ASSESSMENT OF COST-EFFECTIVE SOLUTIONS FOR DISTRICT HEATING SYSTEMS MODERNIZATION

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Rezumat. În analiză, se compară valoarea economiei de energie (în echivalent combustibil) realizată prin aplicarea soluției de modernizare, cu surplusul de investiții şi cheltuieli anuale necesare realizării modernizării instalațiilor şi a anexelor acestora. Se folosesc indicatorii de eficiență economică, luându-se în considerare efectele anuale, efectele economice integrale, costurile de investiții şi de exploatare. Efectele economice se analizează pe baza criteriilor: cost – beneficiu, cheltuielilor anuale, durata de recuperare a investiției, criteriul rentabilității, criteriul productivității şi termenul de recuperare a investiției. În lucrare sunt analizate problemele poluării, prețului energiei termice, precum si implicațiile economice şi de mediu ale noilor soluții privind producerea, transportul şi distribuția energiei termice. Soluțiile sunt particularizate prin studiul de caz efectuat asupra unor consumatori urbani cu date reale din sistem. Rezultatele obținute răspund cerințelor legate de reducerea costurilor privind producerea energiei termice, scăderea prețurilor la consumatorii de energie termică, reducerea emisiilor de noxe, precum şi economia investițiilor.

Cuvinte cheie: eficienţă energetică, poluare, consumatori urbani.

ABSTRACT. In this analysis, it is compared the value of energy saving (fuel equivalent) achieved by applying solutions with extra investments and annual costs needed for the modernization of equipments and their annexes. Therefore, economic efficiency indicators are used taking into consideration annual effects and integral economic effects including costs of investment and operation. Economic effects are evaluated according to the cost-benefit criterion, annual cost criterion, and pay back time criterion. In this paper, the pollution problems, price of thermal energy, as well as economic and environment implications of new solutions concerning production and distribution of thermal energy, are analysed. The solutions are particularized on a case study performed on real data of urban consumers in the system. The results meet requirements of costs reduction concerning thermal energy production, the cost reduction to consumers, emission reduction as well as investment profitability.

Keywords: economic efficiency,pollution, urban consumers.

1. INTRODUCTION

The deployment of combined heat and power (CHP) units has become a practice profitable enough. One of the problems in the selection of these units is the assessment of the economic and technical aspects. To evaluate the economic optimisation of a CHP unit the most used criteria are the net present value (NPV), the internal rate of return (IRR) and the payback period (PP).

Biezma and Cristobal [1] dealed with a review about the investment criteria for cogeneration plants. They described criteria as NPV, IRR and PP necessary for the economic optimisation in the design and operation of a combined heat and power unit (CHP).

Persson and Werner [2] examined the competitiveness of district heating taking into consideration the distribution capital. They transformed linear heat density by means of population density, specific building space, specific heat demand and effective width, in an analytical equation in order to model distribution capital cost levels in areas where there is no district heating. The study concluded that estimated capital costs are low for district heat distribution in very dense cities.

Lund et al. [3] studied the role of district heating in future Renewable Energy Systems. A detailed energy system analysis was made where CO_2 emissions and cost were calculated for various heating options, including district heating as well as individual heat pumps and micro CHPs. An optimal solution given by them was to combine a gradual expansion of district heating with individual heat pumps in the remaining houses.

Dzenajaviciene et al. [4] made an economic analysis of heat generation costs for renovation or replacement with individual heating systems of small district heating systems (DHS). The analysis includes long-run heat generating costs in natural gas and biofuel boiler houses and CHP installations, considering individual buildings and small DHS.

Economic efficiency indicators of district heat production, transport and distribution plants (Fig.1), are obtained according to mathematical calculations in which the costs are compared. These mathematical models carry out a costs comparation.

