ENVIRONMENTAL IMPACT QUANTIFICATION OF THE COGENERATION SYSTEMS – CASE ANALYSIS

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Se consideră un studiu de caz privind determinarea indicatorilor de impact asupra mediului a unei centrale de cogenerare, în vederea evaluării impactului asupra mediului a producerii energiei, pentru o sursă deja existentă.

To assess the environmental impact of the energy production for an already existent source, we have applied a case study to determine the effects scores of the environmental impact of one CHP.

Keywords: emissions, energy production, environment protection

1. Introduction

The definition and the calculation of the effect scores for the CHP systems conduct to the quantification of their ecological impact, which is an important tool both for the implementation phase of a new cogeneration solution and for the case of an audit realization for the already existent systems. Effect scores and impact valuation factors are associated to each impact type. On their basis, from the ecological point of view, it can be made the assessment of different cogeneration systems [1]. The calculation of the impact valuations factors is based to the evacuated pollutants. Two main stages of the life cycle are considered to determining the main effect scores:

"A" – stage of the extraction, processing and transport of the fuel; all this processes before the energy source.

"B" – stage of the energetic transformations from the energy production and distribution source (distribution between source and consummator).

The calculation of the afferent atmospheric emissions to the cogeneration systems is necessary to determine the effect scores taking into consideration the fuel type.

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2. The determination of the atmospheric emissions afferent to the different cogeneration systems

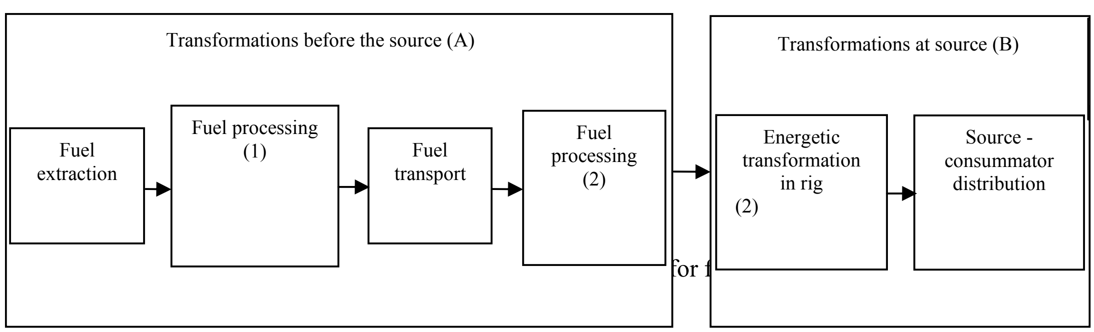
The environmental impact of the production of one useful energy form (heat, power) depends to the next aspects:

1. the type of the energy production source (taking into account the form of the energy produced);
2. the type of the fuel used in the source for the energy production;
3. the stages of the life cycle, considered at every fuel system analysed.

Generally and not depending on the type of the energy production source and on the type of the used fuel, it makes the next considerations:

- The balance is made on the basis of one functional unit as useful energy: E_u = 100kWh.
- The goal is the determination, for the entire life, of the real fuel quantity cycle, necessary to obtain this quantity of useful energy and the afferent emissions evacuated during the production of this useful energy quantity.
- Starting from the value of the useful energy consumption, the analysis is realised remaking the complet energetic chain.

The figure 1 presents the energetic chain afferent to the entire life cycle for one fuel:



3. Impact types, characteristic to the cogeneration systems

The main effect scores are presented in the sequel. It characterises the ecological effect of one cogeneration system and will be determined during the case analyses [2] .

Raw Material Depletion (RMD)

For the cogeneration systems, this effect score is characterised by the raw materials consumption, M, and the contribution of the analysed system to the natural raw material depletion, RMD.

Raw materials consumption, M, shows the impact intensity. It is defined by the sum of all quantities of the fuel consumed and expressed in mass units reported to the functional unit.

$$M = \sum M_i = \sum m_{ij} \ [unit\ mass / functional\ unit] \quad (1)$$

where: M_i is the energetic raw materials consumption of the subsystem "i", expressed in units mass /functional unit; m_{ij} – the mass of the energetic raw material, with the type "j", consumed in the subsystem "i", in units mass /functional unit.

