Energy price and Carbon Balances Scenarios tool (ENPAC) – a summary of recent updates

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1. Introduction

The Energy price and Carbon Balances Scenarios tool (the ENPAC tool) is presented in the publication "Scenarios for assessing profitability and carbon balances of energy investments in industry" by Axelsson and Harvey [1]. This PM presents the updates of the ENPAC tool performed during 2011-2014. It is a supplement to the publication by Axelsson and Harvey and cannot be read independently. For background, context, scope and a thorough description of the tool the reader is referred to Axelsson and Harvey. New features of the tool will here be described in more detail, while for features already presented in [1] only the updates will be described.

2. Summary of updates

The version of the tool presented in Axelsson and Harvey [1] is version 1.6. The versions presented here are the versions called 1.8 and 1.9. The major differences between version 1.8 compared to version 1.6 are:

- A motor fuel market model including gate prices for different biofuels has been added to the tool
- New heat market model
- Willingness to pay for biomass for different biofuel plants has been added to the wood fuel market model
- Other greenhouse gases than CO_2 have been included in the tool
- Prices in 2010 money value
- New scenario standard input data (fossil fuel prices and policy instruments)
- The scenario tool has been translated into English

The differences between version 1.9 and version 1.8 are:

- A waste market model has been added to the tool
- Prices in 2012 money value
- New scenario standard input data (fossil fuel prices and policy instruments)

The tool has been used in several studies assessing not only investments in energy efficiency in industry but also investments in new biomass conversion technologies for production of high value products integrated to existing industries or district heating systems or located stand-alone. The motor fuel market model has been developed, so revenues from biofuel production can be estimated.

3. Indexes and currencies

The tool is based on cost data from different years and in different currencies. Recalculation of costs (investment costs, operation and maintenance costs, distributions costs, etc) to a different currency and a different year is done according to:

1. Recalculation to EUR (the currency used in ENPAC) using the exchange rate for the year that the value is given.

2. By using different indexes (depending on the type of cost), the cost is updated to a specific years money value (As described in the previous section 2010 is used in ENPAC 1.8 and 2012 in ENPAC 1.9. In ENPAC 1.6, 2006 year money value was used).

Three different indexes are used in the tool:

- Chemical engineering plant cost index (CEPCI) [2]
- Eurostat's EU fuel [3]
- Eurostat's HICP (harmonized indices of consumer prices) [3]

All economic values presented in this PM are in 2012 money value, i.e. the standard settings for ENPAC 1.9.

4. Emission factors

The tool has been updated to include other greenhouse gases (GHG) than CO_2. CH_4 and N_2O has been recalculated into CO_{2eq} (using conversion factors of 23 and 296 respectively). The emission factors are taken from [4]. Table 1 presents combustion and well-to-gate emissions for different fuels, both in CO_2 emissions only and in CO_{2eq} emissions.

Table 1. Combustion and well-to-gate CO_2 and CO_{2eq} emissions for different fuels (kg/MWh).

	EO1	EO5	Coal	NG	Diesel	Gasoline	Biomass	DME[a]	MeOH[a]	EtOH[a]	FTD[a]
CO_2 emissions											
Combustion	267	274	349	204	263	259	0	0	0	0	0
Well-to-gate	19	19	15	20	21	21	8	4	4	3	3
Total	287	293	364	224	284	280	8	4	4	3	3
CO_{2eq} emissions											
Combustion	268	275	349	206	265	262	0	0	0	0	0
Well-to-gate	21	21	61	42	24	24	9	4	4	3	3
Total	289	296	411	248	289	286	9	4	4	3	3

[a] Do not include emissions related to production. From [5].

As was described in [1], it is assumed that the CO_2 charge is harmonized, i.e. it is assumed to be the same for all types of emitter. This assumption implies that it is possible to assume that the CO_2 charge can be put on well-to-gate emissions as well as combustion emissions. Default in the tool is that for cost calculations total, i.e. both well-to-gate and combustion, CO_2 (only) emissions are used. However, the calculated emissions associated with different energy carriers also include the other GHG. This can, however, easily be changed by the user.

5. Policy instruments

Besides a charge for emitting fossil CO_2 emissions and support for renewable electricity, the tool now also includes support for renewable transportation fuels.

6. Fossil fuel market

The prices of light fuel oil and heavy fuel oil are calculated as a function of the crude oil price. The relation between crude oil and the two oil products (light and heavy fuel oil) is based on an analysis of oil product price statistics. Equations 1 and 2 in [1] has been updated with data from [6]:

Eq 1:
Price of light fuel oil = 1.1 · crude oil price + 3.2 (€/MWh)

Eq 2:
Price of heavy fuel oil = 0.7 · crude oil price + 8.0 (€/MWh)

Also for other fossil fuels the cost assumptions have been updated. For natural gas, the EU import price plus a transit and distribution cost of 5.5 €/MWh is used. For coal an average transportation cost from port to end-user of 1.2 €/MWh is assumed.

The CO_2 emission factors used for calculation of total fuel costs have been updated according to Table 1 above.