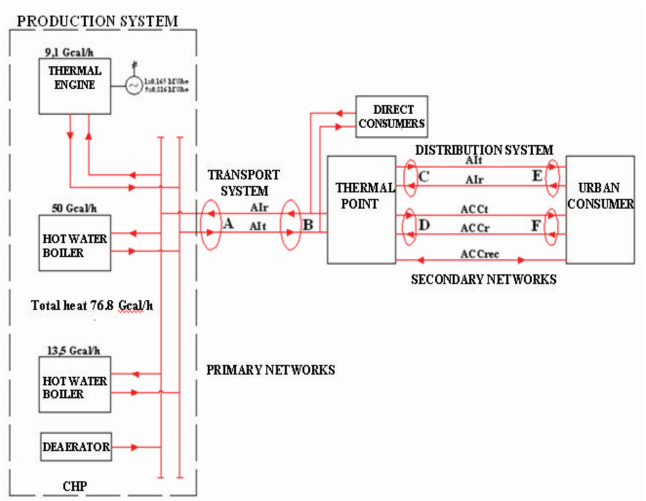

Fig.1. Layout of the district heating system

The comparative technical-economic analysis between the different energy modernization solutions supposes to apply some ranking criteria and utilization of some indicators of economic efficiency.

The indicators of economic efficiency represent a link between efforts and effects and are expressed as:

- specific efforts (costs) to obtain a unity of economic effects;
- specific effects (results) on unit of measurement of costs.

To calculate these indicators, the annual effects are taken into consideration, especially, integral economic effects, investment costs, as well as total investment and operating costs.

Considering the specific effects indicators, a bigger volume of economic effect per effort unit has to be obtained. For the specific efforts indicators, an unit of economic effects having the lowest costs has to be assured [5].

Of these, the most important indicators (criteria) which calculate the economic effects are:

- *cost-benefit* criterion;
- *annual expenses* criterion;
- *payback period* criterion;
- *profitability* criterion;
- *productivity* criterion.

2. CRITERIA FOR TECHNICAL-ECONOMIC COMPUTATIONS

2.1. Cost – benefit criterion

To determine the return of investment in a modernization solution, the cost-benefit criterion must be applied. Its application involves to calculate the internal rate of return, *IRR*. By ranking the final results of computation, many modernization solutions can be analyzed taking into account:

- the same reference level;
- the initial solution;
- the same source for financing the investment.

For an investment in modernization solution to be profitable, the limit value of annual efficiency rate rlim (discount rate) has to be established.

The main computation phases are:

- calculation of updated effective investment in the modernization plant and its annexes;
- calculation of annual revenues;
- calculation of annual operating costs;
- calculation of annual gross income;
- calculation of updated gross income;
- calculation of updated net income;
- calculation of the internal rate of capital accumulation;
- calculation of internal rate of return [5].

2.1.1. Calculation of updated effective investments in the modernization plant and its annexes

The updated effective investments $I_{ef,act}$ are written as:

$$I_{ef,act} = I_{ef} \sum_{j=1}^{d} \gamma_j (l + r)^j \text{ , [euros]} \qquad (1)$$

where:

r – discount rate, r = 8 % according to the present rules;

γ_j – total effective share of investments I_{ef} in year „j", from the execution period „d" of the analized period:

$$\gamma_j = I_{efj} / I_{ef} \qquad (2)$$

The total effective investment I_{ef} is calculated according to the following expression:

$$I_{ef} = I_r + I_{annexes}, \text{ [euros]} \qquad (3)$$

where:

I_r – investments in the modernization plants, in [euros];

$I_{annexes}$ – investments of the corresponding plants which refer to indirect investments (investments for consolidations and improvements, as well as collateral investments to assure utilities as the gas and water supply to the new modernized plants), in [euros].

Considering that the execution periods „d" for the modernization solutions are less than three years, the simplified form is written as:

$$I_{ef,act} = k_{al} \cdot I_{ef}, \text{ [euros]} \qquad (4)$$

where:

k_{al} - update operator for effective investments.

Table 1 shows the values of update operator for effective investments, for a discount rate r = 8%, considering that the effective investment is uniformly distributed in the execution period d.

Table 1

Value of update operator for effective investments, k_{al}

Execution period	**Years**	**1**	**2**	**3**
k_{al}	-	1.08	1.12	1.15

2.1.2. Calculation of annual revenues

The annual revenues IA are written as:

$$IA = \Delta B \cdot C_b, \text{ [euros/year]} \qquad (5)$$

where:

ΔB – annual fuel saving achieved by application of modernizing solution to the initial solution, in [saved fuel units/year];

C_b – saved fuel price, in [euros/unit of fuel] .

In the case of heating system in cogeneration plants, the annual revenues can be calculated with the following equation:

$$IA = E_e \cdot C_e + E_t \cdot C_t, \text{[euros/year]} \qquad (6)$$

where:

E_e – electrical energy production, in MWh/year;

C_e – electrical energy cost, in euros/MWh;

E_t – thermal energy production in Gcal/year;

C_t – thermal energy cost, in euro/Gcal.

