THE TECHNO-ECONOMIC EFFICIENCY OF THE CHP PLANT USING SIMULTANEOUSLY RENEWABLE ENERGY RESOURCES AND CLASSIC FUELS

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The paper looks the technical aspects, the energy efficiency, environmental impact of the use both classical fuels and renewable energy resources as forms of primary energy used in the CHP plants for heat supply of urban consumers. It also highlights the advantages, disadvantages and limitations that occur simultaneously with the efficient use both classic fuels and renewable energy resources. It presents the model of calculation for the techno-economic efficiency of CHP.

The contribution of the paper lies in the new issue that is raised: setting the optimal techno-economic share of renewable energy resources compared that classic form of fuel for heat supply to urban consumers and those similar to them.

Keywords: cogeneration, heat supply, renewable energy resources, classic fuel

1. Purpose:

This paper aims to draw attention to specific aspects of conception, sizing - design - and operation of combined heat and power plants, which uses as its primary energy resources in the form of biomass and the classic fuels. It presents a model of calculation for the techno-economic efficiency of CHP, it starting from the main hypothesis of use renewable energy resources in ICG and classic fuels in ITV. It shows who the main factors are influencing the economic efficiency of such plants, starting from the last directive of the CE on high-efficiency cogeneration and on the use of renewable energy resources.

2. Heat characteristics of urban consumers

Urban heat demand is driven mainly by urban consumers, tertiary and those similar to them. It aims to heating and / or cooling and prepare hot water for sanitary purposes and domestic.

Heat demand for heating q_i is characterized by:

- size and changes over time caused by microclimatic parameters required for the enclosure (internal temperature, speed of displacement and

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relative humidity inside air) and outside macroclimatic characteristic parameters, in which there are that enclosure (outdoor temperature, solar radiation, air velocity external, solid and / or liquid precipitation);

- the required heat within the enclosure, which is constant during heating at a given temperature difference under the same outside. The value of the internal temperature is averaging 20 ... 24°C during heating (depending on the nature of the heated premises).

The demand of heat as hot water q_{hw} is characterized by a constant heat level $t_{hw} = 50°C$ and a variable flow G_{hw}, depending on the type of consumer.

During the year $\tau_u^{year} = 8760 h/year$, urban heat demand structure depends on the type of its insurance.

From the paper [1] result that in the climatic conditions specific to Romania, urban heat demand for heating and hot water consumption, as the allure is strongly influenced by climatic conditions specific to various areas of the country and its structure, characterized by the share of demand heat consumption for hot water heating from that.

Thus, are noted following the specific values the three climate zones considered in [1]:

Table 1

	Hot areas	Cold areas	Average areas
1. annual duration of the heating period, h/year	4400	5760	5080
2. average demand during the heating $(\bar{q}_w^{md})$, on the amount of calculation $(\bar{q}_w^c)$, %	0,45	0,50	0,48
3. the average demands of hot water by consumption during: ▪ Heating $(\bar{q}_{hw}^{md})$; ▪ Summer $(\bar{q}_{hw}^{md,s})$, reported on a calculation $(\bar{q}_w^c)$, %	0,23 0,15	0,19 0,20	0,18 0,16
4. average total urban demand $(\bar{q}_u^{md})$, reported at value of calculation $(\bar{q}_u^c)$, %	0,35	0,42	0,39

It appears that the annual duration of the heating period is between 4400 ... 5760 h/year, the remainder of the period summer, being 4360 … 3680 h/year. There are, however, by revealed the average relative values of heat demand, compared to those maximum considered in sizing the source by production of heat, which are:

a) Heating period: $\bar{q}_{w}^{md} = q_{w}^{md} / q_{w}^{c} = 45...50\%$,

b) for the summer: $\bar{q}_{wh}^{md,s} = q_{hw}^{md,s} / q_{w}^{c} = 15...19\%$,

c) for all year: $\bar{q}_{u}^{md} = q_{u}^{md} / q_{u}^{c} = 35...42\%$.

In other words, thermal annual average loading of a source of heat-production for urban consumers, in the weather conditions from Romania and with a weight average $q_{hw}^{md,year} / q_{u}^{c} \approx 18\%$, is between 35% (in warmer areas of the country) and 42% (in cold areas), namely an average value on country of 39%.

