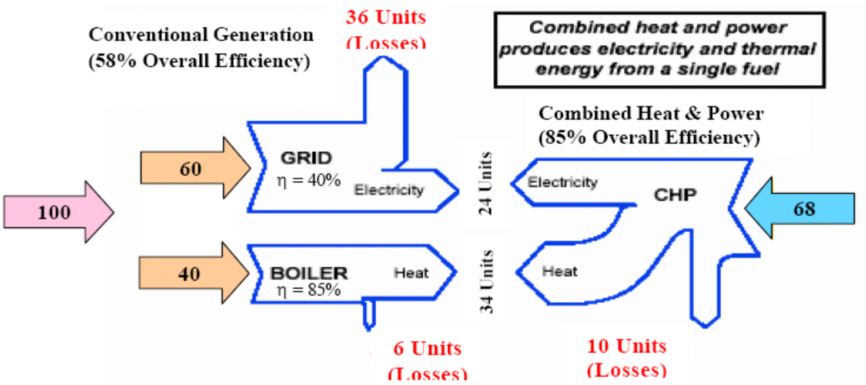
CO2 emission calculation in CHP systems and recommendations

1 Motivation

The CO2 emission allocation methods are very important **energy-policy tools** and they are developed to **support energy-systems planning** as well as **decision-making** and **policy development** at both governmental, regional and industrial levels. The allocation of CO2 emission to the CHP energy outputs is required especially in the case when produced heat and electricity are consumed by different customers and when a comparison needs to be made with other means of supplying heat.

Cogeneration systems produces electric energy and heat but heat can be produce from fossil fuels or electricity with efficiency more than 95% and electric energy is produced from fossil fuels/heat with efficiency up to 45%. The following question arises:

How much of emission should we allocate to energy and heat production ?



Energy efficiency advantage of a cogeneration system (UNESCAP, 2000)

2 Assessing GHG emissions

There are 3 standard equations that describe CO_2 emissions for each type of combusted fuel:

$$GHG\ emissions = Fuel * EF1 \qquad (1)$$

GHG emissions = Amount of CO_2, CH_4 or N_2O emitted, ***Fuel*** = mass or volume of fuel combusted, ***EF1*** = CO_2, CH_4 or N_2O **emission factor** per mass or volume unit,

$$GHG\ Emissions = Fuel * HHV * EF2 \qquad (2)$$

HHV = Fuel heat content (higher heating value), in units of energy per mass or volume of fuel ; ***EF2*** = CO_2, CH_4, or N_2O emission factor per energy unit

$$GHG\ Emissions = Fuel * CC * 44/12 \qquad (3)$$

CC = Fuel carbon content in units of mass of carbon per mass or volume of fuel, 44/12 = ratio of molecular weights of CO_2 and carbon.

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2.1 Primary energy (PE)

Primary energy means energy from renewable and non-renewable sources which has not undergone any conversion or transformation. PE may be fossil or renewable or a combination of both. It can be converted and delivered to end users as final energy, e.g. electricity or heat. PE inputs generally include the upstream activities and processes in supply chain (i.e. extraction, transport and preparation of input fuels).

2.2 Primary Energy Factor (PEF)

The primary energy factor connects primary and final energy - shows how much PE is used to generate a unit of electricity or a unit of useable thermal energy.

Primary energy * System efficiency = final energy

Primary energy factor = Primary energy/final energy

3 CO_2 allocation methods

The following (most popular in EU) methods were assessed in LowTemp project: **Energy method, Alternative generation method, Power bonus method, Exergy method, 200% method, Pas 2050, Dresden method.** There are other methods in literature: Work method, Finnish method, All savings allocated to electricity, All savings allocated to heat, 50%-50% sharing of savings between heat an electricity, Primary energy content of heat and electricity

3.1 Energy method

The Energy Method - fuel input or CO_2 emissions are allocated to the produced heat and electricity based on the energy content of the produced products. The advantage of this method is that it is very simple and transparent. The disadvantage is that the energy content of the products does not distinguish energy products, i.e. does not take into account their qualities (electricity can be easier transformed to heat than opposite). **CO2 allocation factor for heat production:**

$$f_Q = Q / (Q + E)$$

3.2 Alternative generation method

The Alternative Generation method also known as the Efficiency Method or the Benefit Sharing Method (BSM) has been developed by The Finnish District Heating Association. The method allocates CO_2 emissions and resources to the heat and power production in proportion to the fuel needed to produce the same amount of heat or power in separate plants. Alternative production in two separate plants, will depend on their efficiencies η_{heat} and η_{elec} respectively.

$$f_Q = (Q/\eta_{alt\_heat}) / (Q/\eta_{alt\_heat} + E/\eta_{alt\_elec})$$

3.3 Power bonus method

The Power Bonus Method is often used for allocation of CO_2 emissions between heat and power production in the European Union. In this method the heat is the main product, while power produced during the process is considered as a bonus. The primary energy is allocated first to the electricity produced in the CHP plant, which is later subtracted from primary energy input.

$$f_Q = (E_{P,in} - W_{CHP} f_{P,elt}) / (Q_{del} + E_{del})$$

3.4 Exergy method

The Exergy Method (physically correct method) - fuel use or CO_2 emissions are allocated to the produced heat and electricity based on the exergy content of the products. The exergy content of a product is a measure for the maximum useful work that can be performed by the product. The ratio between the energy and exergy content is referred to as the quality factor.