The life cycle's contribution of the cogeneration systems to the depletion of the natural raw material resources, RMD, characterises the extent in which one type of raw material can be submitted to its depletion because of its consumption. This effect score allows estimating the cogeneration system's contribution to the depletion of the raw materials depending on the mass fraction of each raw material consumed. Starting from the plenty period "a" (due to the each type of the primary resource, fuel), the parameter can be defined by the next formula:

$$a = \frac{World\ \mathrm{Re}serve}{Annual\ World\ Consumption} \quad [years] \quad (2)$$

This parameter is variable in time and depends on the place of the reserve. The plenty period values of the principal (energetic) raw materials are presented in the next table [2].

Table 1

The plenty periods of the raw materials (energetic material) [3]

a (years)	Energetic raw materials				
	Coal	Oil	Gas	Uranium	Municipal wastes
	220	40	50	50	1

Observation: Because on made the hypothesis that all the wastes reserves are completely consumed, the plenty period due to the municipal wastes used as fuel (it is the case of the incineration process with energy recovery) has the value 1.

Since we know the plenty period (a), using the next relation, we can calculate the contribution of the cogeneration solution to the depletion of the raw material resources (available for each subsystem "i"):

$$RMDi = \frac{\sum m_{ij} / a_j}{M_i} \tag{3}$$

where: a_j represents the plenty period of the raw material "j", expressed in years.

The value of the RMD parameter belongs to the interval 0 – 1 and the limits of this interval are:

RMD = 0 means that the contribution to the depletion of the raw material is null;

RMD = 1 means that there is a contribution to the total depletion of the raw material.

Greenhouse Effect

It represents the warming of the atmosphere, caused to the infrared radiations reflected from the earth surface. The cogeneration is also a process responsible for the production of this impact type.

The heating potentials due to the gases emission from the different cogeneration system can be compared using the next effect score: Global Warming Potential. It is recommended by the SETAC (Society of Environmental Toxicology and Chemistry).

For a gas, the GWP is defined by the Intergovernmental Panel on Climate Change (IPCC) like a time integral of the variation of the energy radiation change, generated by the injection of one kg of gas to the atmosphere [1].

For a gaseous effluent, the Global Warming Potential can be calculated making the sum of the elementary potentials of the effect, which corresponds to each gas from the emissions evacuated from the cogeneration system:

$$S(k_i) = \sum S_{ij} = \sum m_{ij} s_j \quad [kg / functional\ unit] \tag{4}$$

where: $S(k_i)$ represents the greenhouse potential of the gaseous effluent "k", which is emitted by the system "i"; S_{ij} – the greenhouse potential of the element "j", evacuated by the subsystem "i"; m_{ij} – the quantity of the element which produces the greenhouse effect "*j*" emitted by the subsystem "*i*" [kg/functional unit]; s_j – the GWP (for 20 years) of one kg of the element "*j*".

The principal gases with greenhouse effect are: carbon dioxide (CO_2), methane (CH_4), nitrogen protoxide (N_2O), water (H_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), ozone, carbon monoxide (CO) and other volatile organic compounds (COV). Since the first gases (CO_2, CH_4, N_2O) have a direct effect, the others have an indirect effect to the greenhouse effect.

Table 2

The characteristic GWP for the principal greenhouse gases [3]

Substance	GWP (20 years)	GWP (100 years)	GWP (500 years)
CO_2	1	1	1
CH_4	35	11	4
N_2O	260	270	170

The plenty periods can attain 20, 100 or 500 years. Usually, for the calculations, on considers the shorter period: 20 years.

For a system, the GWP effect score can be calculated making the sum of the elementary potentials of this effect which correspond of each gas from the gaseous effluent composition, potentials which are multiplied by the quantity of each component.

$$GWP = \sum_i m_i \times GWP_i \qquad (5)$$

where :
GWP_i : the potential of the greenhouse effect of the element *i* from the gaseous effluent (equivalent kg CO_2)
m_i : the quantity of the element i (kg / functional unit).

Acidification

The acidification represents the perturbation of the equilibrium acid-base of the atmosphere, which happens because of the gaseous emissions with acid character (resulted from the processes afferent to the cogeneration). These emissions can increase the pH and so create an important perturbation to the environment (air, water, soil).

The most used acidification score is the equivalent acidification (reported to the SO_2 evacuated).

$$I^i = \sum_j AP_j * m_j^i = \sum \frac{\frac{\gamma_j}{M_j}}{\frac{\gamma_{SO2}}{M_{SO2}}} * m_j^i \quad [kg\ SO_2\ equivalent] \qquad (6)$$

where

I^i represents the contribution to the acidification of the subsystem "i", the unit is kg SO_2 equivalent; AP_j – acidification potential of the substance "*j*" (defined value); γ_j – free protons number of the one mol of the substance "j"; M_j – molar mass of the substance "j".

