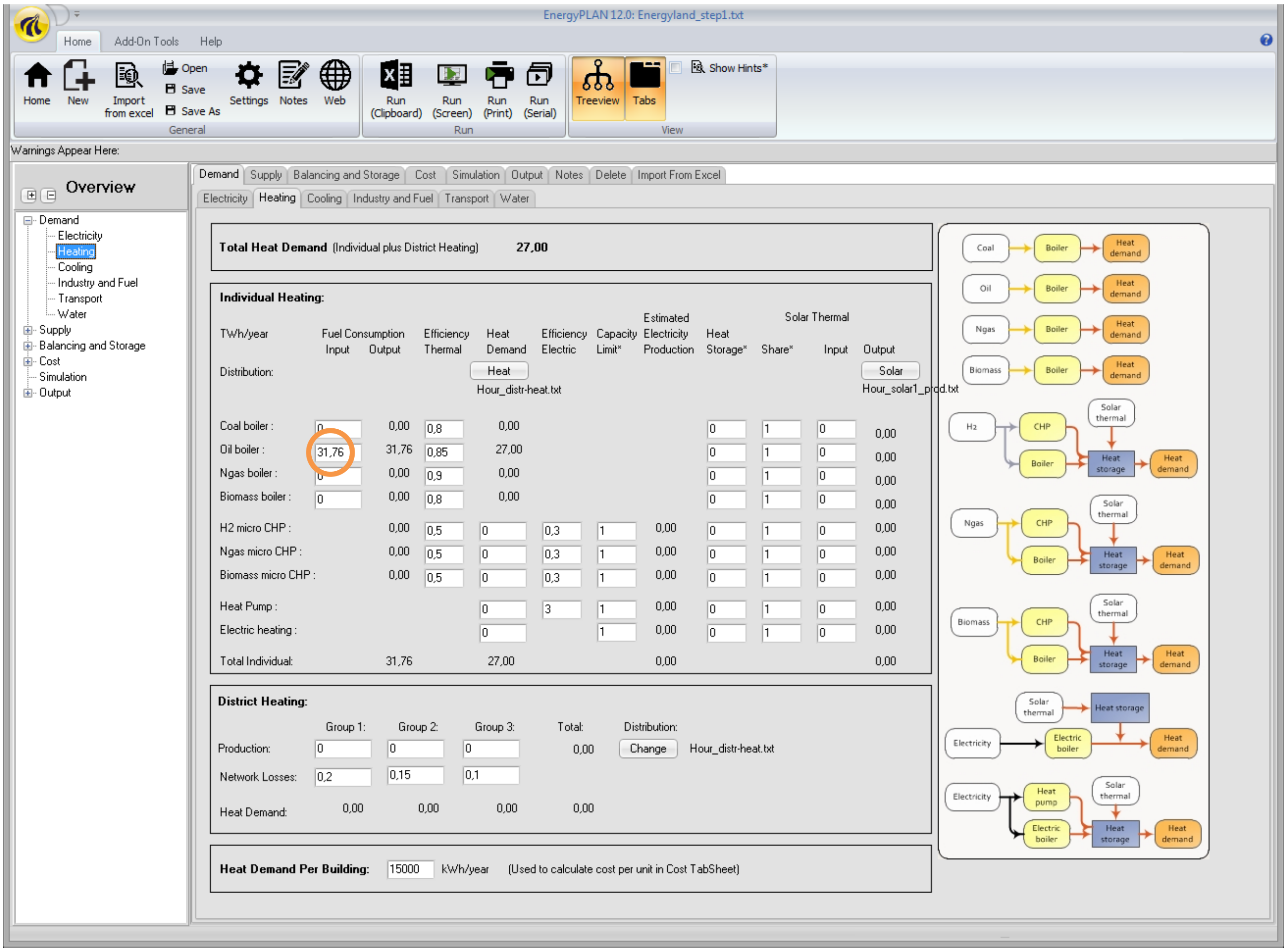
Run the results and save your file:

Metric	Electricity Sector Only	Electricity & Heat Sectors	Electricity, Heating, and Transport	Electricity, Heating, Transports, and Industry	Unit
Primary Energy Supply (PES)	66.67				TWh
Annual CO2 Emissions (CO2)	13.608				Mt
Annual Energy System Costs (Costs)	2914				Million Euro (M€)