7. Electricity market

Nuclear and wind power have been added as possible build margin technologies. However, as for the option of CCS, it is up to the user if this option should be considered. Default in the tool is that these options are not included as possible build margin technologies. Table 2 presents data for the base load build margin options for power production that are included in the tool (thus, this table presents updated and new data compared to Table 2 in [1]).

Table 2. Base load build margin alternatives for electric power production. Data from [7].

Build margin	Inv. €/kW_{el}	Fixed O&M €/kW_{el}	Var O&M €/MWh_{fuel}	η_{el}[c]	Operating h/yr	a 1/yr
Coal power plant	1613	32	0,8	0.48-0.56	7700	0,078
Coal power plant with CCS[a]	3226	72	1,1	0.37-0.43	7700	0,078
NGCC	779	22	1,1	0.63-0.71	7700	0,078
NGCC with CCS[a]	2058	56	1,7	0.47-0.53	7700	0,078
Nuclear	3115	-	11,1[b]	-	7600	0,066
Wind	1724	31	-	-	2360	0,087

[a]The CO_2 capture efficiency is assumed to be 88%.
[b]MWh_{el}.
[c]Different electricity efficiencies depending on year of commission.

The cost of electricity (COE) is calculated according to Equation 3.

Eq 3:

$$COE = \frac{Inv \cdot a + C_{O\&M} + C_{fuel} + E_{CO2} \cdot C_{CO2}(-R_{RES-E})}{El_{\mathrm{Prod}}}$$

where:
COE = Cost for electricity production (€/MWh), calculated as annual average.
Inv = Investment cost for the power plant (€)
a = annuity factor (yr^{-1})
$C_{O\&M}$ = Operating and maintenance costs (€/yr)
C_{fuel} = Cost for fuel (€/yr)
E_{CO2} = CO_2 emissions based on data in Table 1 (tonne/yr)
C_{CO2} = CO_2 emissions charge (€/tonne)

$R_{RES\text{-}E}$ = Revenue from policy instrument promoting electricity produced from renewable energy sources (€/MWh)
El_{prod} = Annual electricity production (MWh/yr)

The only difference compared to Equation 3 in [1], is that a revenue for producing renewable electricity has been added ($R_{RES\text{-}E}$). Of the included build margin options this parameter is only applicable for wind power. The annuity factor (a) has been modified to reflect different life times for different technologies. This can be seen in Table 2.

8. Motor fuel market

The now included motor fuel market has not been directly included in previous versions of the tool. However, it has been indirectly included since biofuel (DME) production has been considered as a possible marginal user of biomass.

The motor fuel market include gate and consumer prices for different renewable transportation fuels (also called biofuels) including methanol, ethanol, DME (dimethyl ether), FTD (Fisher Tropsch diesel) and FTG (Fisher Tropsch gasoline). The gate prices of renewable motor fuels (i.e. the revenue that the company that produces renewable motor fuels can receive, excluding possible revenues from policy instruments) have been calculated by assuming that the consumer should have the same cost per fuel energy as for conventional fuels (diesel and petrol). Moreover, it is assumed that energy taxes and VAT are the same for renewable and conventional fuels. This means that by taking the consumer (market) price (excl. VAT and energy taxes) for conventional fuels and subtracting the distribution cost for biofuels, the biofuel gate prices can be calculated. This is described in Equation 5 in [1] for DME, and the same principle is used for all biofuels in the now included motor fuel market model. So called renewable diesel fuels (DME, FTD) are related to conventional diesel, whereas the renewable petrol fuels (methanol, ethanol, FTG) are related to conventional petrol. Thus, Equation 5 in [1] has been replaced by[1]:

Eq 5a:
Gate price of renewable diesel fuel = Market price of fossil diesel transportation fuel (incl. CO_2 emission charge) – distribution cost for renewable diesel fuel – (CO_2 emission charge) (€/MWh)

Eq 5b:
Gate price of renewable petrol fuel = Market price of fossil petrol transportation fuel (incl. CO_2 emission charge) – distribution cost for renewable petrol fuel – (CO_2 emission charge) (€/MWh)

Figure 1 illustrates an example of the consumer prices for all included motor fuels and what they consist off for different fuels. As can be seen in the figure, the charge for CO_2 emissions related to the gate-to-wheel operation of biofuels is neglectable[2].

[1] Today, the support for biofuels in some countries is in the form of reduced energy taxes. However, since Equations 5a and 5b describe the revenue for biofuel producers excluding the support, support e.g. corresponding to reduced energy taxes could then be added to this revenue.
[2] Since a harmonized CO_2 charge is assumed, fossil emissions related to the life cycle of renewable fuels are also considered. The gate price is calculated based on the assumption that the emissions related to the production of the fuel are taken care of by the producer.