This shows that an investment made to deliver maximum heat demand will be used on average each year, only about 39%.

From this basic condition, determined by specific heat demand of urban Romania, should be considered the conditions by sizing of future the sources by production of heat, under the aspect type equipments and the technologies used, simultaneously with the type of primary energy use, including resources renewable energy and the typo-sizes of their rated capacity.

Finally, all these conditions will determine the technical profile, economic efficiency and environmental impact of future energy sources, whether it will be a simple a heating plant or a combined heat and power plants, in conjunction with all other elements listed above.

3. Sizing and optimal of urban CHP plant using renewable energy resources - a case example

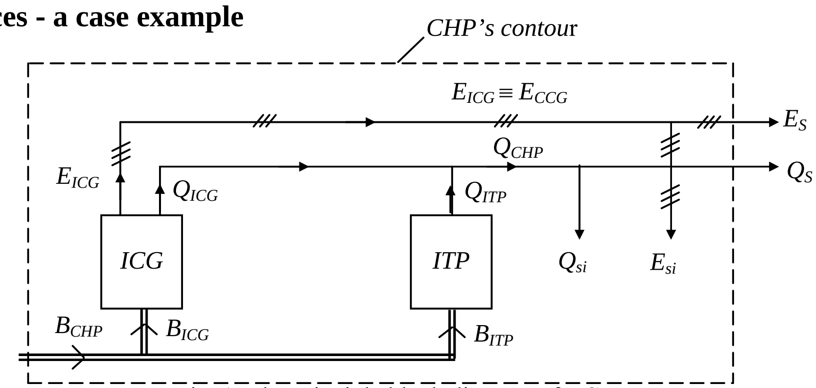

Fig. 1. The principle block diagram of a CHP
ICG - combined heat and power plant, ITP - thermal installation of peak; B_{CHP} - Fuel consumption (primary energy) of the CHP; B_{ICG}, B_{ITP} - fuel consumption of ICG, respectively ITP; E_{ICG} - electricity produced by the ICG, Q_{CHP} - heat produced in the CHP, Q_{ICG}, Q_{ITP} – heat produced by ICG, respectively ITP; E_{si}, Q_{si} - own consumption of CHP electricity, respectively heat, E_S, Q_S - electricity, respectively heat supplied by CHP [2], [3]

On the base of the block diagram by principle of a CHP, shown in figure1, the energy balances on contour are:

a) for heat produced:

- in the nominal regime, by the sizing of the CHP:

$$q_{CHP}^{n} = q_{rer,cg}^{n} + q_{cf,ITP}^{n} \text{ [kWt]} \quad (1)$$

- annual:

$$Q_{CHP} = Q_{rer,cg} + Q_{cf,ITP} \text{ [kWht /year]} \quad (2)$$

- heat structure being denoted by:

$$\alpha_{rer,t}^{n} = \frac{q_{rer,cg}^{n}}{q_{CHP}^{n}} \quad (3)$$

and respectively
$$\alpha_{rer,t} = \frac{Q_{rer,cg}}{Q_{CHP}} \quad (4)$$

- heat produced in ITV:

$$Q_{cf,ITP} = Q_{CHP} - Q_{rer,cg} = Q_{CHP} \cdot (1 - \alpha_{rer,t}) \text{ [kWht /year]} \quad (5)$$

b) for produced electricity:

- in the nominal regime, by the size of the CHP:

$$P_{CHP}^{n} = P_{cg}^{n} + P_{ncg}^{n} = P_{rer}^{n} + P_{cf}^{n} \text{ [kWe]} \quad (6)$$

- annual:

$$E_{CHP} = E_{cg} + E_{ncg} = E_{rer} + E_{cf} \text{ [kWe]} \quad (7)$$

- electricity production structure being marked with:

$$\alpha_{rer,e}^{n} = \frac{P_{rer,cg}^{n}}{P_{CHP}} \quad (8)$$

and respectively
$$\alpha_{rer,e} = \frac{E_{rer,cg}}{E_{CHP}} \quad (9)$$

Taking into account by the specific electricity production in "regime by cogeneration", due to heat produced in this regime y_{cg} for an installation (technology) of cogeneration (ICG), we can write:

- in the nominal values:

$$y_{cg}^{n} = \frac{P_{rer,cg}^{n}}{q_{rer,cg}^{n}} \text{ [kWe / kWt]} \quad (10)$$

- in the annual values:

$$y_{cg} = \frac{E_{rer,cg}}{Q_{rer,cg}} \text{ [kWhe / kWht]} \quad (11)$$

c) for total energy production, at the level the CHP, its structure is by:

- for the nominal values, by the sizing:

$$y_S^n = \frac{P_{CHP}^n}{q_{CHP}^n} \text{ [kWe / kWt]} \quad (12)$$

- in the annual values:

$$y_S = \frac{E_{CHP}}{Q_{CHP}} \text{ [kWhe / kWht]} \quad (13)$$

- power produced in ITV:

$$E_{cf,ncg} = E_{CHP} - E_{rer,cg} = Q_{CHP} \cdot y_S (1 - \alpha_{rer,e}) \text{ [kWht / year]} \quad (14)$$

Based on the energy balances, it follows to determine the total annual fuel consumption of the CHP. It has the structure:

$$B_{CHP} = B_{ICG} + B_{ITP} = B_{rer,cg} + B_{cf,ncg} + B_{ITP} \text{ [MWhfuel/year]}, \quad (15)$$

where:

$$B_{CHP} = \frac{E_{rer,cg} + Q_{rer,cg}}{\eta_{gl,rer}^{cg}} + \frac{E_{cf,ncg}}{\eta_{gl,cf}^{ncg}} + \frac{Q_{cf,ITP}}{\eta_{ITP}} =$$

$$= Q_{CHP} \cdot \left[\alpha_{rer,t} \cdot \frac{(y_{cg} + 1)}{\eta_{gl,rer}^{cg}} + y_S \cdot \frac{1 - \alpha_{rer,e}}{\eta_{gl,cf}^{e,ncg}} + \frac{1 - \alpha_{rer,t}}{\eta_{ITP}} \right] \text{ [MWhfuel / year]} \quad (16)$$

The setting of optimal conditions by sizing and operation of the CHP makes on base the economic criterion of "discount net income” - NPV. Its general form is:

$$NPV = VB \cdot K_V - I \cdot K_i \text{ [€]} \quad (17)$$

where K_v and K_i are the coefficients by updated of gross income (VB) respectively, total investment of CHP (I). It is determine for the following conditions:

a) total revenue (V) and total annual costs (C), the income (VB) is updated for the duration of the study (t = 15 years) with a discount rate (a = 10%);

- total investment (I) are updated during the implementation of investment (t_r= 2 years) with the same discount rate (a = 10%).

In these conditions:

- income on account of sale of electricity and heat is:

$$V = V^e + V^q = (E_{rer,cg} \cdot p_{e,cg} + E_{cf,ncg} \cdot p_{e,ncg} + E_{CHP} \cdot N_{GC} \cdot v_{GC} + Q_{CHP} \cdot p_q) \text{ [€/year]} \quad (18)$$

and

$$C = \frac{C_B}{\gamma_{CB}} \cdot (1+\gamma_{CF}) = \frac{(1+\gamma_{CF})}{\gamma_{CB}} \cdot \left[B_{rer,cg} \cdot p_{rer} + (B_{cf,ncg} + B_{ITP}) \cdot p_{cf}\right] \quad [€ / \text{year}] \quad (19)$$

How $VB = V - C$ [€ / year] (20)

taking into account the relations of E_{cg}, E_{ncg}, Q_{CHP}, B_{CHP}, resulting

$$V = Q_{CHP} \cdot \left[\alpha_{rer,t} \cdot y_{cg} \cdot p_{e,cg} + y_s \cdot (1-\alpha_{rer,e}) p_{e,ncg} + y_s \cdot N_{GC} \cdot v_{GC} + p_q\right] \quad [€/\text{year}] \quad (21)$$

and

$$C = Q_{CHP} \cdot \frac{1+\gamma_{CF}}{\gamma_{CB}} \cdot \left[\alpha_{rer,t} \cdot \frac{(y_{cg}+1)}{\eta_{gl,rer}^{cg}} \cdot p_{rer} + (y_s \cdot \frac{1-\alpha_{rer,e}}{\eta_{gl,cf}^{ncg}} + \frac{1-\alpha_{rer,t}}{\eta_{ITP}}) \cdot p_{cf}\right] \quad [€/\text{year}] \quad (22)$$