The acidification can be determined using the relation:

$$AP = \sum_i m_i \times AP_i \tag{7}$$

where:
AP: acidification potential [kg SO_2 equivalent /functional unit].
m_i : the quantity of the substance "i" [kg/functional unit]
AP_i : acidification potential of the substance "i" (Table N° 3)

Ecotoxicity

This effect score considers that the toxic effects resulted from the heavy metals and aromatic not halogenated hydrocarbons, which can be found in the aquatic and terrestrial ecosystems. Two quantification scores can be defined: aquatic ecotoxicity and terrestrial ecotoxicity.

ECA (Ecotoxicological Classification factor for Aquatic Ecosystem) is available for the aquatic ecosystem: sweet water and salted water.

ECT (Ecotoxicological Classification factor for Terrestrial Ecosystem) is available for the terrestrial ecosystem.

These effect scores are calculated like the inverse of the tolerable maxim concentration (MTC):

$$ECA\ (T)_i = 1/MTC\ A(T)_i \tag{8}$$

Formulas corresponding for one substance "i" are:

$$ECA = \sum_i m_{a\,i} \times ECA_i \tag{9}$$

$$ECT = \sum_i m_{t\,i} \times ECT_i \tag{10}$$

where:

ECA_i, ECT_i are weight factors of the aquatic and terrestrial ecotoxicity (impact valuation factors) for one substance "i", [kg/mg], [m^3/mg],
m_{ai}, m_{ti} represent the quantities evacuated in water or soil by one substance "i" [mg/functional unit]
ECA, ECT: impact valuation factors for the characterisation of the aquatic and terrestrial ecosystems [m^3/functional unit], [kg/functional unit]

4. Photochemical Ozone Creation Potential

As a result of the reactions between the nitrogen oxides and volatile organic compounds (COV), important quantities of the photo-oxidants are formed at the base of the troposphere, which are very harmful for the animated organism. The most important photo-oxidant is the ozone.

Photochemical Ozone Creation Potential is the effect score which takes in account the creation potential of the ozone. It represents (HEIJUNGS, 92) the ozone mass which is produced by 1 kg of one substance emitted supplementary [4]. For the reference, the substance used is the ethylene. That is why the photochemical ozone creation potential is expressed in kg of the ethylene equivalent.

The other name used for this effect score is "summer smog". The ozone is considered very harmful for people.

We can calculate the photochemical creation potential with the next equation:

$$POCP = \sum_i m_i \times POCP_i \qquad (11)$$

where:

$POCP_i$: the impact valuation factors of the photochemical ozone creation potential for the substance "i"
m_i: the quantities of the substance emitted "i", which influence the creation of the photochemical ozone [kg/functional unit]
$POCP$: the photochemical ozone creation potential [kg C_2H_4 equivalent/functional unit].

The presentation of the case analysis

A CHP plant, equipped with a gas turbine (without post-burning), has an installed electrical power by 20 MW and utilises like fuel the natural gas. This has the calorific power value: $H_i = 35000$ kJ/Nm^3.

The global efficiency of the energy conversion from the power plant is: $\eta_{TG} = 0{,}85$. The characteristic efficiencies of the subsystems from the first stage of the life cycle analysis are:

- $\eta_{extraction} = 0{,}99$
- $\eta_{transforming} = 0{,}75$
- $\eta_{transport} = 0{,}95$.

The annual fuel consumption at the source is: $B = 2{,}8 \cdot 10^8$ Nm^3.

The specific emissions (for the useful energy = 100 kWh) are presented in the next table:

Table 3

Emissions for the stages of the life cycle[4]

Emission type	First Stage [g/100 kWh]	Second stage [g/100 kWh]
Dust	0,00528	0,715
CO	1,85	14,3
SO_x	13,4	1,43
NO_x	9,94	14,3
CO_2	671	22000
CH_4	0,1	-
HC	1,19	-