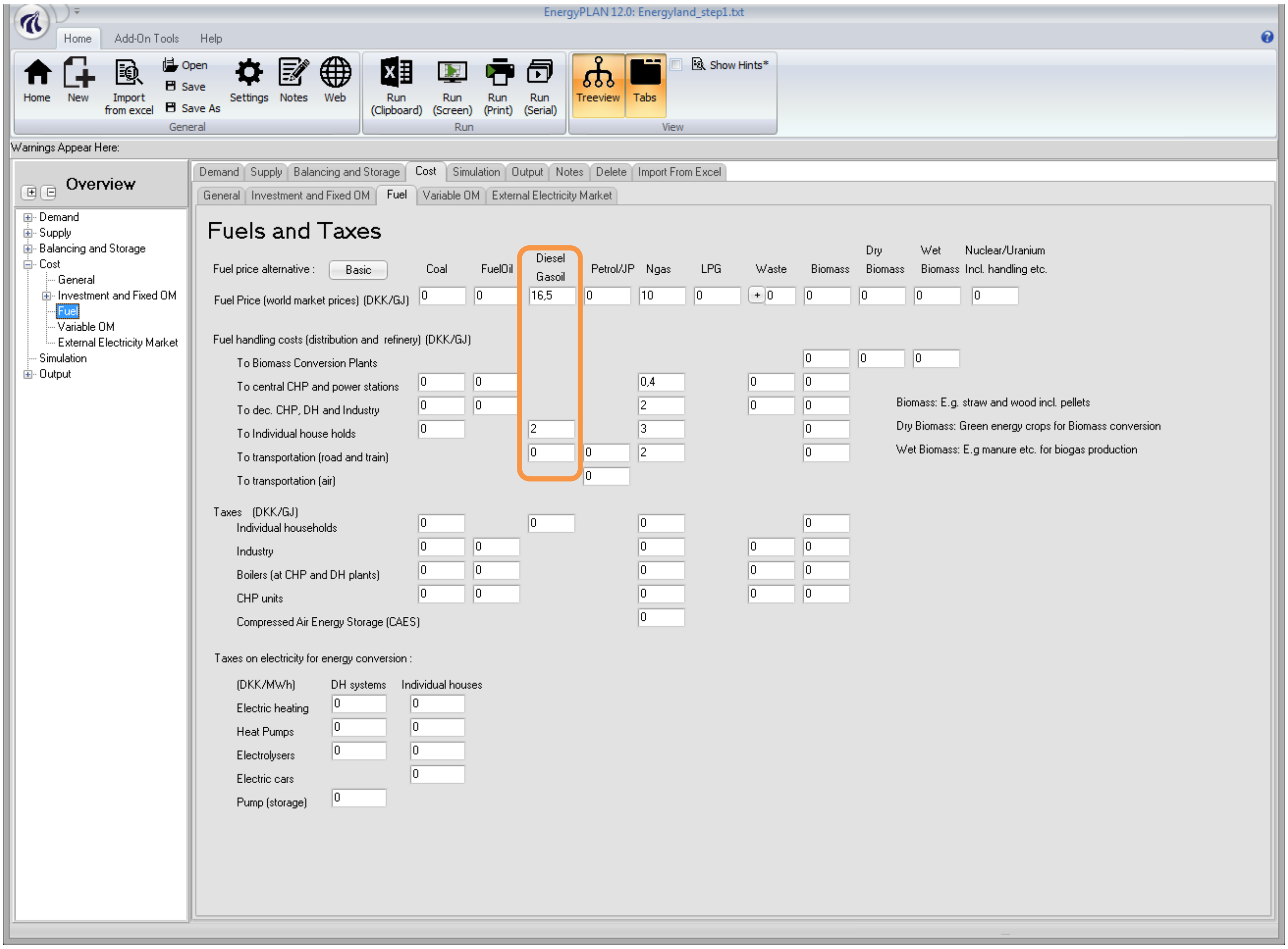
Heat Sector

Sector	Demand (TWh)	Supply
Electricity	30	6000 MW of gas power plants
Heat	27	2 million individual oil boilers
Industry	25	Coal
Transport	70	Oil
Petrol	*35*	*2 million cars*
Diesel	*25*	*70,000 trucks*
Jet Fuel	*10*	

- Go to the Heating tabsheet under "Demand" and insert 31.76 TWh (27/0.85 = 31.76) for the individual oil boilers. The final heat demand is then 27 TWh.



