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THE INVESTMENT REQUIRED TO IMPLEMENT THE URBAN COGENERATION PLANTS WITH GAS-STEAM COMBINED CYCLE AND ITS INFLUENCE OVER THE MAIN TECHNICAL-ECONOMIC PARAMETERS

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This paper presents the influence of the investment in the urban cogeneration plants with gas and steam combined cycle, at its implementation. After some complex calculations for the CHP plants sizing, there were presented results regarding on the influence of: ▪ the components investments, ▪ the total investment and ▪ the finance manner of the total investment over the economic efficiency and over the optimal cogeneration nominal coefficient of the CHP plants, under the conditions in which these CHP plants have possibility to sell electricity for different types of contracts.

Keywords: specific investment, economic efficiency, optimal cogeneration nominal coefficient, cogeneration plant, combined cycle, small and medium powers

List of abbreviations:

Notation	Description	UM
α_{cg}^{n}	Cogeneration nominal coefficient	-
$(\alpha_{cg}^{n})_{opt}$	Optimal value of the cogeneration nominal coefficient	-
CHP	Combined heat and power	-
ICG	Cogeneration equipment	-
ITV	Peak thermal installation	-
NPV	Net present value	€
I_T	Total investment in the CHP plant	€

1. Contributions

The purpose of this article was to present the role of the investment in CHP plants with gas-steam combined cycle for small and medium power at their implementation in Romania (investment size and its funding manner influences over the economic efficiency and load of these cogeneration plants).

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To implement the gas and steam turbines combined cycle cogeneration solutions for small and medium power in Romania, was developed a computer program based on a mathematical algorithm for its optimal sizing, taking into account the technical, economic and environmental targets set by legislation, for a study duration of 18 years.

For the technical-economic calculation is applied the most used economic criterion based on the method of discounted, Net Present Value (NPV), taking into account the funding method adopted to realize the objective pursued. The financial effort required for implementing such a cogeneration project is determined by two factors: investment costs and annual costs of the cogeneration plants with gas and steam combined cycle for small and medium power.

2. The investment needed to implement the urban cogeneration plants. The structure and determination mode

2.1 Introductory notions

The investment represents a unique expense which is advancing throughout an edifying lens that is used and can be recovered during the entire period of operation. Basically, the investment costs are useful only if they are able to produce the positive economic effects.

2.2 The structure and calculation of the investment in the cogeneration plants for small and medium powers

The total investment in the gas and steam turbines combined cycle cogeneration plants for small and medium powers (I_{total}) consists of three elements, as shown in below:

$$I_{total} = I_{icg} + I_{itv} + I_{aux} \ [€] \quad (2.1.)$$

where: I_{icg} [€] - the investment in the cogeneration equipments;

I_{itv} [€] - the investment in the peak thermal installations;

I_{aux} [€] - the investment in the auxiliary equipments, necessary for operation and commissioning of the CHP plant.

2.3 Modes of financing the investment required to implement the cogeneration plants

A. The investment covered from own funds (I_P) is calculated as below

$$I_P = k_{ip} \cdot I_{total} \ [€] \quad (2.2.)$$

where: k_{ip} [%] represents the percentage from the total investment which is covered from own funds;

I_{total} [€] represent the total investment in the CHP plants.

B. The investment is covered from bank loans. The determination manner of the annual costs with the bank loan returns for investment (C_{loan})

At the CHP plants implementation, the total investment required can be covered not only from own fund, but also partially or totally from bank loans. In this case, the costs for returning the bank loan are determined according to the follow relation:

$$C_{loan} = C_{repayment} + C_{interest} \left[\frac{€}{year}\right] \tag{2.3.}$$

where: $C_{repayment}\left[\frac{€}{year}\right]$ represent the annual costs for loan repayment;

$C_{interest}\left[\frac{€}{year}\right]$ represent the annual costs with the loan interest.

Since the formulas for the repayment of a bank loan and interest accrued thereon heavily dependent by the institution providing these loans, these were estimated using specific formulas using Excel.

$$C_{repayment} = ROUND\left(-PPMT\left(d_{imp}; t^{i}_{imp}; t_{imp}; \left(I_{total} - I_{P}\right)\right)\right)\left[\frac{€}{year}\right] \tag{2.4.}$$

$$C_{interest} = ROUND\left(-ISPMT\left(d_{imp}; t^{i}_{imp}; t_{imp}; \left(I_{total} - I_{P}\right)\right)\right)\left[\frac{€}{year}\right] \tag{2.5.}$$

where: t_{imp} [years] is the time length for witch is made the bank loan;

d_{imp} [%] is the annual interest of the bank loan;

t^{i}_{imp} [years] is the year in which is calculated the interest and the repaid rate.