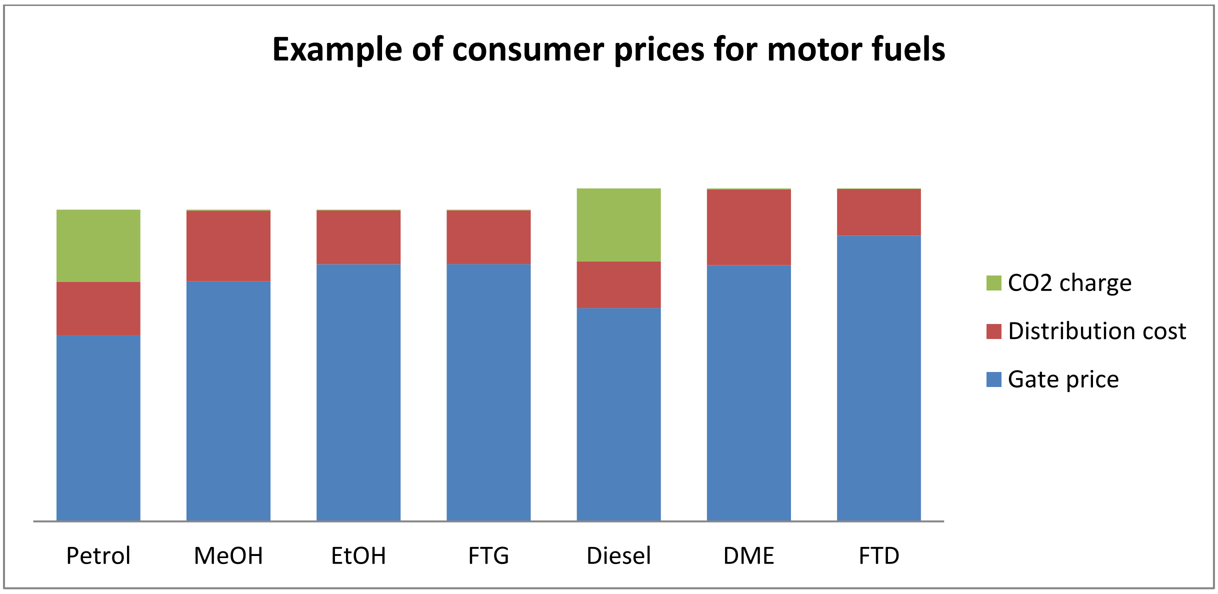

Figure 1. Example of a breakdown of consumer prices of motor fuels (excl. energy tax and VAT).

Thus, in order to calculate the gate prices for biofuels the consumer prices of fossil transportation fuels needs to be calculated first. This is done from statistics describing the relation between crude oil price and the price of diesel/petrol (gate price + distribution cost) and by then adding the CO_2 charge. This is described in Equation 6 in [1][3]. Equation 6 is calculated based on data for both diesel and petrol. This equation has been updated with data from [6] and changed to separately handle diesel and petrol. The following equations are now used:

Eq 6a:
Market price of fossil diesel transportation fuel = 1.1 · price of crude oil + 19.4 €/MWh + CO_2 charge (€/MWh)

Eq 6b:
Market price of fossil petrol transportation fuel = 1.0 · price of crude oil + 19.7 €/MWh + CO_2 charge (€/MWh)

All the emission factors used are presented in Table 1. The distribution costs for biofuels that are used are presented in Table 3.

Table 3. Distribution cost for biofuels (€/MWh). Data is taken from [8].

Fuel	Distribution cost
Methanol	20,3
Ethanol[a]	15,4
DME	21,8
FTD	13,4
FTG[a]	15,4

[a]Has been asumed to be the same as for petrol.

[3] There is a printing error in [1]. 1.18 should be 11.8.

9. Wood fuel market

The term in Equation 4 (coal power plants willingness to pay (WTP) for wood fuel) in [1], accounting for the additional costs at the power plant related to use of wood fuel instead of coal has been increased from 2.9 to 3.6 €/MWh.

WTP for wood fuel has been added for other biofuels besides DME. The willingness to pay for wood fuel for biofuel plants are calculated according to Equation 7 (replaces Equation 7 in [1]).

Eq 7:

$$\mathrm{WTP}_{\text{Wood fuel,Biofuel}} = \frac{\mathrm{Biofuel}_{\text{Prod}} \cdot (\mathrm{P}_{\text{Biofuel}} + \mathrm{R}_{\text{RES-T}}) - \mathrm{Inv} \cdot \mathrm{a} - \mathrm{C}_{\text{O\&M}} -/+ \mathrm{El} \cdot \mathrm{P}_{\text{el}}}{\text{Wood fuel}} (- \; WF_{CO2} \cdot \mathrm{C}_{CO2})$$

where:

$WTP_{Wood\ fuel,\ Biofuel}$ = WTP for wood fuel for biofuel production plants (€/MWh)

$Biofuel_{Prod}$ = Biofuel production, annual average (MWh/yr)

$P_{Biofuel}$ = Gate price of biofuel (€/MWh)

R_{RES-T} = Revenue from policy instrument promoting transportation fuel produced from renewables

Inv = Investment cost for the biofuel plant (€)

a = annuity factor (yr^{-1}), 0.087 is used (corresponding to 20 years and 6 % discount rate)

$C_{O\&M}$ = Operating and maintenance cost (€/yr)

El = Electricity surplus/deficit (MWh/yr)

P_{el} = Electricity price (€/MWh), possibly including R_{RES-E}

Wood fuel = consumption of wood fuel (MWh/yr)

energy sources (€/MWh)

WF_{CO2} = CO_2 emissions for biomass based on data in Table 1 (tonne/yr)

C_{CO2} = CO_2 emissions charge (€/tonne)

Data that has been used for the different biofuel plants are presented in Table 4. These are examples of biofuel production plants from the literature. They have not been adjusted for example in terms of size, which would make the comparison between them fairer. They should be seen as examples of biofuel production process processes that could be potential marginal, price-setting users of biomass.

