THE DETERMINATION OF THE PRODUCTION ENERGY COSTS FOR DIFFERENT COGENERATION SYSTEMS APPLYING THE ECO-TAXES – CASE ANALYSIS

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The economic quantification of the ecological effects of the different cogeneration systems must reflect the production costs, the power and the heat prices. Concerning this domain, the Europeans studies emphasize the principal characteristic of the environmental taxes. Different from the other taxes, these improve the energetic efficiency and the eco-efficiency. This characteristic results from the fact that the environmental taxes increase the interest for the use of the clean energetic renewable resources and, both, for the clean production technologies (technologies with high energetic efficiency and reduced pollution).

In this case analysis, we have presented the application of the internalization methodology for the environmental externalizations in the costs of the heat and power production. This methodology was applied in the case of one industrial platform from a CHP. It can be used only if the law frame exists and stipulates the eco-taxes values. This economic "justification" of the ecological effects can be a part of the pre-feasibility study, and, then, of the feasibility study for the optimum solution's implementation of the energy supply. In the pre-feasibility study, as alternative solutions for the energy supply of the proposed industrial platform it can be considered: Air Turbine CHP (AT CHP), Gas Turbine CHP (GT CHP), Thermal Motors CHP (TM CHP), Steam Power Plant (SPP). For all these energy production alternatives, we will analyze the influence of the eco-taxes on the energy production costs.

For this case study very important are: the establishment of the assumptions for the economic quantification analysis of the ecological effects and the establishment of the existent connections between the ecological aspects (the emissions value, the effect scores value) and the proper economic values (the energy tax, the carbon tax, the mixed tax, other taxes for different pollutants – if these pollutant exist). Following this case analysis, we have obtained that, for all energy production alternatives, the introduction of the eco-taxes has a big influence on the production costs for the both forms of the energy production. Under these circumstances, the ecological analysis of the solutions, which were proposed in the pre-feasibility and in the feasibility studies, can have an important influence on the proposed solutions ranking and on the tacked decision.

Keywords: eco-taxes, ecological effects, energy production, energy supply solutions

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1. The Case Analysis Objective

This case analysis presents the application of the internalization methodology for the environmental externalizations, exposed by the model. The methodology can be applied only if the law frame exists and contains the values of the eco-taxes. The economical justification of the ecological effects can be a part of the pre-feasibility study and then of the feasibility study for the implementation of the optimal energy supply solution of the presented industrial platform. In the feasibility study the alternative energy supply solutions are: CHP equipped with steam turbine (CHP with ST), CHP equipped with gas turbine (CHP with GT), CHP equipped with heat motors (CHP with HM), steam-generation station (SGM). For these alternative energy production solutions we will analyze the influence of the eco-taxes on the energy production costs.

A very important point is the preceding establishment of the hypothesis for the analysis of the ecological effects quantification and also the establishment of the existent relations between the ecological aspects (emissions value, effect scores value) and the corresponding economical values (energy taxes, carbon taxes, mixed taxes, other taxes for different pollutants – if these exist).

2. Hypothesis and calculation stages

The calculation stages are:

- calculation of the fuel expenses and their deduction for the two energy forms;
- liquidation calculation for the two energy forms;
- calculation of the operation and maintenance expenses;
- determination of the power production and heat cost without tacking into account the eco-taxes value;
- deduction of the supplementary expenses afferent to the eco-taxes for the two energy forms;
- calculation of the two energy forms production including the eco-taxes;
- determination of the percentage increasing of the production cost calculated with the eco-taxes.

For the case analysis we have made the next hypothesis:

- the considered energy production solutions use the same fuel: natural gas;
- the deduction of the liquidation for the two energy forms is made agree to the hypothesis which stipulates that the liquidation quotations are equal for the integer working life of the equipments;
- it was considered an hypothetical value of the qualitative eco-taxes for CO_2.