2.5 The specific investments in the cogeneration equipments and in the peak thermal installations of the cogeneration plants, based on a market statistical data

A. The specific investment in the cogeneration equipments

It is depending by the rated electrical capacity of these equipments. It is based on the results of a statistical analysis for determining the specific investment of this kind of equipments and it is given by:

$$i_{ICG} = 745{,}89 \cdot e^{-0{,}0028 \cdot P^{n}_{ICG}} \left[\frac{€}{kW_{el}}\right] \qquad (2.6.)$$

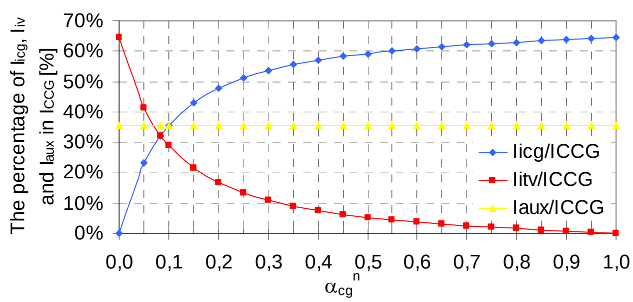
B. The specific investment in the peak thermal installations (i_{itv})

It is depending by the peak thermal installation type and its nominal capacity. Based on a statistical analysis, the investment in the peak thermal installation can be determined by the following empirical formula:

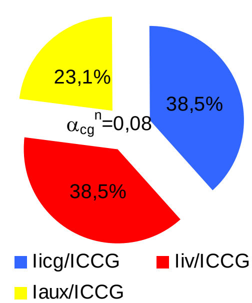
$$i_{itv} = 250 \cdot {q^{n}_{itv}}^{-0{,}13} \left[\frac{€}{kW_{t}}\right] \qquad (2.7.)$$

3. The influence of the specific investment in ICG, ITV and in the auxiliary equipments. The cover manner of the total investment from own founds or bank loans and their effect over the economic efficiency of CHP plants

Since the total investment has an important role in the decision to implement the cogeneration plants, it was pursued the influence of the specific investment modification over the economic efficiency of these CHP plants. Since the modification of the cogeneration nominal coefficient influences especially following ratios: I_{ICG}/I_{CCG} respectively I_{ITV}/I_{CCG}, it was analyzed which is the value of this coefficient for which the presented ratios have equal percentages. The results of this calculation are shown in the Fig. 3.1.



a) The variation of I_{ICG}/I_{CCG}, I_{IV}/I_{CCG} and I_{aux}/I_{CCG} depending by α^{n}_{cg}



b) $\alpha^{n}_{cg} = 0{,}08$

Fig. 3.1 The share of the component investments in the total investment of the CHP plant

From the Fig. 3.1 b) it is found that for a cogeneration nominal coefficient of 0,08, the investments in ICG and ITV have equal percentage in the total investment of the CHP plant, $\frac{I_{ICG}}{I_{CCG}} = \frac{I_{ITV}}{I_{CCG}} = 38{,}5\%$. Fig. 3.1 a) shows that the share in the total investment (of the CHP plant) which it holds the investment in ITV, I_{ITV}/I_{CCG}, decreases with increasing the nominal cogeneration coefficient, and compared with I_{aux}/I_{CCG} and especially with I_{ICG}/I_{CCG}, it is much lower for values of $\alpha_{cg}^{n} > 0{,}08$. From this point of view, it was pursued only the effect of the variation of the investment in ICG and also of the auxiliaries equipments of the CHP plant over its economic efficiency.

3.1 The variation effect of the specific investment in ICG over the economic efficiency of CHP plants

The Fig. 3.2 shows which is the investment in ICG when is changing the specific investment in ICG, for different nominal electric power of ICG.