Table 4. Biofuel production plant data. Data is taken from [9-11].

		DME[b]	EtOH[c]	FT[d]	FT CCS[d]
Biofuel produced	MW	131	99	200	200
Wood fuel input	MW	200	354	500	500
Electricity (+/-)[a]	MW	-13	27	-5	-10
CO_2 captured	t/h	-	-	-	40
Inv.	€/$kW_{biofuel}$	2808	2624	2918	2950
O&M	M€/yr	17	24	23	33
Operating time	h/yr	8000	8000	8000	8000

[a] - indicates import to plant, + indicates export from plant

[b] Data from [9].

[c] Data from [10].

[d] Data from [11].

Equation 7 and Equation 4 (in [1]) reflect prices for wood fuel delivered to the end user. To obtain the corresponding revenue for fuel producers, the buyer's price must be reduced with transportation costs which in the ENPAC tool as a standard has been set to the value of 4.9 €/MWh.

Equation 8 in [1], describing the price of pellets in relation to the price of low grade biomass, has been updated with data from [12]:

Eq 8:
Price of pellets = Price of low grade biomass · 1.2 + 7.9 (€/MWh)

10. Waste fuel market

In ENPAC 1.9 a waste fuel market model is included to give price and CO_2 emissions of waste fuel. For estimating the willingness to pay for waste fuel, the marginal user of the fuel is assumed to be waste fuel fired condensing plants, applying Equation 9 as well as Table 5. All technical and environmental performance presented in the tables are based on Profus knowledge about the waste market.

Eq 9:

$$WTP_{WF} = (P_{el} - (Inv \cdot a + O\&M_F)/OT - O\&M_R) \cdot n_{el} - E_{CO2} \cdot C_{CO2}$$

where:
WTP_{WF} = WTP for waste fuel (€/MWh)
P_{el} = Electricity price (€/MWh)
Inv = Investment cost for waste fuel fired condensing plant (€/MW)
a = annuity factor (yr^{-1}), 0.087 is used (corresponding to 20 years and 6 % discount rate)
$O\&M_F$ = Fixed operating and maintenance cost (€/MW, yr)
OT = Operation time (h/yr)
$O\&M_R$ = Running operating and maintenance cost (€/MWh_{el})
n_{el} = Electricity efficiency of condensing plant
E_{CO2} = Emissions factor for waste fuel (ton/MWh_{fuel})
C_{CO2} = CO_2 emissions charge (€/tonne)

Table 5. Technology data for a waste fuel fired condensing plant.

Investment cost	€/kW	5710
Fixed O&M cost	€/kWel, yr	163
Running O&M cost	€/MWhel	20
Operating hours	h/yr	7074
ηel		0.30-0.45[a]

[a]Different electricity efficiencies depending on year of commission.

The real fossil CO_2 emission factor for waste fuel varies with the composition of waste and is not easy to estimate. Waste fuel was excluded from the EU ETS until December 2012. However, from January 2013 waste fuel is included and a standard value is included unless online measurement is applied.

11. Heat market

The heat market model has been updated to give a more precise price estimate of excess heat, and to also give a separate price estimate for Swedish conditions. For estimating heat prices on a European level, the two main types of district heating cases in Europe has been considered: electricity coupled system as well as a European cost ranked system. To give separate prices for Swedish conditions the model also includes a Swedish cost ranked system. Hence, Equations 9 and 10 in [1] should be replaced with the equations presented below. Another update in the new heat market model is estimates on possible utilisation times for excess heat. This is an important aspect of excess heat since one can seldom expect to be able to sell excess heat 8760 h due to the heat profile of a typical building. The estimated utilisations times below consider the fact that the time decreases with delivered load compared to the total load of the receiving district heating system (load share).

Electricity coupled system in Europe

In Europe, many district heating producers are in the form of large power plants with condensing turbines that can tap of some of the steam at a higher temperature level to provide heat to a city. For every unit heat produced, the electricity production decreases with 0.15 units (electricity efficiency of condensing part). When the electricity production decreases, marginal electricity production has to be increased. Considering the electricity efficiency the heat price and CO_2 benefit of using excess heat can be set to price and CO_2 emissions from marginal electricity production (which is defined in ENPAC) times 0.15 according to Equations 10 and 11. For utilization time Equation 12 can be used.