Then:

$$VB = Q_{CHP} \cdot \{\left[\alpha_{rer,t} \cdot y_{cg} \cdot p_{e,cg} + y_s \cdot (1-\alpha_{rer,e}) p_{e,ncg} + y_s \cdot N_{GC} \cdot v_{GC} + p_q\right] -$$
$$- \frac{1+\gamma_{CF}}{\gamma_{CB}} \cdot \left[\alpha_{rer,t} \cdot \frac{(y_{cg}+1)}{\eta_{gl,rer}^{cg}} \cdot p_{rer} + (y_s \cdot \frac{1-\alpha_{rer,e}}{\eta_{gl,cf}^{e,ncg}} + \frac{1-\alpha_{rer,t}}{\eta_{ITP}}) \cdot p_{cf}\right] \quad [€/\text{year}] \quad (23)$$

b) The total investments related to the CHP are:

$$I = I_{ICG} + I_{ITP} = I_{ICG,rer} + I_{ITP,cf} == P_{rer,cg}^{n} \cdot i_{icg,rer} + q_{ITV,cf}^{n} \cdot i_{ITV,cf} \quad [€] \quad (24)$$

Taking into account that:

$$P_{rer,cg}^{n} = q_{rer,cg}^{n} \cdot y_{cg}^{n} \quad (25)$$

$$q_{rer,cg}^{n} = q_{CHP}^{n} \cdot \alpha_{rer,t}^{n} \quad (26)$$

$$q_{ITP,cf}^{n} = q_{CHP}^{n} \cdot (1-\alpha_{rer,t}^{n}) \quad (27)$$

then equation (24) becomes:

$$I = q_{CCG}^{n} \cdot [\alpha_{rer,t}^{n} \cdot y_{rer,cg}^{n} \cdot i_{ICG,rer} + (1-\alpha_{rer,t}^{n}) \cdot i_{ITP,cf}] \quad [€] \quad (28)$$

Given relations (23) and (28) then expression (17) becomes a function of the form:

$$\text{NPV} = f\begin{pmatrix} q_{CHP}^{n}, Q_{CHP}, y_s, y_{cg}^{n}, y_{cg}, \alpha_{rer,t}^{n}, \alpha_{rer,t}, \eta_{gl,rer}^{cg}, \eta_{gl,cf}^{e,ncg}, \eta_{ITP}, \\ p_{e,cg}, p_{e,ncg}, p_q, p_{rer}, p_{cf}, N_{GC}, v_{GC}, i_{ICG,rer}, i_{cf,ITP} \end{pmatrix} \quad [€] \quad (29)$$

In the relation (29) should consider the relationship between q_{CHP}^{n} and Q_{CHP}, respectively $\alpha_{rer,t}^{n}$ and $\alpha_{rer,t}$. This is dependent on the allure of the annual thermal load ranked curve under consideration.

For an annual curve of heat load, the functions $Q_{CCG} = f(q_{CHP}^{n})$ and $\alpha_{rer,t} = f(\alpha_{rer,t}^{n})$ are known elements. Also, from the technical characteristics of installation by cogeneration (ICG) used, it result the dependency by type: $y_{cg} = f(y_{cg}^{n})$, in function by the actual annual average load.