2.1.3. Computation of annual operating (recuperation) expedintures C_{ex}, at the start up moment at nominal capacity for modernized plant

In the case of district heating system with cogeneration, these costs are composed of the sum of the following costs:

○ the maintenance and repair expedintures, which in the current computations are assessed in percent of the effective investment value:

$$C_{ir} = \beta \cdot I_{ef}, \text{ [euros/year]} \qquad (7)$$

where:

β is a coefficient (in general, β~2%);

○ the annual costs for depreciations:

$$C_a = \frac{I_{ef}}{t_{sn}}, \text{[euros/year]} \qquad (8)$$

where:

t_{sn} is the normated service period, for district heating system and is considered to be 30 years.

○ the annual costs for fuel consumption:

$$C_B = B \cdot C_b \qquad (9)$$

where:

B – annual fuel consumption in [fuel unit/year]

C_b – price of the consumed fuel, in [euros/fuel unit];

○ the annual costs for salaries of operating personnel:

$$C_s = N \cdot S, \text{ [euros/year]} \qquad (10)$$

where:

N – number of operating personnel units;

S – medium annual salary of a person, in [euros/year].

2.1.4. Calculation of annual gross income

The annual gross income VB represents the difference between the annual revenues and annual operating costs:

$$VB = IA - C_{ex}, \text{[euros/year]} \qquad (11)$$

2.1.5. Calculation of updated gross income

The updated gross income, VBA for normated period of service t_{sn} is written as:

$$VBA = VB \cdot T_{sn}^{r}, \text{[euros]} \qquad (12)$$

where:

$T_{sn}^{(r)}$ is the size updated in years and computed with the following equation:

$$T_{sn}^{(r)} = \frac{1-(1+r)^{-t_{sn}}}{r}, [\text{years}] \quad (13)$$

2.1.6. Calculation of updated net income

The updated net income, *VNA* is the difference between the updated gross income and update effective investments:

$$VNA = VBA - I_{ef,act} \, [\text{euros}] \quad (14)$$

The updated net income can be:

○ $VNA < 0$, in this case the analyzed modernization solution is unprofitable, because investments are not recovered due to gross income, on the life time of the equipment;

○ if $VNA \geq 0$, computation of profitability follows up with determination of efficiency indicators.

2.1.7. Calculation of the internal rate of capital accumulation

The internal rate of capital accumulation, *RIA* represents the ratio between the updated gross income and the updated effective investments:

$$RIA = \frac{VBA}{I_{ef,act}} \quad (15)$$

The internal rate of capital accumulation can be:

○ if $RIA < 1$, the return on investment solution is not profitable because the updated investment cannot be recovered;

○ if $RIA \geq 1$, the return on investment solution is efficient in terms of *VBA* and the computation is followed up.

2.1.8. Calculation of internal rate of return

From the following equation:

$$VBA - I_{ef,act} = 0, [\text{euros}] \quad (16)$$

In limit conditions, the internal rate of return is given by:

$$\left(T_{sn}^{(r)}\right)_{\lim} = \frac{I_{ef,act}}{VB} \quad (17)$$

Taking into consideration Eq. (17), the discount rate limit is:

$$r_{\lim} = IRR \quad (18)$$

Final analysis of profitability of modernization solution is made by comparing *IRR* with *r* with the following possibilities:

○ if $IRR < r$, investment in the modernization solution is not profitable;

○ if $IRR = r$, investment is at the profitability limit;

○ if $IRR > r$, investment is profitable.

In the case of comparing many solutions, the optimal solution is with the highest value *IRR*.

To quantize the ecologic effect of the modernization solutions, the fees for exceeding the allowable limits of pollutants can be taken into account.

2.2.Criterion of annual costs, *Z*

This criterion can be applied in terms of applying the afferent investments in a single year, of some annual operating cost as well as a study period at least equal to the life time of the equipment.

The analytical expression of this criterion is:

$$\Delta Z = Z_1 - Z_2, \; [\text{euros/year}] \quad (19)$$

or:

$$\Delta Z = \Delta I \cdot p_n + \Delta C \; , [\text{euros/year}] \quad (20)$$

where:

Z_1 and Z_2 – annual costs in the „initial” variant, respectively „with modernization”, in [euros/year];

p_n – normated coefficient of economic efficiency of investments which has the inverse value of the normated term of investments recovery $p_n=1/t_m=r$.