Eq 10:
$$\text{Heat price} = \text{Electricity price} \cdot 0.15$$

Eq 11:
$$CO_2 \text{ benefit from using excess} = CO_2 \text{ emission from marginal electricity} \cdot 0.15$$

Eq 12:
$$\text{Utilization time (full hours equivalents)} = 8760 - 5725 \cdot \text{load share}$$

Where *load share* is load of delivered heat divided with maximum needed load.

Cost ranked district heating production in Europe

In a cost ranked systems the climate benefit of using external heat and the willingness to pay for the heat is more complex and depends on how the excess heat is utilized in the production mix. One way to include industrial excess heat in a cost ranked production system is to place it between two existing production units. With current situation on an aggregated European level, excess heat can be priced after running production costs in natural gas fired CHP plants. However, with time natural gas plants are expected to be phased out for waste incineration and bio CHP. Hence, the price of heat is set to running heat production cost for NG CHP before 2035 and for bio CHP after 2035 according to Equation 13 with figures from Table 6. Utilization time (UT) in full hours equivalents (FHE) for the two alternatives are presented in Equations 14-17.

Eq 13:
$$\text{Heat price} = (1+\alpha)/\eta_{tot} \cdot P_{fuel} - \alpha \cdot (P_{el} + \text{RES-E support}) + C_{O\&M}$$

where:
Heat price = Price of industrial excess heat (€/MWh)
α = Electricity to heat ratio in price setting CHP plant
η_{tot} = Total efficiency in price setting CHP plant
P_{fuel} = Fuel (including CO_2 charge) for price setting CHP plant (€/MWh)
P_{el} = price for electricity (€/MWh)
RES-E support = support for renewable electricity production (e.g. for bio-CHP)
$C_{O\&M}$ = Operating and maintenance cost for price setting CHP plant (€/MWh_{heat})

Table 6. Data for price setting technologies.

	Fuel	η_{tot}	α	$C_{O\&M}$ (€/MWh_{heat})
NG CHP	Natural gas	0.9	1.04	2
Bio CHP	Wood fuel	1,0	0.45	5
Bio HOB (for Sw eden)	Wood fuel	0,95	-	3,8

Eq 14:
UT for NG CHP year 2020 = 5740 - 4730 · LS, LS > 0.76

Eq 15:
UT for NG CHP year 2020 = 4980 - 4690 · LS, LS > 0.66

Eq 16:
UT for Bio CHP year 2020 = 6780 - 4660 · LS, LS > 0.86

Eq 17:
UT for Bio CHP year 2020 = 6680 - 4680 · LS, LS > 0.85

where:
UT = Utilization time (full hours equivalents)
LS = Load share (load of delivered heat divided with maximum load)

One simplified way to quantify the CO_2 impact of introducing excess heat is to assume that heat production with the distribution above excess heat will be replaced. For example mainly NG CHP will be replaced before 2035, but also production units above NG, i.e. coal HOB and NG HOB are significant. The CO_2 emissions from these units are calculated according to Equations 18 and 19 for CHP plants and HOB plants respectively, with figures from Table 6 and Table 7.

Eq 18:
$CO_2 \text{ emissions CHP} = (1+\alpha)/\eta_{tot} \cdot C_{fuel} - \alpha \cdot C_{elec}$

Eq 19:
$CO_2 \text{ emissions HOB} = 1/\eta_{tot} \cdot C_{fuel}$

where:
α = Electricity to heat ratio in price setting CHP plant
η_{tot} = Total efficiency in price setting CHP plant
C_{fuel} = CO_2 intensity of fuel
C_{elec} = CO_2 emissions from marginal electricity production (kg/MWh)

Table 7. Data for technologies that will be replaced by excess heat (other than the price setting ones).

	Fuel	η_{tot}	α
Coal CHP	Coal	0.88	0.55
Heat pump	Electricity	3	-
Oil CHP	Eo5	0.88	0.6
Coal HOB	Coal	0.9	-
NG HOB	Natural gas	0.92	-
Oil HOB	Eo5	0.9	-

Cost ranked district heating production in Sweden

In Sweden all district heating systems are of the kind cost ranked, rather than electricity coupled. Hence, the approach described above for European cost ranked system can also be applied for Sweden. In Sweden two different price setting technologies have been identified: bio CHP and bio HOB. The price for heat for these technologies can be determined by applying Equation 12 above, using the data in Table 6 (for bio HOB α is set 0 in Equation 12). Also the CO_2 benefit from using excess heat can be determined with the approach described above, that is applying Equations 17 and 18 as well as Table 6 and Table 7. Utilization time (UT) in full hours equivalents (FHE) for the two alternatives are presented in Equation 20, using figures presented in Table 8.

Eq 20:

$$UT = a - b \cdot LS, \; LS > c$$

where:

UT = Utilization time (full hours equivalents)

LS = Load share (load of delivered heat divided with maximum load)

Table 8. Equation components for Equation 12.