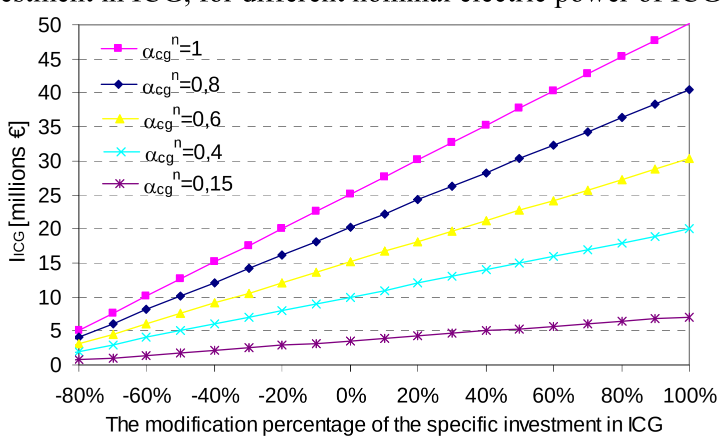


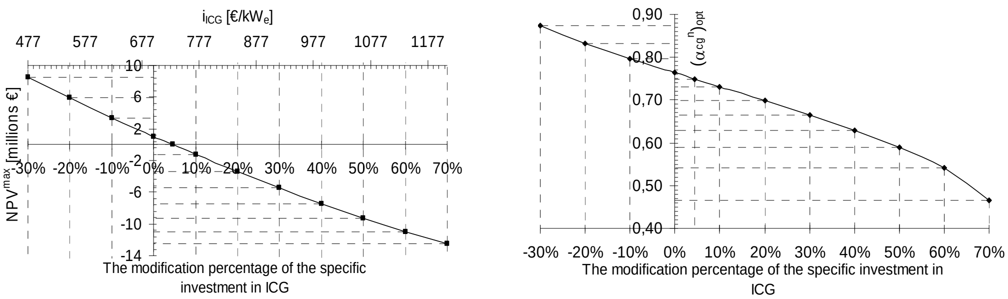
Fig. 3.2 The investment in ICG depending by the specific investment in ICG for different values of the cogeneration nominal coefficient

The Fig. 3.2 follows that with decreasing of the specific investment in the cogeneration equipment, the investment in ICG and total investment in the CHP plant decrease.

Because, increasing of the cogeneration nominal coefficient determines the increase of the nominal electric power, the specific investment in ICG decreases, accordance to the scale effect.

For example, in the Fig. 3.3 were determined NPV^{max} and $\left(\alpha_{cg}^{n}\right)_{opt}$ values for a variation domain of the specific investment in ICG comprised between

[30%, 70%], under the conditions in which the CHP plant sells electricity through regulated contracts.



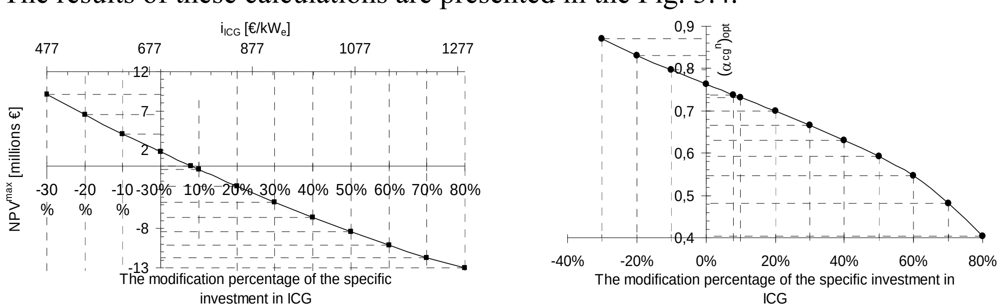
a) NPV^{max} variation depending by i_{ICG} b) $\left(\alpha_{cg}^{n}\right)_{opt}$ variation depending by i_{ICG}

Fig. 3.3 The influence of the specific investment in ICG over NPV^{max}, determined at the optimum value of the cogeneration nominal coefficient, under the condition in which the CHP plant sells electricity through regulated contracts

The Fig. 3.3 shows that when the CHP plant sells electricity through regulated contracts:

- NPV^{max} increases with decreasing of the specific investment in ICG; thus, lowering of i_{ICG} by 5% determines an increase of NPV^{max} by 113,7%;
- the CHP plant is on the breakeven point, $NPV^{max} = 0$, for an increase of i_{ICG} with 4,5%;
- the optimal value of the cogeneration nominal coefficient increases in the interval [0,47; 0,87] with decreasing of the specific investment in ICG in the interval [477, 1211] € / kWe.