ΔI and ΔC – total investments differences, respectively, annual total costs between two variants, in [euros], respectively, [euros/year] computed with the following equations:

$$\Delta I = I_1 - I_2 \; ,[\text{euros}] \quad (21)$$

$$\Delta C = C_1 - C_2 \; , \; [\text{euros/year}] \quad (22)$$

where:

I_1, I_2 – afferent investments of „inițial” solution, respectively, „modernization”solution, in [euros] ;

C_1, C_2 – afferent costs of of „inițial” solution, respectively, „modernization”solution, in [euros/year].

The differences of investment and costs between „initial” solution and „modernization” solution are computed with the following equations:

$$\Delta I = I_{in} - (I_r + I_{annexes}), [\text{euros}] \quad (23)$$

$$\Delta C = C_{in} - (C_r + C_{annexes}), \; [\text{euros/year}] \quad (24)$$

where:

I_{in}, C_{in} – total annual investments and total annual costs afferent to part of the replaced plant or which is

available by using the modernization solution, in [euros/year];
I_r, C_r – investments and costs afferent to modernization installations, in [euros/year];
$I_{annexes}$, $C_{annexes}$ – total annual investments and total annual costs afferent to annexes of the modernization installations, in [euros/year]; these total annual costs include the costs for additional energy consumption of the annex after modernization (fans, pumps, etc.):

$$C_{in} = \Delta B \cdot c_b + \Delta C_{in}\text{, [euros/year]} \quad (25)$$

where:
ΔC_{in} – difference of annual operating costs for replaced installations by using the modernization solution, in [euros/year].
Modernization solution is efficient from the economic point of view if the condition $\Delta Z > 0$ is satisfied.
When several modernization solutions are compared, the optimum solution occurs when ΔZ has the maximum value.
In the equation of the cost difference ΔC, the fees Tap which should have been paid for not applying the solution are taken into consideration.
Thus, the equation:

$$\Delta C = C_{in} - (C_r + C_{anexe}) \quad (26)$$

has the following form:

$$\Delta C = C_{in} + Ta_p - (C_r + C_{anexe}),\ \text{[euros/year]} \quad (27)$$

2.3. Return criterion

In the market economy, profitability is one of the most important economic efficiency indicator. In practice it is called rate of return or profitability rate.
The most used formula is:

$$r = 100\frac{P}{C} \quad (28)$$

where:
r – rate of return;
P – profit,[euros];
C – production costs, [euros];.
In economic analyisis, the variant which has the highest profit is chosen. The profit summarizes purpose on the market (the final effect of any productive activity), and cost summarizes the human, material, financial resources which are consumed.

2.4. Productivity criterion

The productivity is given by the following equation:

$$W = \frac{T}{q} \quad (29)$$

where:
W – productivity, $\left[\frac{h}{Gcal}\right]$;
T – time necessary to obtain a production quantity, [hour] ;
q – amount of production obtained in a time period, [Gcal].
The variant which has the highest productivity is chosen.

2.5. The payback term

It is a synthetic indicator of economic efficiency of investments which expresses the correlation between the invested effort of capital, on the one hand and the effect obtained in the form of annual profit, on the other hand.

$$T = \frac{I}{P},\ [\text{years}] \quad (30)$$

where:
T – payback time of the invested capital, [years].;
I – invested capital, [euros];
P – annual profit, [euros].
This criterion reflects how long time in which the invested capital will be recovered in annual profit obtained [5], [6].

3. TECHNICAL-ECONOMIC ANALYSIS AND DESCRIPTION OF THE PROPOSED VARIANT

Production and distribution of thermal energy supposes important investments for modernizing the primary transport and secondary distribution networks, as well as for thermal insulation of buildings.
Technical-economic analysis was carried out for two variants depending on the medium price with which Gcal was invoiced:

- the medium invoiced price is 70 euros/Gcal; for centralized and decentralized variants, the heat supply an industrial consumer is (48,000 Gcal/year) is considered;
- the medium invoiced price is 90 euros/Gcal; for centralized and decentralized variants, the heat supply for household consumers (50,000 Gcal/year) is considered.

These variants were applied for:

- centralized system;
- decentralized system.