	Bio HOB			Bio CHP		
Year	a	b	c	a	b	c
2020	4360	4440	0.57	7230	5320	0.82
2030	4270	4460	0.55	6960	5150	0.81
2040	3970	4560	0.52	6580	4970	0.78
2050	3830	4590	0.50	6420	4900	0.77

12. Examples of scenario input data and resulting output data

Figure 2 presents an example of scenario input data. This input data constitutes the standard input data for 2030 in ENPAC 1.9. The input data is taken from World Energy Outlook 2013 [13]. The scenarios presented in Figure 2 (indicated by numbers) refer to the following scenarios in World Energy Outlook (WEO):

- Scenario 1: WEO Current policy 2030
- Scenario 2: WEO New policy 2030
- Scenario 3: average values based on the Current policy and 450 ppm scenarios from WEO
- Scenario 4: WEO 450 ppm 2030

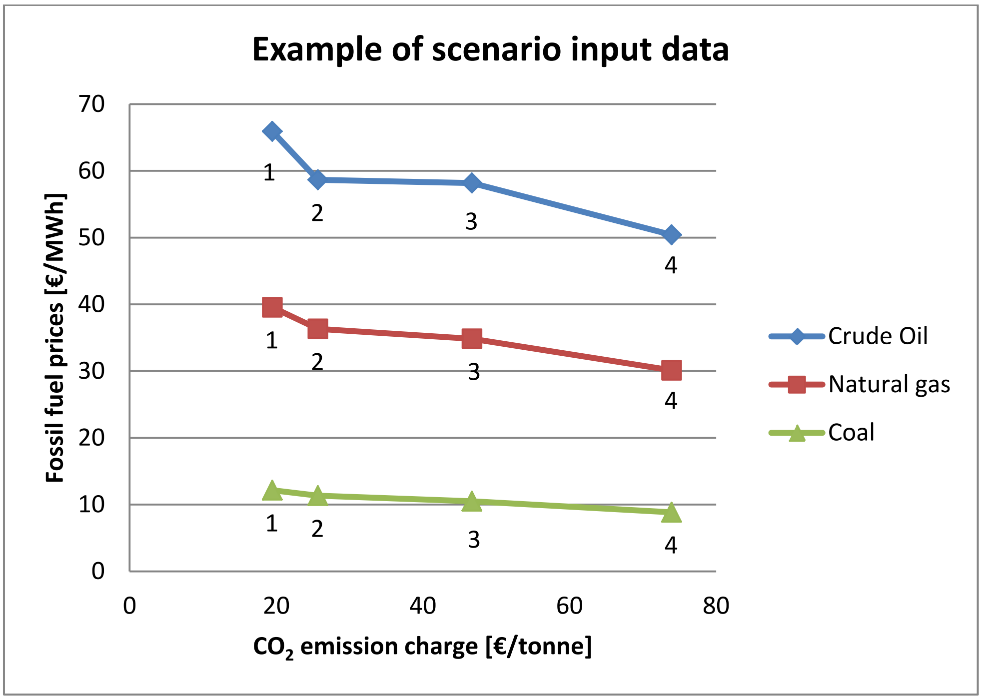

Figure 2. Example of scenario input data.

The support for renewable electricity and motor fuels are not varied between the scenarios and are as a standard set to represent average values for Europe; 20 €/MWh for electricity, 26 €/MWh for renewable diesel fuels and 35 €/MWh for renewable petrol fuels. Figure 3 presents a selection of output data from the tool based on the input data presented in Figure 2 and the values for support of renewable electricity and renewable motor fuels. CCS has not been considered to be an option in this example. As can be seen, waste fuel has negative prices.

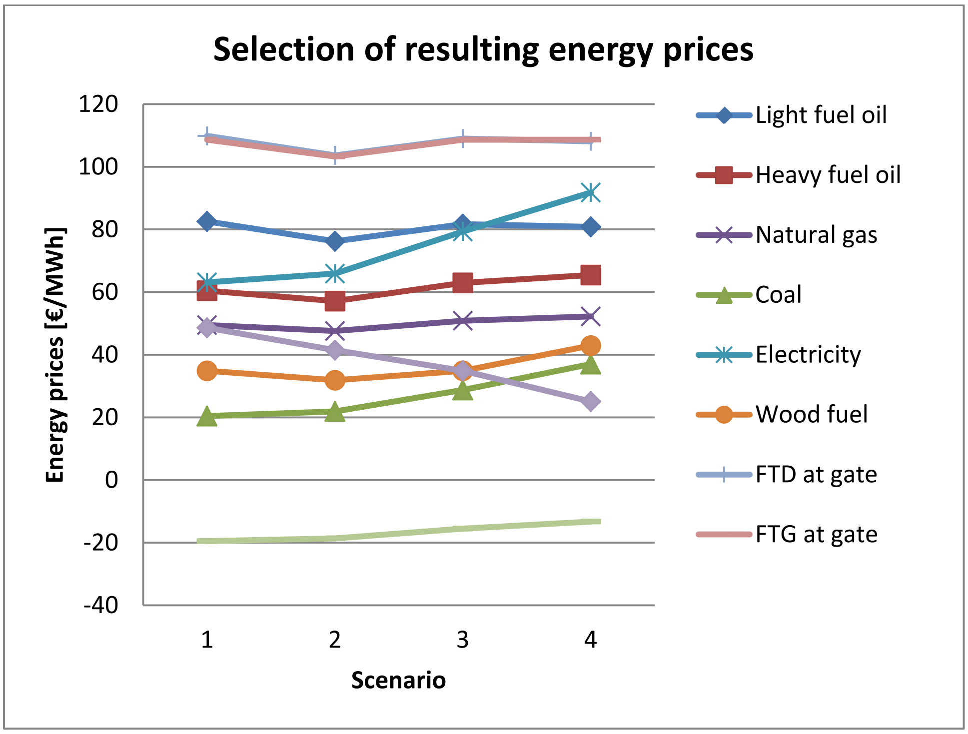

Figure 3. Selection of resulting scenario output data based on the example of input data.