From the thermodynamic point of view, electricity generated during cogeneration is rated with an exergy factor of 1, so the exergy of electricity is defined as $Ex_E = E$. This means that 100% of electricity can be converted to any form of energy. Heat can be converted to power or any other form of energy only to some extent, so the heat exergy can be calculated

$$Ex_Q = (1 - T_o/T)\,Q$$

where T_o – is the average ambient temperature during the heating period and T – is DH thermodynamic mean temperature $T = (T_s - T_r)/\ln(T_s/T_r)$

$$f_Q = Ex_Q / (Ex_Q + Ex_E)$$

3.5 200% method

assumes 200% efficiency for heat production. This means that, in order to produce 1 unit of heat, 0.5 unit of fuel has to be used and the other 0.5 unit will be recovered from the turbine condenser. This means that half of emissions related to heat production can be associated with power generation. This method, introduced by the Danish Energy Agency, can be used when allocating the fuel costs of the CHP to the heat production in the energy and emission statistics.

$$f_Q = Q / 2\,Fuel_{in}$$

3.6 Pas 2050

PAS 2050 method is the British standard, which explains the calculation of GHG emissions for production of goods and services. Allocating the emissions from CHP system to the heat and power produced, the special 'intensity' coefficient '*n*' is used, which specifies the emissions released during fuel combustion

$$f_Q = Q / (Q + n\,E)$$

The allocation of emissions to heat and electricity relies on the process-specific ratio of heat to electricity from each CHP system. For boiler-based CHP systems (coal, wood, solid fuel), the coefficient *n is 2.5*, while for turbine-based CHP systems (natural gas, landfill gas) $n = 2.0$.

3.7 Dresden method

The Dresden method is based on exergy assessment. In power plants all primary energy is related to electricity production. At the same time in the CHP plants, one part of primary energy is consumed for thermal energy production. The *Dresden method* describes how to evaluate the electricity loss caused by the heat extraction (water steam condensation) in the CHP plant $\Delta E = Q\,\eta_c\,\nu_p$, where η_c is Carnot efficiency and ν_p is degree of process quality.

$$f_Q = \Delta E / E$$

Method	Allocation factor of heat production, f_Q	*E.g. f_Q value*
Energy method	$Q/(Q+E)$	0,2162
Alternative generation meth.	$(Q/\eta_{alt\_heat}) / (Q/\eta_{alt\_heat} + E/\eta_{alt\_elec})$	0,3830
Power bonus method	$(E_{P,in} - W_{CHP}\, f_{P,elt}) / (Q_{del} + E_{del})$	0,2226
Exergy method	$Ex_Q / (Ex_Q + Ex_E)$	0,1507
200% method	$Q / 2\, Fuel_{in}$	0,0608
PAS 2050	$Q/(Q + n\,E)$	0,1212
Dresden method	$\Delta E / E$	0,0834

Allocation factor for CHP system with annual heat load 27 GWh and maximum heat requirement 14 MW

Source: T. Tereshenko T, Nord N, Uncertainty of the allocation factors of heat and electricity production of combined cycle power plant, Applied Thermal Engineering 2015; 76:410-422.

4 Conclusions

Method	AGFW	ZEBAU	BTU	RTU	IMP PAN	Thermopolis	HEM	SUM	Ranking	Variation
Energy method	52.000	52.000	49.857	52.286	53.143	59.143	53.143	371.57	5	5.0%
Alternative generation method	43.286	53.286	46.429	52.714	45.857	36.429	40.571	318.57	7	12.5%
Power bonus method	48.286	48.286	41.286	52.143	55.429	44.571	39.857	329.86	6	11.1%
Exergy method	71.000	71.000	70.714	60.714	60.571	59.429	57.000	450.43	1	9.0%
200% method	60.286	56.857	59.143	56.143	53.143	44.571	66.000	396.14	3	10.9%
PAS 2050	57.571	57.000	59.429	63.857	57.286	44.571	58.571	398.29	2	9.6%
Dresden Method	63.857	63.857	45.714	60.143	46.286	44.571	50.429	374.86	4	15.1%
	15.5%	12.4%	17.9%	7.7%	9.5%	16.5%	16.9%			

LowTemp project partner evaluated the allocation method using Multi-criteria decision analysis (MCDA)

- The Partners have pointed **Exergy (Carnot) method** as the best available method (above 450 points) for CO_2 allocation at least among the considered. Two other methods: **PAS 2050** and **200%** should be considered as possible alternatives – they have received similar score i.e. almost 400 points.
- The most appropriate from a thermodynamic point of view – the **Exergy method** – includes more extensively energy quality and maps a physical upper limit for the CO_2 allocation to heat as a by-product. There is a variant of the Exergy method – **Dresden**, but it requires more data availability and more extensive calculations.
- The **Alternative generation** and **Power bonus method** have been found as least useful ones by the project partnership.

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