We continue with the calculation model for the production cost of the two energy forms in case of all considered energy supply solutions. Table 1 presents the characteristics of the power and heat demand of the industrial platform. Table

2 presents the principal components and the results of the technical-economical calculation.

Table 1

Characteristics of the energy demand

Measure	CHP with GT	CHP with HM	CHP with ST	SPP
E_t (MWh/an)	43645,2	43645,2	43645,2	43645,2
Q_{cg} (MWh/an)	86982	46087,8	139934,8	-
Q_v (MWh/an)	65618	106518,2	12665,8	152600
B (MWh/an)	291135	231667,3	225230,4	169555,5

Note: It was considered the installed electrical power by 14 MW and the thermal power by 80,04 MW.

Table 2

Results of the technical-economical calculation

Measure	SPP	ST	HM	GT
Investment	9.600E+06	1.973E+07	1.720E+07	1.506E+07
Expenses	3.973E+06	2.920E+06	3.053E+06	3.232E+06
Proceeds	3.052E+06	5.234E+06	5.234E+06	5.234E+06
Gross Proceeds	-9.210E+05	2.314E+06	2.181E+06	2.002E+06
Discounted Present Net Profit	-1.648E+07	-2.446E+06	-9.051E+05	1.031E+05

In the calculations realized for the determination of the eco-taxes influence on the productions costs we have used the next notations:

E_{ce} – the electric power produced every year in cogeneration, MWh/year
E_{el} – the electric power produced every year in electrical state, MWh/year;
Q_{cg} – the heat produced every year in cogeneration, MWh/year;
B_{cg} – yearly fuel consumption of the cogeneration system, MWh/year;
p_B – the price of the used fuel, \$;
Q_t – the total electric power produced every year, MWh/year;
B_v – the peak fuel consumption of the installations, MWh/year;
q_{cg} – the settled heat capacity in the cogeneration, MW;
P_{cg} – the settled electric power in the cogeneration, MW;
I_B – the investment in the base installation, \$;

C_B – yearly fuel expenses, \$/year;
C_{mo} – yearly operation and maintenance expenses, \$/year;
C_{mov} – yearly operation and maintenance expenses and peak loads, \$/year;
C_B – yearly fuel expenses, \$/year;
C_A –yearly liquidation fuel expenses, \$/year;
T_{CO2} – the eco-taxes for the CO_2, \$/t CO_2;
C_{Et}– the cost of the electric power production, \$/ MWh;
C_{Qt} – the cost of the heat production, \$/ MWh.

For all cogeneration solutions we have respected the same calculation stages and the same notations, previously presented.

3. Calculation of the electrical power and heat power production cost (tacking into account the eco-taxes application)

3.1. Calculation of the electrical power and heat power production cost in case of the eco-taxes for CO_2 application for CHP with GT case

The production cost of the two energy forms will be determined here.

⇨ **Determination of the fuel expenses for the two energy forms:**

A global efficiency of the fuel use in cogeneration is defined:

$$\eta_{glcg} := \frac{(E_{cg} + Q_{cg})}{B_{cg}} \qquad \eta_{glcg} = 0.72 \qquad (1)$$

Specific fuel consumption in the cogeneration:

$$b_{cg} := \frac{1}{\eta_{glcg}} \qquad b_{cg} = 1.389 \qquad (2)$$

Specific fuel consumption for the electrical state:

$$b_{el} := \frac{B_{el}}{E_{el}} \qquad b_{el} = 5 \qquad (3)$$

Deduction of the fuel expenses for the two energy forms:

$$C_{Be} := \frac{(b_{cg} \cdot E_{cg} \cdot p_B + b_{el} \cdot E_{el} \cdot p_B)}{E_t} \qquad C_{Be} = 22.31\ \$/\text{MWh} \qquad (4)$$

$$C_{Bq} := \frac{(b_{cg} \cdot Q_{cg} \cdot p_B + B_v \cdot p_B)}{Q_t} \qquad C_{Bq} = 12.697\ \$/\text{MWh} \qquad (5)$$