In this paper, among the four cases that can be extracted from the combinations of the above indicated prices and variants, only the cases with the medium invoiced price of 70 euros/Gcal (industrial consumer) are presented.

The following indicators for technical-economic analysis are taken into account as well:

- wage personnel;
- fuel used-natural gas;
- official period of service;
- production costs;
- incomes;
- profit;
- the heat produced;
- the electric power produced;
- rentability;
- payback term of the invested capital.

3.1. Centralized production variant

The centralized production variant was analyzed considering that the source of energy production of an urban district corresponds to the further requirements of heat supply which represent the heat delivery of:

- 48,000 Gcal/year for social and household consumers (schools, kindergarden, hospitals);
- 50,000 Gcal/year for agricultural consumers.

Cogeneration equipments composed by 7 internal combustion engines were installed and put into service recently, it can be said that the equipments did not wear being practically new.

To increase the energy efficiency to consumer in this variant, the investments for primary transport and secondary distribution networks have to be taken into consideration. This measure is necessary to reduce energy losses in thermal network from 43% to about 20%.

Table 2 shows the estimates concerning the total value of investment. To actualize the values for 2011, a constant value of investment in euros has been taken into account.

The secondary distribution network of hot water from distribution thermal points to consumers and the zone which have to be replaced with preinsulated pipes were proportioned according to heat requirement of consumer from the urban district.

Table 2

Investments for rehabilitation of primary network of heat transport

No.	Specifications	Value
1	Investments in primary network, [euros]	8,483,394

The investments for rehabilitation of secondary distribution networks are shown in Table 3.

Table 3

Investments for rehabilitation of secondary distribution networks

No.	Specifications	Value
1	Investments in secondary networks, [euros]	6,740,550

To make the heat consumption more efficient, besides modernization of transport and distribution networks, some buildings supplied with heat from the centralized system have to be rehabilitated.

Specific costs for thermal rehabilitation of an apartment are estimated to about 3000 euros. Table 4 shows the estimates concerning the investments necessary to increase needed to increase energy efficiency in all apartments supplied with heat from centralized system.

Table 4

Investments values for apartments

No.	Specifications	Values
1	Investment to consumers, [euros]	15,759,000

3.2. Decentralized production variant

The decentralized production variant was analyzed by partitioning the theritorial domain in three main zones.

In each of these zones, it was considered that a zonal cogeneration plant will supply the zone. The equipment in the zonal cogeneration systems is composed of an internal combustion engines (ICE) and an auxiliary boiler.

- Zone 1 will be equipped with a boiler with hot water of 50 Gcal, a boiler with hot water of 13.5 Gcal, a boiler with industrial steam of 10 Gcal and three internal combustion engines.
- Zone 2 will be supplied from a combined heating-and-power plant CHP equipped with two boilers of 10 Gcal and two internal combustion engines.
- Zone 3 will be equipped with two boilers of 10 Gcal and two internal combustion engines.

To compare the investitional effort from this variant with the centralized variant, the investment will be summed up with the investments for the other three zones.

Likewise, with the centralized production variant to increase energy efficiency to consumers in this variant, the investments for modernizing the transport and distribution networks were taken into consideration.

This measure is necessary to reduce the energy losses in thermal network from 43% to about 20%. Due to the fact that zonal systems are placed closer to the consumer, the size of transport network was reduced as well.

Table 5 shows the estimations concerning the total investments to rehabilitate the primary network of heat distribution.

Table 5

Investments to rehabilitate the primary network of thermal energy

No.	Specifications	Value
1	Investments in primary network, [euro]	7,892,630

Estimates concerning the total investment to rehabilitate secondary network of heat distribution respectively, thermal rehabilitation are the same as the centralized variant.

In addition, in the decentralized variant, the investments for equipping the new combined heating-and-power plants are taken into consideration.

Table 6 shows the estimations concerning the direct investments:

- Investments in two boilers of 10 Gcal (about 600,000 euros);
- Investments for four boilers (about 800,000 euros) and four internal combustion engines (about 972,000 euro).

Table 6

The direct investments (equipment and construction and assembly of boilers, boiler and internal combustion engines)

No.	Specifications	Value
1	Investments in equipments, [euros]	2,632,352

Table 7 shows the connection investments as investments in gas network and investments in two water treatment plants, chimneys and so on.