When the CHP plant sells electricity only through bilateral contracts, the variations of the specific investment in ICG were made in the range [-30%, 80%]. The results of these calculations are presented in the Fig. 3.4.



a) NPV^{max} variation depending by i_{ICG} b) $\left(\alpha_{cg}^{n}\right)_{opt}$ variation depending by i_{ICG}

Fig. 3.4 The influence of the specific investment in ICG over the NPV^{max}, determined at the optimal value of the cogeneration nominal coefficient, under the condition in which the CHP plant sells electricity through bilateral contracts

It is found that when the CHP plant opts to trade electricity through bilateral contracts, it becomes profitable for higher values of the specific investment in ICG (being profitable for increases of i_{ICG} up to a maximum of 7,9%, where the CHP plant is at the breakeven point, $NPV^{max} = 0$), offering great advantages in choosing of more efficient cogeneration equipments, which are more expensive. The optimal value of the cogeneration nominal coefficient varies widely in the range [0,4; 0,87] for a ICG's specific investment variations ranging between [477; 1291] € / kWe

3.2 The variation effect of the investment in the auxiliary equipments over the economic efficiency of cogeneration plants

According to the literature, the coefficient k_{aux} is in the range 0% ÷ 65%, and it can be determined with: $k_{aux} = I_{aux} /(I_{CCG} + I_{ITV})$. Thus, it was determined which is the influence of the variation of this percentage (k_{aux}) over the ratio I_{aux} / I_T (investment in the auxiliary equipment divided by the total investment of the CHP plant). The results of this calculation are shown in the Fig. 3.5.

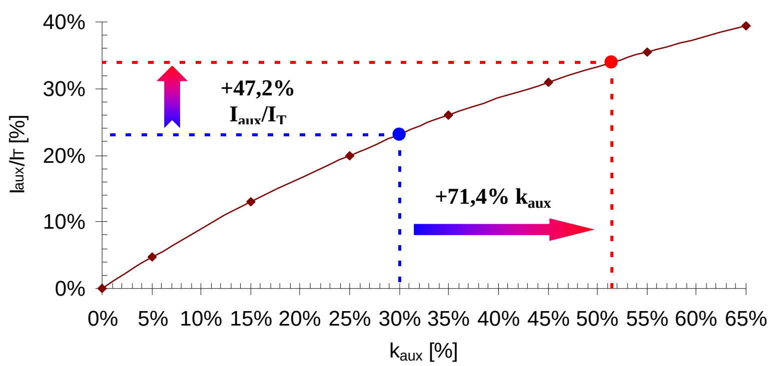


Fig. 3.5 I_{aux}/I_{CCG} variation depending by the coefficient value of k_{aux}

From the Fig. 3.5 it is found that for an increase in share of the investment in auxiliary equipments (required for the CHP plant operation) of 71,4%, it was recorded an increase in the share of I_{aux} / I_T with 47,2%. In this case, there was recorded the decrease of NPV^{max} with decreasing of the optimal cogeneration nominal coefficient.

For example, it was considered a calculation example whose results are shown in the Fig. 3.6. Thus, in the Fig. 3.6 it is shown the influence of increasing in share of the investment made in the auxiliary equipment, required for the CHP plant operation over the optimal value of the cogeneration nominal coefficient. It is found that the optimal value of the cogeneration nominal coefficient decreases approximately linearly with the increasing of k_{aux} coefficient.

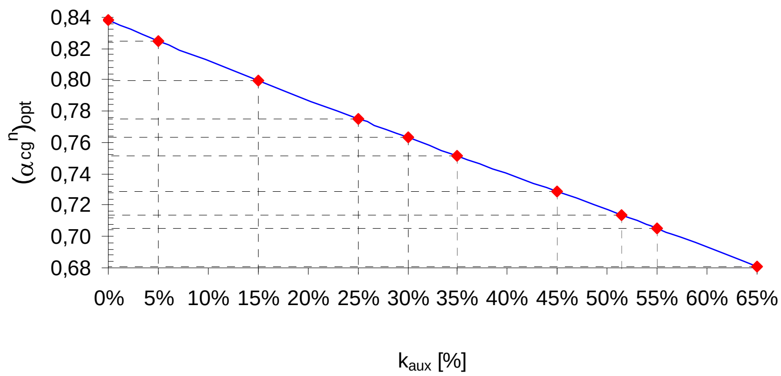


Fig. 3.6 Variation of $\left(\alpha_{cg}^{n}\right)_{opt}$ depending by the k_{aux}, under the condition in which the CHP plant sells electricity through regulated contracts