⇨ **Determination of the liquidations for the two energy forms:**

A specific investment of the base grid is determined:

$$i := \frac{I_B}{(q_{cg} + P_{cg})} \qquad I = 2.167 \cdot 10^5 \$/\text{MW} \qquad (8)$$

Deduction of the liquidation expenses for the two energy forms:

$$C_{Ae} := \frac{iP_{cg}}{20 \cdot 43645.2} \qquad C_{Ae} = 3.476\$/\text{MWh} \qquad (9)$$

$$C_{Aq} := \frac{i \cdot q_{cg} + I_V}{20 \cdot 152600} \qquad C_{Aq} = 3.938\$/\text{MWh} \qquad (10)$$

⇨ **Determination of operation & maintenance cost for the two energy forms:**

A specific expense of the base grid is determined:

$$c_{mo} := \frac{C_{mo}}{q_{cg} + P_{cg}} \qquad c_{mo} = 6.546 \cdot 10^3 \qquad (11)$$

Deduction of the maintenance and operation expenses for the two energy forms:

$$C_{moe} := \frac{c_{mo} \cdot p_{cg} + 2 \cdot E_{el}}{E_t} \qquad C_{moe} = 2.566\ \$/\text{MWh} \qquad (12)$$

$$C_{moq} := \frac{c_{mo} \cdot q_{cg} + C_{mov}}{Q_t} \qquad C_{moq} = 1.505\ \$/\text{MWh} \qquad (13)$$

⇨ **Determination of the eco-taxes expenses for the two energy forms:**

$$x_e := \frac{E_{cg}}{E_{cg} + Q_{cg}} \qquad x_e = 0.278 \qquad (14)$$

$$x_q := \frac{Q_{cg}}{E_{cg} + Q_{cg}} \qquad x_q = 0.722 \qquad (15)$$

$$C_{Ee} := \left(x_e \cdot e_{BCO_2} \cdot B_{cg} + e_{BCO_2} \cdot B_{el}\right) \cdot \frac{T_{CO_2}}{E_t} \qquad C_{Ee} = 4.908\$/\text{MWh} \qquad (16)$$

$$C_{Eq} := \left(x_q \cdot e_{BCO_2} \cdot B_{cg} + e_{VCO_2} \cdot B_V\right) \cdot \frac{T_{CO_2}}{Q_t} \qquad C_{Eq} = 2.712\ \$/\text{MWh} \qquad (17)$$

The production cost (without eco-taxes) is:

$$C_{EF} := C_{Be} + C_{Ae} + C_{moe} \qquad C_{Ef} = 28.325\ \$/\text{MWh} \qquad (18)$$

$$C_{Qf} := C_{Bq} + C_{Aq} + C_{moq} \qquad C_{Qf} = 18.14\ \$/\text{MWh} \qquad (19)$$

The production cost (with eco-taxes) is:

$$C_{Et} := C_{Be} + C_{Ae} + C_{moe} + C_{Ee} \qquad C_{Et} = 33.26\$\ \$/\text{MWh} \qquad (20)$$

$$C_{Qt} := C_{Bq} + C_{Aq} + C_{moq} + C_{Bq} \qquad C_{Qt} = 20.853\ \$/\text{MWh} \qquad (21)$$

The increasing of the production cost for the two energy forms due of the eco-taxes:

$$\Delta C_E := \frac{C_{Et} - C_{Ef}}{C_{Ef}} \qquad \Delta C_E = 0.173 \qquad (22)$$

$$\Delta C_Q := \frac{C_{Qt} - C_{Qf}}{C_{Qf}} \qquad \Delta C_Q = 0.15 \qquad (23)$$

3.2. Calculation of the electrical power and heat power production cost in case of the eco-taxes for CO_2 application for CHP with HM case

⇨ **Deduction of the fuel expenses for the two energy forms:**

A global efficiency of the fuel used in cogeneration is defined:

$$\eta_{glcg} := \frac{(E_{cg} + Q_{cg}}{B_{cg}} \qquad \eta_{glcg} = 0.792 \qquad (24)$$