Figure 4 shows the resulting electricity production costs for different potential marginal production technologies and the CO_{2eq} emissions (total) associated with the marginal production technology. As can be seen in Figure 4, coal power has the lowest production cost in Scenarios 1-3, while NGCC power has the lowest production cost in Scenario 4. The resulting electricity prices set by the technology having the lowest production cost, corresponds to the electricity price presented in Figure 3.

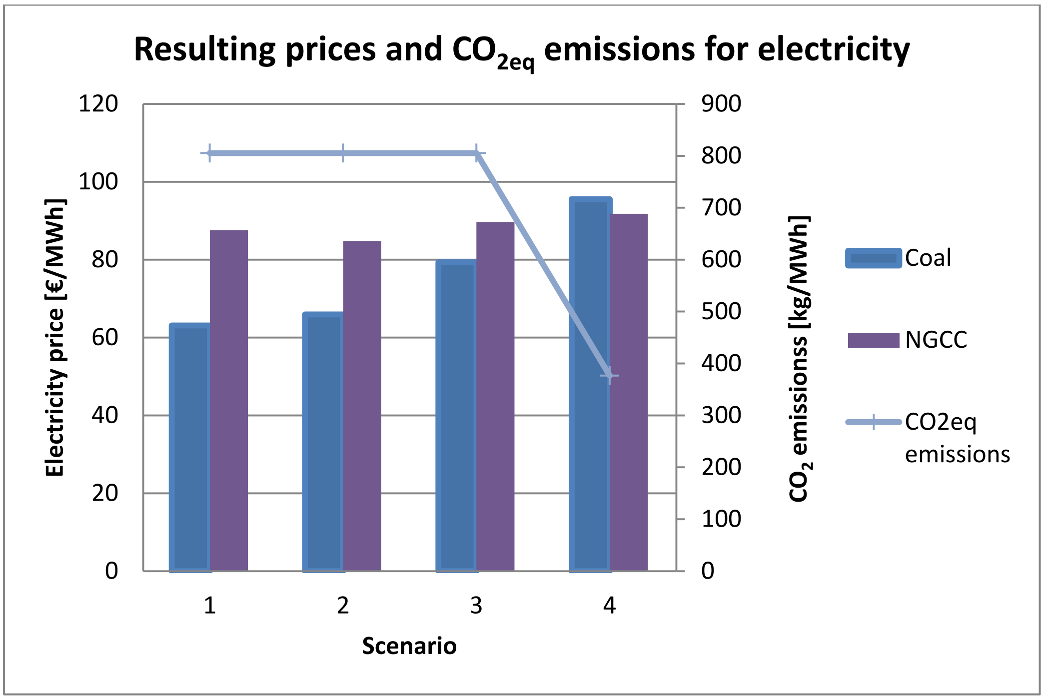

Figure 4. Resulting electricity production costs based on the example of input data. The electricity price is set by the marginal production technology, i.e. the technology having the lowest production cost. The CO_{2eq} emissions for marginal electricity production are also shown.

Figure 5 shows the resulting willingness to pay (WTP) for different potential marginal users of wood fuel and the CO_{2eq} emissions associated with marginal usage of wood fuel. As can be seen in Figure 5, FT production plants have the highest WTP in Scenarios 1 and 2, while coal power plants have the highest WTP in Scenarios 3 and 4. The resulting wood fuel prices set by the technology having the highest WTP, corresponds to the wood fuel price presented in Figure 3.