Taking into account these dependencies, the relation (29) becomes:

$$\overline{\text{NPV}} = \frac{NPV}{q_{CHP}^{n}} \cdot 100 = f\begin{pmatrix} y_s, y_{cg}^{n}, \alpha_{rer,t}^{n}, \eta_{gl,rer}^{n(cg)}, \eta_{gl,cf}^{n(e,ncg)}, \eta_{ITP}^{n}, p_{e,cg}, p_{e,ncg}, \\ p_q, p_{rer}, p_{cf}, N_{GC}, v_{GC}, i_{ICG,rer}, i_{cf,ITP} \end{pmatrix} [€] \quad (30)$$

where $\alpha_{rer,t}^{n}$ is the variable who it must be optimized, which decides then sizing and operation of the CHP, for different values of other sizes from equation (30) and conditions of use envisaged.

4. Conclusions

- The proposed method allows optimal sizing in point of view technical - economic of a CHP using both fuels: biomass and classic fuels.
- The proposed calculation algorithm can be applied to any solutions by CHP, irrespective of: type of the consumer by heat, cogeneration technology used and operating conditions of the facilities used, economic factors such as price and specific investments.
- Optimal value of the "coefficient of cogeneration" - $\alpha_{rer,t}^{n}$ - depends, in descending order of influence on him by:
  - the relationship between the selling price of electricity $(p_{e,cg}$ and $p_{e,ncg})$ and fuels (p_{rer}, p_{cf});
  - allure annual thermal load ranked curve;
  - index CHP (y_{cg}) of CHP plants used.

R E F E R E N C E S

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NOMENCLATURE

B_{CHP}, B_{ICG}, B_{ITP}	annual consumption of primary energy in the form of renewable energy resources and classic fuels, CHP as a whole, that renewable energy resources in ICG, respective classic fuels in ITP in [kWh_t / year];
$B_{rer,cg}, B_{cf,ncg}$	annual consumption of primary energy in the form of renewable energy resources, of the ICG, for the electricity produced in cogeneration, respective classic fuels in the non – cogeneration, in [kWh_t / year];
CHP	combined heat and power plant;
E_{CHP}, E_{cg}, E_{ncg}	the total annual values of electricity, produced by the CHP, namely cogeneration and non – cogeneration, in [kWh_t / year];
ICG	the installation of cogeneration;
ITP	thermal installation of peak;
N_{GC}	number of received green certificates for electricity produced from renewable energy resources into account;
p_{rer}, p_{cf}	unit cost of fuel – biomass and classic fuels - in [€ / kWh_{cb}];
$p_{e,cg}, p_{e,ncg}$	unit cost of sales of electricity, from CHP, produced in cogeneration, respective in non-cogeneration, in [€ / kWh_e];
p_q	unit cost of sales from CHP of heat produced, in [€ / kWh_t];
$P^n_{CHP}, P^n_{cg}, P^n_{ncg}$	nominal values of the total electrical power produced by the CHP, respectively produced in cogeneration mode and non - cogeneration, in [kW_e];
Q_{CHP}, Q_{cg}, Q_{ITP}	The annual values of the quantities of heat produced respectively by the CHP, ICG (in cogeneration) and ITP in [kWh_t / year];
$q^n_{CHP}, q^n_{cg}, q^n_{ITP}$	nominal values of heat flows installed in: CHP, ICG (in cogeneration) and the peak heating systems, in [kW_t];
v_{cv}	unit value of a green certificate, in [€ ⁄ 1 GC];
V^e, V^q	CHP' s annual income on account of sale of electricity, that heat, in [€⁄year];
y^n_{cg}, y_{cg}	nominal index of cogeneration, respectively the average annual, in [kWh_e/kWh_t];
y^n_s, y_s	index structure of the energy produced in the CHP, in nominal terms, respectively the average annual, in [kWh_e/kWh_t];
α^n_e, α_e	coefficient of cogeneration, from the electrical point of view, in nominal terms, respectively year;
α^n_t, α_t	coefficient of cogeneration, from the thermal point of view, in nominal terms, respectively year;
γ_{CB}, γ_{CF}	annual fuel cost share (with renewable energy resources) in the variable annual costs, respectively annual fixed costs that the CHP' s total;
η^{cg}_{gl}	overall efficiency of ICG for cogeneration of heat production (Q_{cg}) and electricity (E_{cg});
$\eta^{e,ncg}_{ICG}$	the yield of electricity production in ICG, in scheme by the non - cogeneration;
η_{ITP}	the yield of thermal installation of peak; to produce heat.