Specific fuel consumption in the cogeneration:

$$b_{cg} := \frac{1}{\eta_{glcg}} \qquad b_{cg} = 1.263 \qquad (25)$$

Deduction of the fuel expenses for the two energy forms:

$$C_{Be} := \frac{(b_{cg} \cdot E_{cg} \cdot p_B)}{E_t} \qquad C_{Be} = 12.629 \text{"\$/MWh"} \qquad (26)$$

$$C_{Bq} := \frac{(b_{cg} \cdot Q_{cg} \cdot p_B + B_V \cdot p_B)}{Q_t} \qquad C_{Bq} = 11.569 \text{"\$/MWh"} \qquad (27)$$

⇨ **Determination of the liquidations for the two energy forms:**

A specific investment of the base grid is determined:

$$i := \frac{I_B}{(q_{cg} + P_{cg})} \qquad I = 3.409 \cdot 10^5 \text{\$/MW} \qquad (28)$$

Deduction of the liquidations for the two energy forms:

$$C_{Ae} := \frac{i \cdot P_{cg}}{20 \cdot 43645.2} \qquad C_{Ae} = 5.468 \text{ \$/MWh} \qquad (29)$$

$$C_{Aq} := \frac{i \cdot q_{cg} + I_v}{20 \cdot 152600} \qquad C_{Aq} = 3.559 \text{ \$MWh} \qquad (30)$$

⇨ **Determination of the operation and maintenance expenses for the two energy forms:**

A specific expense of the base grid is determined:

$$c_{mo} := \frac{C_{mo}}{q_{cg} + p_{cg}} \qquad c_{mo} = 2.47 \cdot 10^4 \text{\$MW} \qquad (31)$$

Deduction of the operation and maintenance expenses for the two energy forms:

$$C_{moe} := \frac{c_{mo} \cdot P_{cg}}{E_t} \qquad C_{moe} = 7.925 \text{\$/MWh} \qquad (32)$$

$$C_{moq} := \frac{c_{mo} \cdot q_{cg} + C_{mov}}{Q_t} \qquad C_{moq} = 2.558 \text{\$/MWh} \qquad (33)$$

⇨ **Determination of the eco-taxes expenses for the two energy forms:**

$$x_e := \frac{E_{cg}}{E_{cg} + Q_{cg}} \qquad x_e = 0.486 \qquad (33)$$

$$x_q := \frac{Q_{cg}}{E_{cg} + Q_{cg}} \qquad x_q = 0.514 \qquad (34)$$

$$C_{Ee} := \left(x_e \cdot e_{BCO_2} \cdot B_{cg}\right) \cdot \frac{T_{CO_2}}{E_t} \qquad C_{Ee} = 3.662\$/\text{MWh} \qquad (34)$$

$$C_{Eq} := \left(x_q \cdot e_{BCO_2} \cdot B_{cg} + e_{VCO_2} B_v\right) \cdot \frac{T_{CO_2}}{Q_t} \qquad C_{Eq} = 2.68\$/\text{MWh} \qquad (35)$$

The production cost (without eco-taxes) is:

$$C_{Ef} := C_{Be} + C_{Ae} + C_{moe} \qquad C_{Ef} = 26.021\$/\text{MWh} \qquad (36)$$

$$C_{Qf} := C_{Bq} + C_{Aq} + C_{moq} \qquad C_{Qf} = 17.687\$/\text{MWh} \qquad (37)$$

The production cost (with eco-taxes) is:

$$C_{Et} := C_{Be} + C_{Ae} + C_{moe} + C_{Be} \qquad C_{Et} = 29.684\$/\text{MWh} \qquad (38)$$

$$C_{Qt} := C_{Bq} + C_{Aq} + C_{moq} + C_{Eq} \qquad C_{Qt} = 20.367\$/\text{MWh} \qquad (39)$$