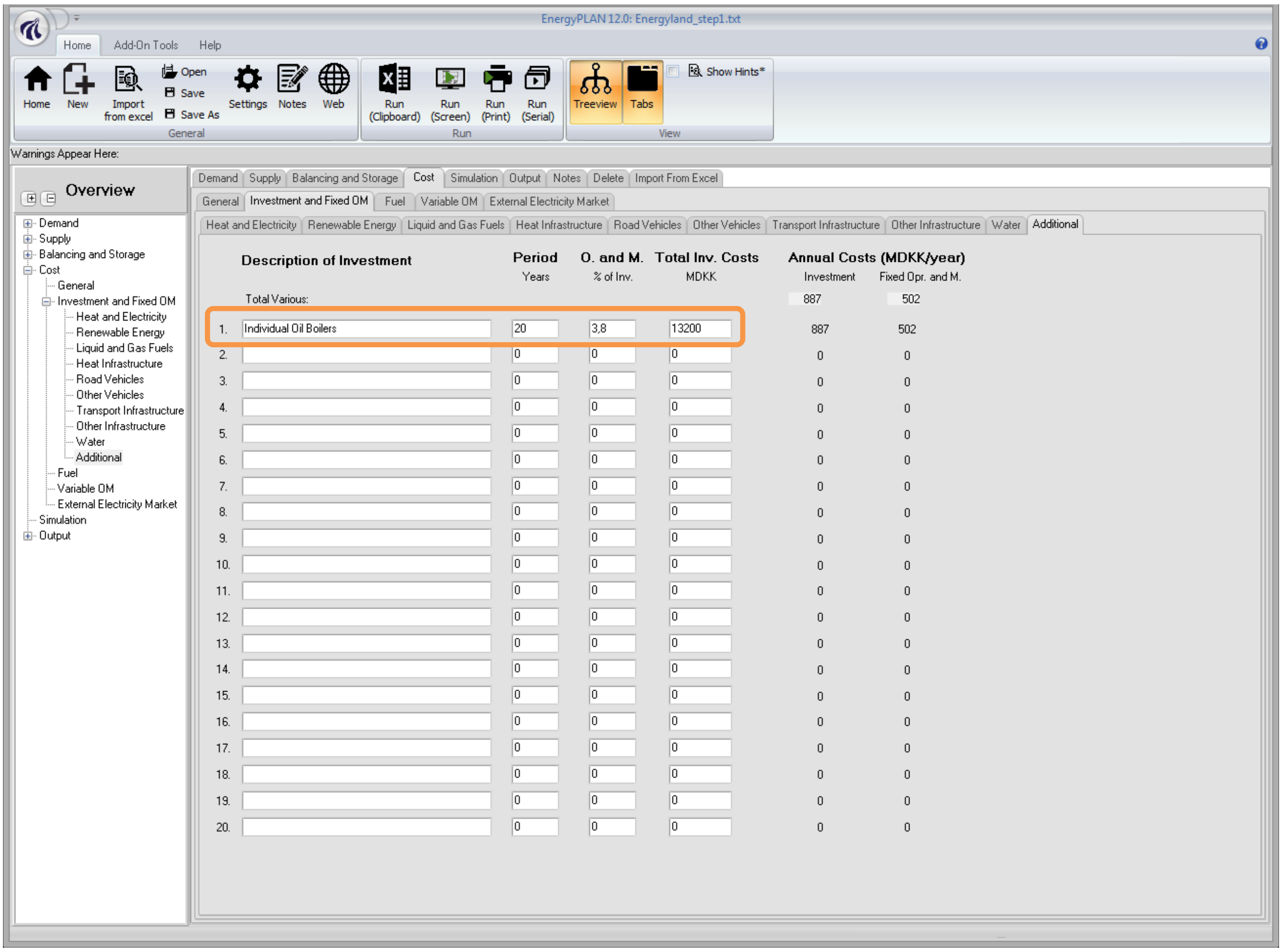
The fuel cost for the oil boilers needs to be inserted under the Cost->fuel tabsheet. Here will assume an oil price of 16.5 €/GJ and a fuel handling cost to the individual buildings of 2 €/GJ.



We need to calculate the individual boiler costs outside of the model. The costs below have been obtained from a report by the Danish Energy Agency called "Technology Data for Energy Plants: Individual Heating Plants and Technology Transport" (2012), which is available from: http://www.ens.dk/.