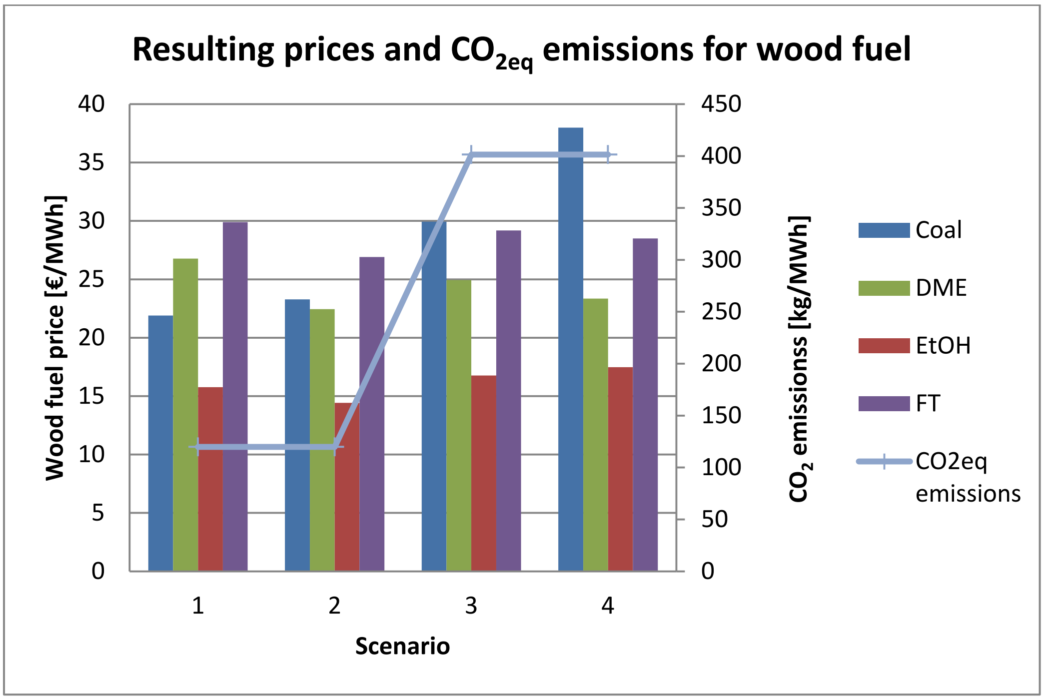

Figure 5. Resulting WTP for wood fuel based on the example of input data. The wood fuel price is set by the marginal user, i.e. the user having the highest willingness to pay for wood fuel. The CO_2 emissions associated with usage of wood fuel are also shown.

There are a number of things that could be changed by the user of the tool. Except for input data, as has been mentioned, for example which GHG that should be accounted for in the cost calculations. Other examples include which year's money value that should be used.

When using the tool it is important to be consistent with other assumptions within ones study. For example, if evaluating process concepts that include CCS, this should probably be an option within the tool as well. It could also be data regarding performances or costs, for example concerning power plants or biofuel plants, which need to be consistent. It could then be necessary to change the input data within the ENPAC tool. Using the standard settings and input data could be an option in some cases. However, often when the tool is used adjustments are needed in order to make the analysis consistent.

13. References

1. Axelsson, E. and S. Harvey, *Scenarios for assessing profitability and carbon balances of energy investments in industry. AGS Pathways report 2010:EU1.*, 2010, AGS, The alliance for global sustainability. Pathways to sustainable European energy systems: Göteborg, Sweden. Available from: http://www.energy-pathways.org/reports.htm.
2. *Chemical Engineering's Plant Cost Index (CEPCI)*. 2014; Available from: http://www.che.com/pci/.
3. *Eurostat. EU fuel*. 2014; Available from: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.
4. Gode, J., et al., *Miljöfaktaboken 2011 Uppskattade emissionsfaktorer för bränslen, el, värme och transporter*, 2011, Värmeforsk: Stockholm. Available from: http://www.varmeforsk.se/rapporter?action=show&id=2423.

5. Edwards, R., et al., *Well-to-wheels analysis of future automotive fuels and powertrains in the European context, version 2c*, 2007, JRC, EUCAR and CONCAWE. Available from: http://ies.jrc.ec.europa.eu/wtw.html.

6. *Energy in Sweden – facts and figures 2010*, 2010, The Swedish Energy Agency. Available from: https://energimyndigheten.a-w2m.se/Home.mvc.

7. Nyström, O., et al., *El från nya och framtida anläggningar 2011. Sammanfattande rapport*, 2011, Elforsk: Stockholm, Sweden.

8. Ekbom, T., N. Berglin, and S. Lögdberg, *Black Liquor Gasification with Motor Fuel Production - BLGMF II*, 2005, Nykomb Synergetics: Stockholm, Sweden. Available from: http://www.osti.gov/etde/servlets/purl/20745853-FskABR/.

9. Boding, H., et al., *BioMeeT II - Stakeholders for biomass based methanol/DME/power/heat energy combine, final report*, 2003, Ecotraffic AB, Nykomb Synergetics AB: Stockholm, Sweden.

10. Fornell, R. and T. Berntsson, *Process integration study of a kraft pulp mill converted to an ethanol production plant – Part A: Potential for heat integration of thermal separation units.* Applied Thermal Engineering, 2012. 35(0): p. 81-90.

11. Johansson, D., *System studies of different CO_2 mitigation options in the oil refining industry: Post-combustion CO_2 capture and biomass gasification*, 2013, Heat and Power Technology, Department of Energy and Environment, Chalmers University of Technology: Göteborg. Available from: http://publications.lib.chalmers.se/records/fulltext/172052/172052.pdf.

12. *The Swedish Energy Agency. Trädbränslen och torvpriser* 2014; Available from: http://www.energimyndigheten.se/Statistik/Energipriser1/.

13. *World Energy Outlook 2013*, 2013, IEA, Organisation for Economic Co-operation and Development: Paris, France.