3.3 The influence manner of ensuring the total investment on the economic efficiency of the cogeneration plants

Concerning the main ways for the total investment financing, needed to implement the gas and steam turbines combined cycle cogeneration plants for small and medium power, were taken into account three variants, in which the total investment is cover:

- totally by own funds of the investor;
- totally by bank loans;
- both by own funds and by bank loans.

When the total investment is partially or totally cover by bank loans, in the calculations for establishing the optimal cogeneration solution, it arise costs with loan return (C_{imp}), taking into account the following elements:

- the percentage which shows what part of the total investment in cogeneration plant it cover by own funds and also by bank loans, k_{ip};
- the annual interest of the bank loan, d_{imp};
- the time length for which the bank loan is made, t_{imp}.

Fig. 3.7 presents the NPV^{max} variation when it is used bank loans to cover the investment in the CHP plant. It was considered the investment in the CHP plant to be totally or partially cover by a bank loan, which is made for a time period equal with the study period considered in the calculation. It was analyzed the influence of the loan size and of the loan's annual interest over NPV^{max}.

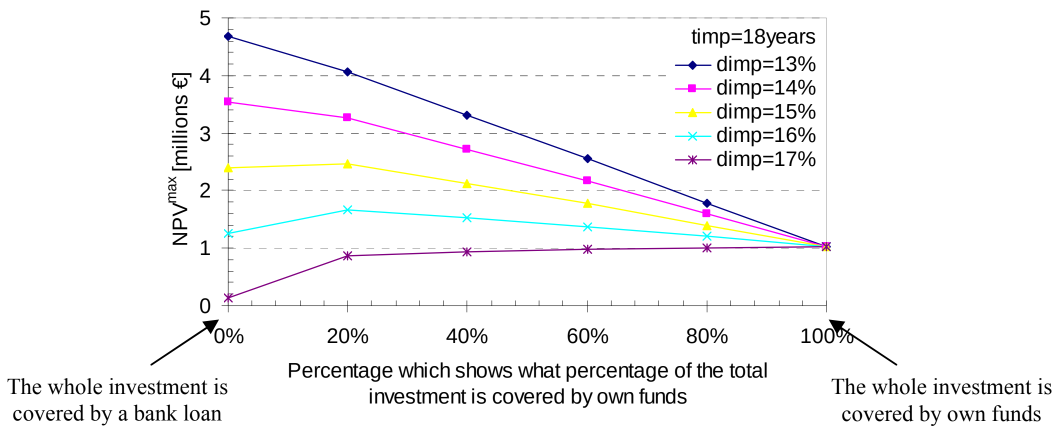


Fig. 3.7 NPV^{max} variation depending by the annual interest and by the bank loan size

Due to the higher investment effort in the CHP plants with gas/steam combined cycle for small and medium power than in the other CHP plants, in the Fig. 3.7, it is founds that NPV^{max} greatly decreases when the bank requires a higher annual interest.

Thus, in the Fig. 3.8, it was analyzed the influence of the loan size and loan period, for a given annual interest, over the NPV^{max} (it was considered an annual interest of 17%).