Boilers	1 Oil Boiler (€)	2 Million Oil Boilers (M€)
Investment	6600	13200
Fixed Operation & Maintenance	250	500
Fixed Operation & Maintenance (%)	3.8%	3.8%
Lifetime (years)	20	20

- Go to the 'Cost->Additional' tab and insert the costs for the individual oil boilers



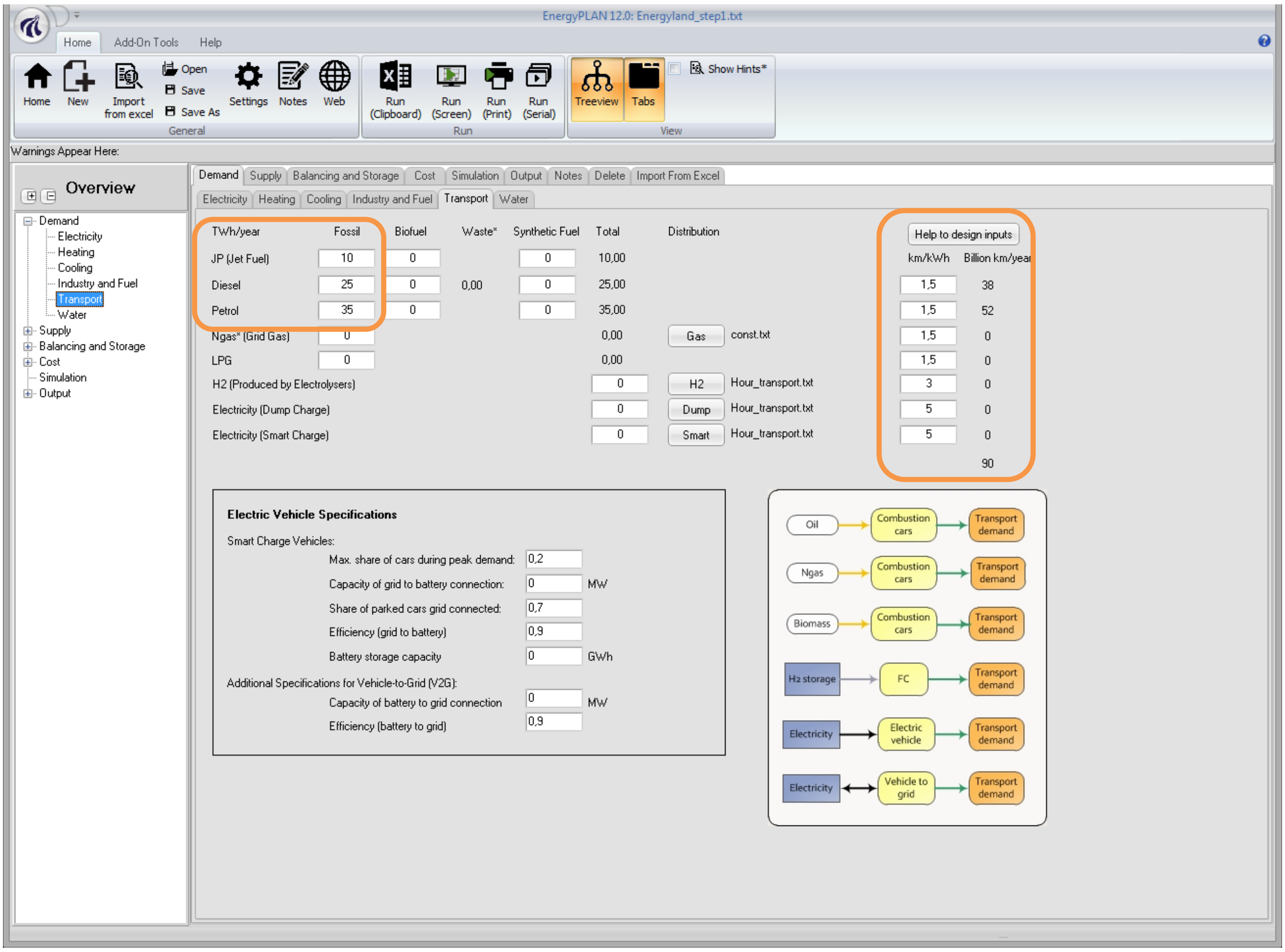
Run the results once again:

Metric	Electricity Sector Only	Electricity & Heat Sectors	Electricity, Heating, and Transport	Electricity, Heating, Transports, and Industry	Unit
Primary Energy Supply (PES)	66.67	98.43			TWh
Annual CO2 Emissions (CO2)	13.608	22.069			Mt
Annual Energy System Costs (Costs)	2914	6418			Million Euro (M€)