The increasing of the production cost for the two energy forms due of the eco-taxes:

$$\Delta C_E := \frac{C_{Et} - C_{Ef}}{C_{Ef}} \qquad \Delta C_E = 0.141 \qquad (40)$$

$$\Delta C_Q := \frac{C_{Qt} - C_{Qf}}{C_{Qf}} \qquad \Delta C_Q = 0.152 \qquad (41)$$

3.3. Calculation of the electrical power and heat power production cost in case of the eco-taxes for CO_2 application for CHP with ST case

⇨ Determination of the fuel expenses for the two energy forms:

$$x_{cgq} := \frac{Q_{cg}}{\frac{b_{CTE}}{b_{CT}} \cdot E_{cg} + Q_{cg}} \qquad x_{cgq} = 0.553 \qquad (42)$$

$$x_{cge} := \frac{\frac{b_{CTE}}{b_{CT}} \cdot E_{cg}}{\frac{b_{CTE}}{b_{CT}} \cdot E_{cg} + Q_{cg}} \qquad x_{cge} = 0.447 \qquad (43)$$

Deduction of the fuel expenses for the two energy forms:

$$C_{Be} := \frac{\left(B_{cg} \cdot x_{cge} \cdot p_B + B_{cd} \cdot p_B\right)}{E_t} \qquad C_{Be} = 29.625\$/\text{MWh} \qquad (44)$$

$$C_{Bq} := \frac{\left(B_{cg} \cdot x_{cgq} \cdot p_B + B_v \cdot p_B\right)}{Q_t} \qquad C_{Bq} = 7.209\text{"\$/MWh"} \qquad (45)$$

⇨ **Determination of the liquidations for the two energy forms:**

$$y_q := \frac{Q_{cg}}{\frac{c_{iCTE}}{c_{iCT}} \cdot E_{cg} + Q_{cg}} \qquad y_q = 0.524 \qquad (46)$$

$$y_e := \frac{\frac{c_{iCTE}}{c_{iCT}} \cdot E_{cg}}{\frac{c_{iCTE}}{c_{iCT}} \cdot E_{cg} + Q_{cg}} \qquad y_e = 0.476 \qquad (47)$$

$$C_{Ae} := y_e \cdot \frac{I_B}{20 \cdot E_t} \qquad C_{Ae} = 8.991\text{"\$/MWh"} \qquad (48)$$

$$C_{Aq} := y_q \cdot \frac{I_B}{20 \cdot Q_t} + \frac{I_V}{20 \cdot Q_t} \qquad C_{Aq} = 3.893\text{"\$/MWh"} \qquad (49)$$

⇨ **Determination of the operation and maintenance expenses for the two energy forms:**

$$z_q := \frac{Q_{cg}}{\frac{c_{fCTE}}{c_{fCT}} \cdot E_{cg} + Q_{cg}} \qquad z_q = 0.541 \qquad (50)$$

$$z_e := \frac{\frac{c_{fCTE}}{c_{fCT}} \cdot E_{cg}}{\frac{c_{fCTE}}{c_{fCT}} \cdot E_{cg} + Q_{cg}} \qquad z_e = 0.459 \qquad (51)$$

$$C_{moe} := z_e \cdot \frac{C_{moB}}{E_t} \qquad C_{moe} = 5.224\$/\text{MWh} \qquad (52)$$

$$C_{moq} := z_q \cdot \frac{C_{moB}}{Q_t} + \frac{C_{moV}}{Q_t} \qquad C_{moq} = 1.973\$/\text{MWh} \qquad (53)$$