Table 7

Connection investments (gas network and water treatment plants)

No.	Specifications	Value
1	Connection investments, [euros]	956,922

3.3. Technical-economic computation

In the first step, the centralized system variant was analyzed considering that the medium invoiced price is 70 euros/Gcal and the heat supply for an industrial consumer is considered.

The input data necessary for computing the updated effective investments are:

- investments of the corresponding plants, $I_{annexes}$ = 6,740,550 euros;
- investments in the modernization plants, I_r=8,483,394 euros;
- discount rate, r = 8 % according to the present rules.

The input data necessary for computing the annual revenues from the fuel saving are:

- average hourly thermal capacity 20 Gcal/h;
- fuel needed before modernization 3000 m_N^3 /h;
- fuel needed after modernization 2250 m_N^3 /h;
- number of hours of DHS operating 7200h/year;
- annual fuel saving achieved by modernizing the initial solution, ΔB=5,400,000 saved fuel units/year;
- price of the consumed fuel, C_b=0.4 euros/ m_N^3 .

The input data necessary for computing the annual operating expedintures are:

- fuel consumption, C_c=16·10^6 m_N^3 /year;
- number of operating personnel units, N=70;
- medium annual salary of a person, S=4000 euros/year.

The input for the updated gross income computation is $T_{sn}^{(r)} = 30$ years.

To compute the profitability the following input data are considered:

- profit P=843,662 euros;
- production costs, C=9,094,338 euros;
- incomes, V=9,938,000 euros;
- medium invoiced price is 70 euros/Gcal;
- heat produced 98,000 Gcal/year;
- price 81 euros/MWh;
- electric power produced 38,000 MWh/year.

To compute the productivity the following data are taken into consideration:

- time necessary to obtain a production quantity, T =0.07 hours;
- amount of production obtained in a time period, q=13.6 Gcal.

In the second step, the decentralized system variant was analyzed considering that the medium invoiced price is 70 euros/Gcal and the heat is supplied to an industrial consumer.

The input data necessary for computing the updated effective investments are:

- investments of the corresponding plants, $I_{annexes}$ = 0 euros;
- investments in the modernization plants, I_r=18·10^6 euros;
- discount rate, r = 8 % according to the present rules.

The input data necessary for computing the annual revenues from the fuel saving are:

- average hourly thermal capacity 20 Gcal/h;
- fuel needed before the modernization 3000 m_N^3 /h;
- fuel needed after the modernization 2150 m_N^3 /h;
- number of hours of DHS operating 7200 h/year;
- annual fuel saving achieved by application of modernizing solution to the initial solution, ΔB=6,120,000 saved fuel units/year;
- price of the consumed fuel, C_b=0.4 euros/ m_N^3 .

The input data necessary for computing the annual operating expedintures are:

- fuel consumption, C_c=15·10^6 m_N^3 /year;
- number of operating personnel units, N=79;
- medium annual salary of a person, S=4000 euros/year.

The input for the updated gross income computation is $T_{sn}^{(r)} = 30$ years.

To compute the profitability the following input data are considered:

- profit P = 433,306 euros;
- production costs C=8,694,694 euros;
- incomes V=9,128,000 euros;
- medium invoiced price is 70 euros/Gcal;
- heat produced 98,000 Gcal/year;
- price 81 euros/MWh;
- electric power produced 28,000 MWh/year.

To compute the productivity the following data are taken into consideration:

- the time necessary to obtain a production quantity, T =0.07 hours;
- the amount of production obtained in a time period, q=13.6 Gcal.

The values obtained from the technical-economic analysis for centralized system and decentralized system for a medium invoiced price is 70 euros/Gcal are shown in Table 8.

4. CONCLUSIONS

This paper focused on some proposals concerning modernization of production, transport and distribution system for a urban territory with medium-sized population. Taking into account that in the last period a lot of consumers have been disconnected from the central heating system, the centralized system operation is becoming less and less profitable.

To capitalize the system, the centralized and decentralized variants have been analyzed for an industrial consumer. A number of results have been obtained according to the comparison indicators and the technical-economic analysis.