Transport Sector

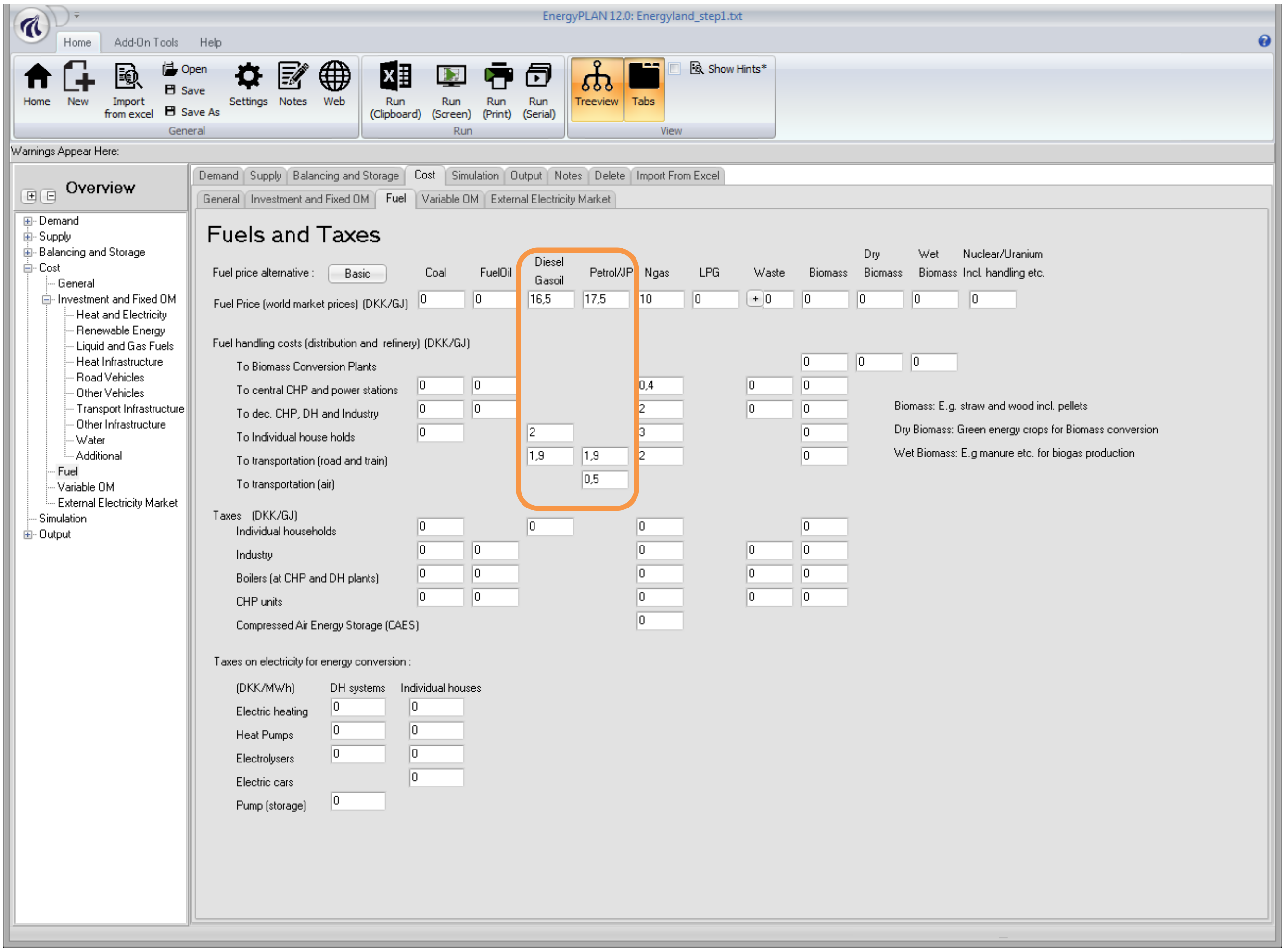
Sector	Demand (TWh)	Supply
Electricity	30	6000 MW of gas power plants
Heat	27	2 million individual oil boilers
Industry	25	Coal
Transport	70	Oil
Petrol	*35*	*2 million cars*
Diesel	*25*	*70,000 trucks*
Jet Fuel	*10*	

- Go to the Transport tabsheet and insert the various fuel demands for transport. You can click on the "Help to design inputs" button to see a rough estimate of the corresponding transport demand.



Now the cost of this fuel must be added.

- Go to the Cost->Fuel tabsheet and insert the fuel and fuel handling costs for oil.