⇨ **Determination of the eco-taxes expenses for the two energy forms:**

$$x_e := \frac{E_{cg}}{E_{cg} + Q_{cg}} \qquad x_e = 0.181 \qquad (54)$$

$$x_q := \frac{Q_{cg}}{E_{cg} + Q_{cg}} \qquad x_q = 0.819 \qquad (55)$$

$$C_{Te} := \left(x_e \cdot E_{BCO_2} \cdot B_{cg} + E_{ECO_2} \cdot B_{cd}\right) \cdot \frac{T_{CO_2}}{E_t} \qquad C_{Te} = 3.868\$/MWh \qquad (56)$$

$$C_{Tq} := \left(x_q \cdot E_{BCO_2} \cdot B_{cg} + E_{VCO_2} \cdot B_v\right) \cdot \frac{T_{CO_2}}{Q_t} \qquad C_{Tq} = 2.077\$/MWh \qquad (57)$$

The costs of the heat power and electrical power (without eco-taxes) are:

$$C_{Et} := C_{Be} + C_{Ae} + C_{moe} + C_{Te} \qquad C_{Et} = 47.708\$/MWh \qquad (58)$$

$$C_{Qt} := C_{Bq} + C_{Aq} + C_{moq} + C_{Tq} \qquad C_{Qt} = 15.152\$/MWh \qquad (59)$$

The increasing of the production cost for the two energy forms due of the eco-taxes is:

$$\Delta C_E := \frac{C_{Et} - C_{Ef}}{C_{Ef}} \qquad \Delta C_E = 0.088 \qquad (60)$$

$$\Delta C_Q := \frac{C_{Qt} - C_{Qf}}{C_{Qf}} \qquad \Delta C_Q = 0.159 \qquad (61)$$

⇨ The calculation of the heat power production cost in case of eco-taxes for CO_2 application for SPP case:

The production cost of the heat power is formed by the: yearly fuel expenses, yearly operation and maintenance expenses and also the investment maintenance corresponding to the respectively year.

It is considered that the liquidation is equaled divided for the working life.

The heat production cost (without eco-taxes) is:

$$C_{Qf} := \frac{\frac{I}{20} + C_B + C_{mo}}{Q_t} \qquad C_{Qf} = 14.886\$/MWh \qquad (62)$$

The heat production cost (with eco-taxes) is:

$$C_{Qt} := C_{Qf} + \frac{C_T}{Q_t} \qquad CQ_t = 17.141\$/MWh \qquad (63)$$

The increasing of the production cost for the two energy forms due of the eco-taxes is:

$$\Delta C_Q := \frac{C_{Qt} - C_{Qf}}{C_{Qf}} \qquad \Delta C_Q = 0.152 \qquad (64)$$

The production cost of the heat power is formed by the: yearly fuel expenses, yearly operation and maintenance expenses and also the investment maintenance corresponding to the respectively year.

4. Conclusions

Table 3 presents the results of the analysis. The already presented analysis showed that the eco-taxes introduction have a small influence on the electrical power production in a CHP with ST. This influence is approximately the same on the heat energy production in case of all considered energy supply solutions.

Table 3

Influence of the eco-taxes on the energy production costs

	CHP with GT	CHP with HM	CHP with ST	SPP
$C_{Q\,f}$ ($/MWh)	18,14	17,68	13,07	14,88
C_{Qt} ($/MWh)	20,85	20,36	15,15	17,14
ΔC_Q (%)	15	15,2	15,9	15,2
C_{Ef} ($/MWh)	26,35	26,02	43,84	–
C_{Et} ($/MWh)	33,26	29,68	47,7	–
ΔC_E (%)	17,3	14,1	8,8	–

The production cost reordered in case of CHP with GT or CHP with HM is smaller than that obtained in case of CHP with ST because a part of the expenses was distributed to the heat energy (which is a recovered energy) and because of the fact that the investment for CHP with ST is bigger than investments for the other solutions. The smaller production cost is recorded in case of the CHP with ST because almost part of the heat is produce in cogeneration, so with better global efficiencies. In case of all energy production solutions the eco-taxes introduction has a big influence on the energy production costs and because of that the ecological analysis of the solutions proposed in the pre-feasibility and feasibility studies can influence a lot the ranking of the solutions and the last decision.

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