Considering the same official period of service of 30 years for the decentralized and centralized systems, and the same quantity of heat produced (98,000 Gcal/year), the comments on the main results are the following:

- the number of staff personnel (79 persons) in the decentralized system is slightly higher than in the centralized system (70 persons);
- the quantity of fuel used (natural gas in both cases), is higher in the centralized system (16·10^6 m_N^3 /year against 15·10^6 m_N^3 /year in the decentralized system;

Table 8

Indicators of economic efficiency for the centralized system and decentralized system for a medium invoiced price is 70 euros/Gcal

1. COST – BENEFIT CRITERION			
INDICATORS OF ECONOMIC EFFICIENCY		**Centralized system**	**Decentralized system**
Updated effective investments	$I_{ef,act} = I_{ef} \sum_{j=1}^{d} \gamma_j (l+r)^j$, [euros]	**16,441,860**	**19,680,250**
Total effective investment	$I_{ef} = I_r + I_{annexes}$, [euros]	**15,223,944**	**18,222,454**
Total effective share of investments I_{ef} in year „j", from the execution period „d" of the analyzed period	$\gamma_j = I_{efj} / I_{ef}$	**1.0000**	**1.0000**
ANNUAL REVENUES			
Annual revenues related to fuel economy achieved by application of modernization plus incomes	$IA = \Delta B \cdot C_b = V$, [euros/year]	**9,938,000**	**9,128,000**
Annual fuel economy achieved by modernization solution to the initial solution	ΔB [saved fuel units/year]	**5,400,000**	**6,120,000**
Saved fuel price	Cb [euros/unit of fuel]	**0.4**	**0.4**
ANNUAL OPERATING COSTS			
Annual operating costs	C_{ex}, [euros/year]	**9,094,338**	**8,694,694**
ANNUAL GROSS INCOME			
Annual gross income	$VB = IA - C_{ex}$, [euros/year]	**843,661.9**	**433,305.5**
UPDATED GROSS INCOME			
Updated gross income	$VBA = VB \cdot T_{sn}^{r}$,[euros]	**25,309,858**	**12,999,166**
UPDATED NET INCOME			
Updated net income	$VNA = VBA - I_{ef,act}$ [euros]	**8,867,998**	**-6,681,085**
INTERNAL RATE OF CAPITAL ACCUMULATION			
Internal rate of capital accumulation	$RIA = \frac{VBA}{I_{ef,act}}$	**1.54**	**0.66**
2. CRITERION OF ANNUAL COSTS			
Criterion of annual costs	$\Delta Z = \Delta I \cdot p_n + \Delta C$, [euros/year]	**7,719,912**	**7,722,830**
3. PROFITABILITY CRITERION			
Profitability	$r = 100 \frac{P}{C}$	**9.276782**	**4.983562**
Profit	P,[euros]	**843,661.9**	**433,305.5**
Production costs	C, [euros]	**9,094,338**	**8,694,694**
4. PRODUCTIVITY CRITERION			
Productivity	$W = \frac{T}{q}, \left[\frac{h}{Gcal}\right]$	**0.01**	**0.01**
Time necessary to obtain a production quantity	T,[h]	**0.07**	**0.,07**
Amount of production obtained in a time period	q [Gcal]	**13.61**	**13.61**
5. THE PAYBACK TERM			
Payback term	$T = \frac{I}{P}$, [years]	**18.05**	**42.05**
Value of invested capital	I [euros]	**15,223,944**	**18,222,454**
Annual profit	P [euros]	**843,662**	**433,306**

- the electric power produced in the centralized system is 26% higher than in the decentralized system, thanks to the impact of cogeneration solutions included in the modernization plans;
- both costs and revenues are higher in the centralized system, but the increase of costs in the
- centralized systems with respect to the decentralized system (4.3%) is lower than the corresponding increase of revenues (8.2%);
- the higher level of revenues in the centralized system results in an annual profit substantially higher (+48.6%) for the centralized system with respect to the decentralized system;
- the above results can be summarized by indicating that profitability in the centralized system (9.27%) is significantly higher than in the decentralized system (4.98%);
- from another point of view, also the payback time of the invested capital in the centralized system (18.05 years) is much better than in the decentralized system (42.05 years). However, the time span of the payback time is relatively long in absolute terms, and its detailed quantification would require further analysis, for instance based on the evaluation of a number of plausible scenarios, also including the incorporation of renewable energy sources in the overall energy system.

From this technical-economic analysis, it results that the centralized system is significantly more efficient than the decentralized system for an invoiced price of 70 euros/Gcal, considered as an average price level for the energy system under analysis.

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