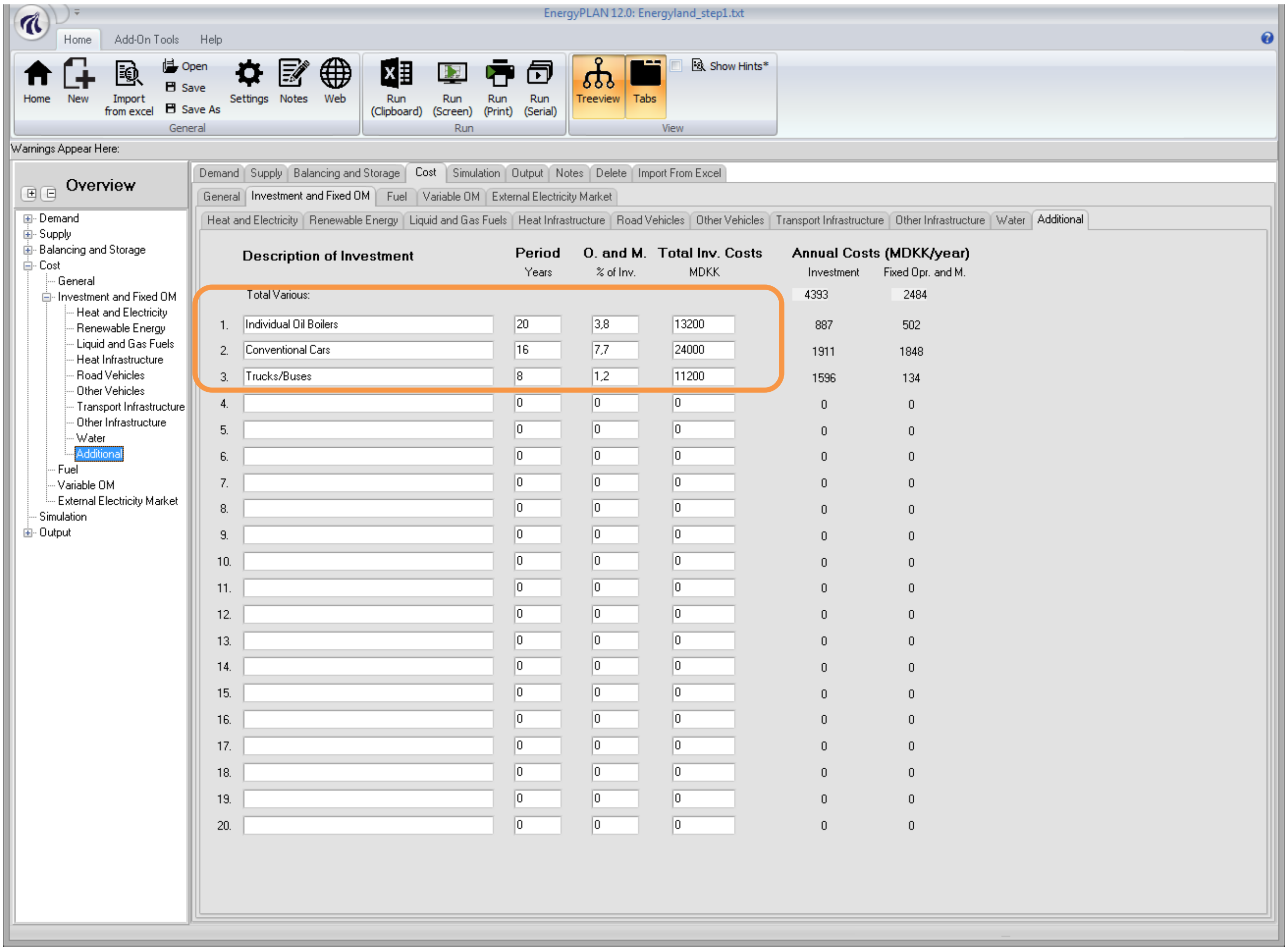


Like the individual boilers, the vehicle costs need to be calculated outside of the model. The cost of a conventional car and a truck have been obtained from the report "Alternative drivmidler i transportsektoren (Alternative Fuels for Transport)" (2012) which was carried out by COWI for the Danish Energy Agency and is available from http://www.ens.dk/.

Conventional Cars	1 Car (€)	2 Million Cars (M€)
Investment	12000	24000
Fixed Operation & Maintenance (%)	7.70%	7.70%
Lifetime (years)	16	16

Trucks/Buses	1 Truck (€)	70,000 Trucks (M€)
Investment	160000	11200
Fixed Operation & Maintenance (%)	1.20%	1.20%
Lifetime (years)	8	8

- Go to the "Cost->Additional" tabsheet and input the cost for cars and trucks



Run the results and save your file:

Metric	Electricity Sector Only	Electricity & Heat Sectors	Electricity, Heating, and Transport	Electricity, Heating, Transports, and Industry	Unit
Primary Energy Supply (PES)	66.67	98.43	168.43		TWh
Annual CO2 Emissions (CO2)	13.608	22.069	40.717		Mt
Annual Energy System Costs (Costs)	2914	6418	16655		Million Euro (M€)