Demands:

a) The raw fuel quantity extracted from the source;
b) The global efficiency of the energy conversion for the entire life cycle;
c) The quantity of the useful energy produced every year (E + Q);
d) The masses of the pollutants for the entire life cycle (10 years), calculated for every stage of the life cycle and for the two stages together;
e) The effect score: dust emissions, raw materials depletion, acidification, ecotoxicity, photochemical ozone creation potential

a) the raw fuel quantity extracted from the source

$$m_{cb} = \frac{B}{\eta_{ex}\eta_{pr}\eta_{tr}} = \frac{2{,}8 \cdot 10^8}{0{,}99 \cdot 0{,}75 \cdot 0{,}95} \cdot 10 = 39{,}70 \cdot 10^8 \quad Nm^3/lc$$

b) the global efficiency of the energy conversion for the entire life cycle

$$\eta_{gl} = \eta_{ex}\eta_{pr}\eta_{tr}\eta_{TG} = 0{,}99 \cdot 0{,}75 \cdot 0{,}95 \cdot 0{,}85 = 0{,}60$$

c) the quantity of the useful energy produced every year

$$E_u = \frac{B \cdot H_i \eta_{tg}}{3600} = \frac{2{,}8 \cdot 10^8 \cdot 35000 \cdot 0{,}85}{3600} = 23{,}139 \cdot 10^8 \quad kWh/an$$

d) Masses of the pollutants

Table 4

Masses of the pollutants

Emission type	First stage [t/lc*]	Second stage [t/lc]	Total [t/lc]
Dust	1,2	165,4	166,7
CO	428,07	3308,98	3736,9
SO_x	3100,6	330,9	3431,5
NO_x	2300	3308,9	5608,9
CO_2	155261,9	509055,6	664317,5
CH_4	23,1	-	23,1
HC	275,4	-	275,4

* lc = life cycle

e) effect scores:

• dust emissions

$$I_{dust} = m_{dust} \cdot C_{dust} = 166,7 \cdot 0,07 = 11,7 \quad [t_{dust}]$$

$C_{dust} = 0,07$

• raw materials depletion

$$RMD = \frac{\frac{m_{cb}}{a}}{m_{cb}} = \frac{1}{50} = 0,02 \quad [t_{cb}]$$

a = 50 years

• global warming pollution

$$GWP = \Sigma GWP_i \cdot m_i = GWP_{CO2} \cdot m_{CO2} + GWP_{CH4} \cdot m_{CH4}$$
$$= 1 \cdot 664317,6 \cdot +35 \cdot 23,1 = 665126,1 \quad [t\, CO_2 \; equivalent]$$

$GWP_{CO2} = 1$
$GWP_{CH4} = 35$

• acidification potential

$$AP = \Sigma AP_i \cdot m_i = AP_{SO2} \cdot m_{SO2} + AP_{NOx} \cdot m_{NOx}$$
$$= 1 \cdot 3431,5 + 0,7 \cdot 5608,9 = 7357,7 \quad [t\, SO_2 \; equivalent]$$

$AP_{SO2} = 1$
$AP_{NOx} = 0,7$

• aquatic ecotoxicity

$$ECA = \Sigma ECA_i \cdot m_i = ECA_{HC} \cdot m_{HC} = 5,9 \cdot 275352,8 = 1624,9 \quad [t\, HC \; equivalent]$$

$ECA_{HC} = 5,9$

• terrestrial ecotoxicity

$$ECT = \Sigma ECT_i \cdot m_i = ECT_{HC} \cdot m_{HC} = 5,3 \cdot 275,4 = 1459,6 \quad [t\, HC \; equivalent]$$

$ECT_{HC} = 5,3$

• photochemical ozone creation potential

$$POCP = \Sigma POCP_i \cdot m_i = POCP_{HC} \cdot m_{HC} + POCP_{CH4} \cdot m_{CH4} + POCP_{CO} \cdot m_{CO}$$
$$= 0,416 \cdot 275,4 + 0,07 \cdot 23,1 + 0,036 \cdot 3736,9 = 250,7 \quad [t\, C_2H_4 \; equivalent]$$

$POCP_{HC} = 0,416$
$POCP_{CH4} = 0,7$
$POCP_{CO} = 0,036$

5. Conclusions

- A big importance is dedicated in present-day to the implementation of the solutions for the "clean energy production", which has an environmental impact reduce. Because of this reason, the pre-fezability and fezability studies, which are associated to the implementation of the energy sources, must also contain the analyses for the environmental impact of the new projects.
- The presented case – a CHP with gas turbine – exemplifies an environmental impact analysis including effect scores determined function of the emissions afferent to the used fuel.
- The specific emissions used are the maximum admissible emissions (according to the actual normative from this department,) available for the power range and facility type, which with the CHP are equipped.
- For the environmental impact analyses, which will be realised in the future life of the energy source, the calculated values of the effect scores can be considered reference values for the real operation of the new energetic system.

R E F E R E N C E S

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