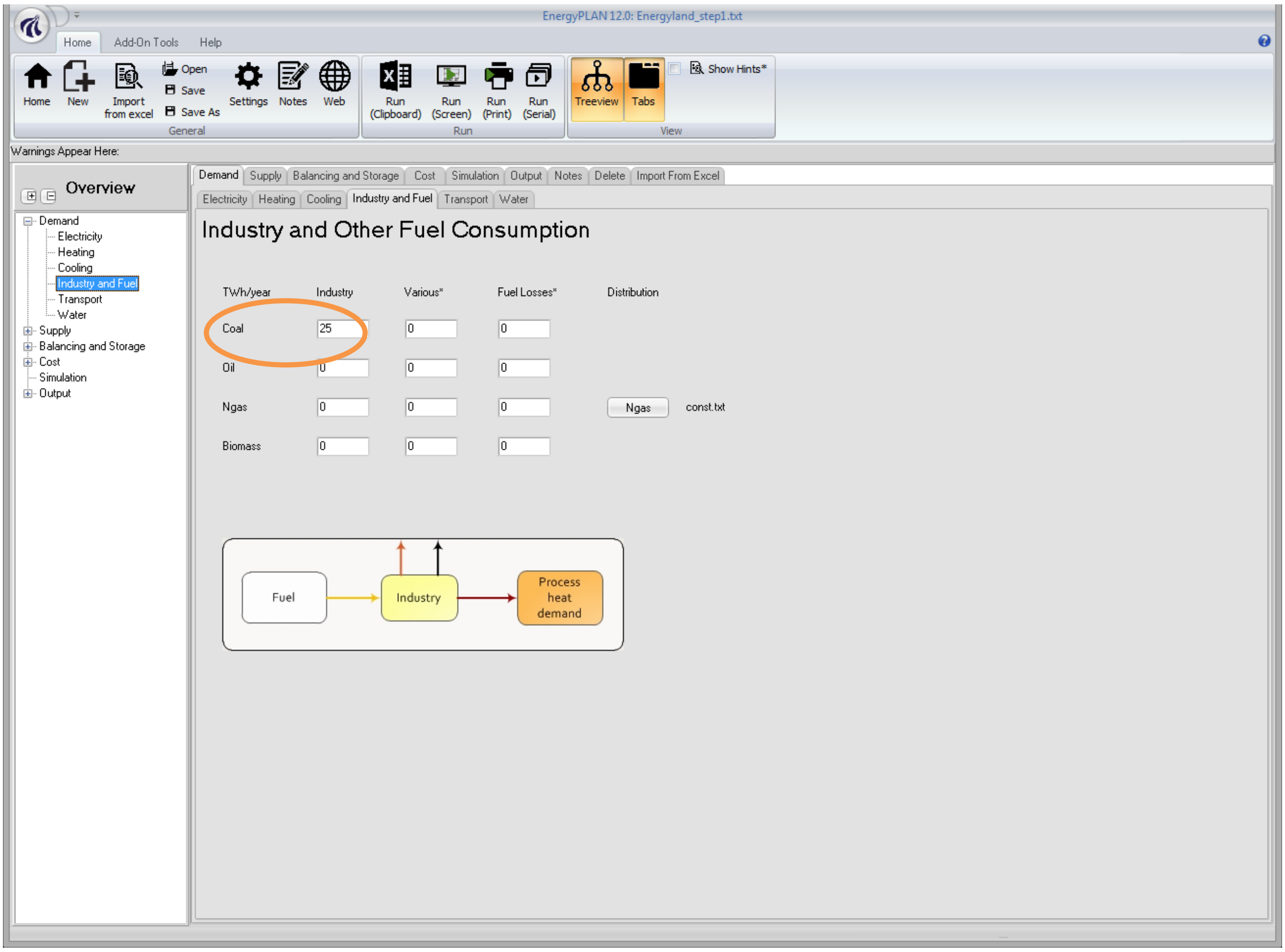
Industry

Sector	Demand (TWh)	Supply
Electricity	30	6000 MW of gas power plants
Heat	27	2 million individual oil boilers
Industry	25	Coal
Transport	70	Oil
Petrol	*35*	*2 million cars*
Diesel	*25*	*70,000 trucks*
Jet Fuel	*10*	

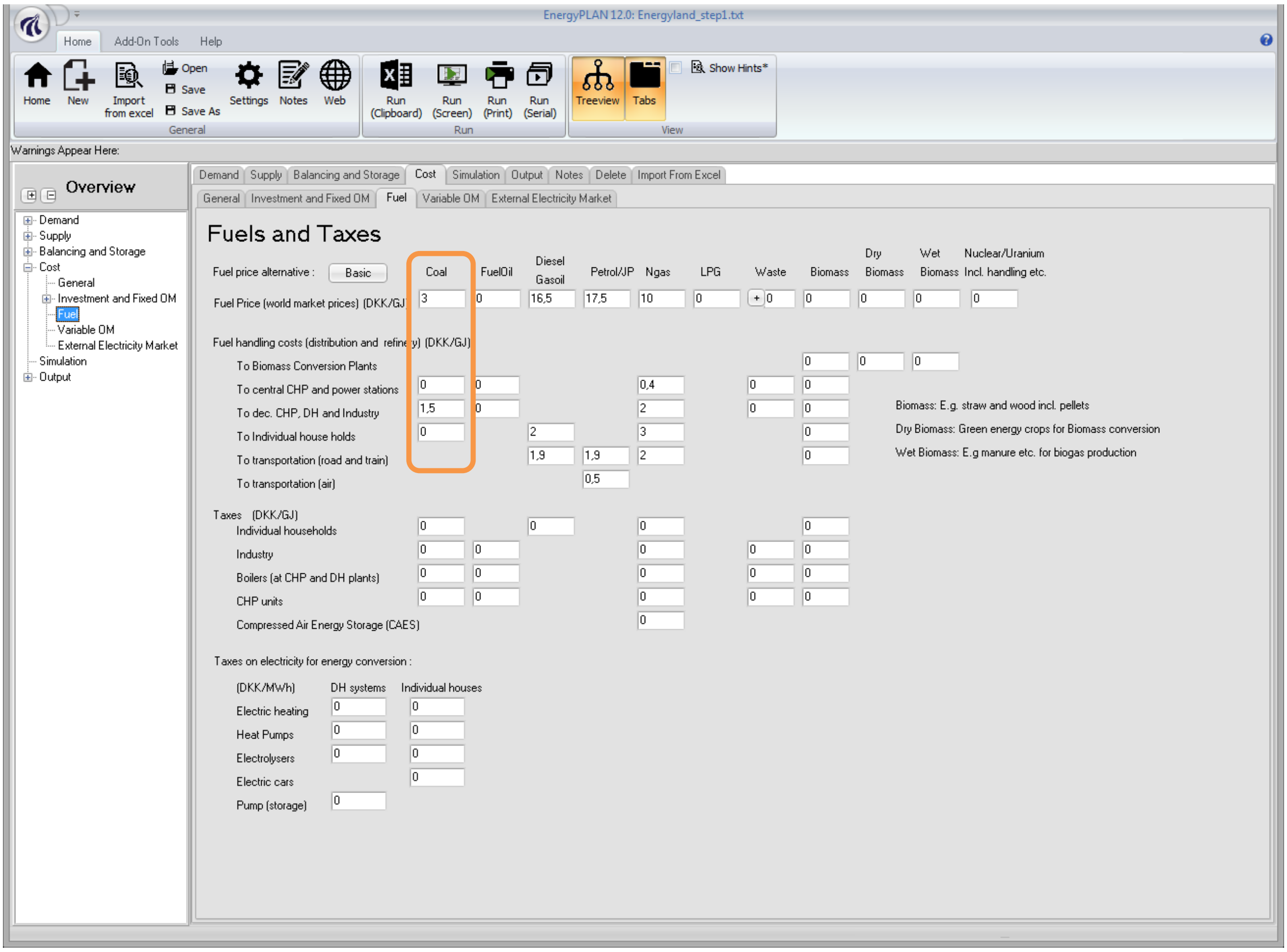
Finally, we will add the 25 TWh of coal for the energy demands in industry.

- Go to the Industry tabsheet and under coal, insert 25 TWh.

We will not be changing the infrastructure for industry, so the costs are not included. Ideally, it would be better to have a profile of the equipment using the fuel in industry so the cost of changing it can be accounted for.



Now we must add the fuel price and the fuel handling costs for coal by going to the “Cost->Fuel” tabsheet:



Run the results and save your file:

Metric	Electricity Sector Only	Electricity & Heat Sectors	Electricity, Heating, and Transport	Electricity, Heating, Transports, and Industry	Unit
Primary Energy Supply (PES)	66.67	98.43	168.43	193.43	TWh
Annual CO2 Emissions (CO2)	13.608	22.069	40.717	49.267	Mt
Annual Energy System Costs (Costs)	2914	6418	16655	17060	Million Euro (M€)

The Energyland system is now modelled in EnergyPLAN. Next, we will need to model some scenarios to analyse the impact of various integration technologies.