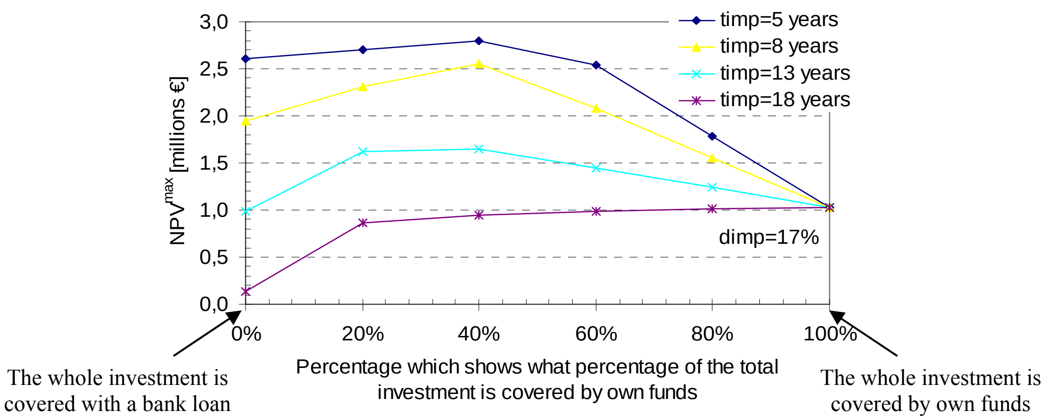
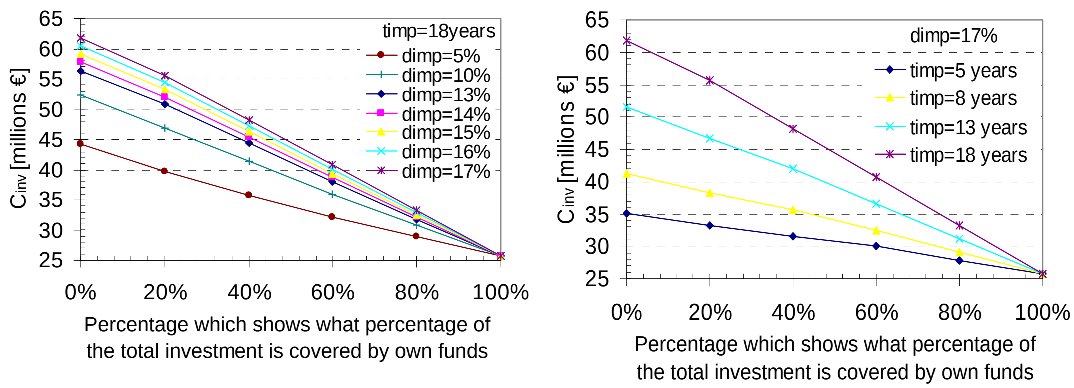


Fig. 3.8 NPV^{max} variation depending by the length and size of the bank loan

Analyzing the Figs. 3.7 and 3.8 it can be said that a higher interest loan and/or a longer time period for which is made the bank loan, always lead to lower values of NPV^{max}, obtained by implementing the CHP plant.

Also, depending on the loan's annual interest and/or the time length of the bank loan, there may be situations where the use of a bank loan to cover partially or totally the investment, will lead for cogeneration solutions more profitable.

If it is considered that the cost of investment in the cogeneration plant (C_{inv}) equal with the amount between the own funds used for investment and the costs for loan return of the investment, it can be said that the use of bank loans to cover partially or totally the investment in the CHP plant, can be regarded as an increase of the investment costs. This thing can be seen in the following calculation example, Fig. 3.9.



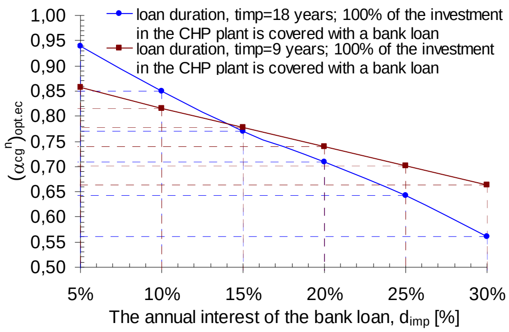
a) The bank loan period is constant b) The loan's annual interest is constant

Fig. 3.9 The variation of the investment costs depending by the interest's annual size and loan size

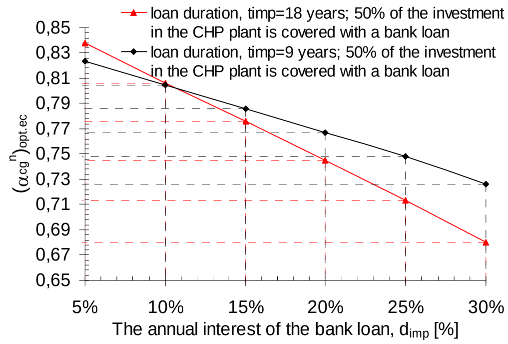
If in the technical-economic calculations is envisaged accessing for bank loans to cover partially or totally the investment in the CHP plant, the loan's annual interest and the time period for which are done, will affects both NPV^{max} and the optimal cogeneration nominal coefficient (Fig. 3.10). Thus, there were taken into account four variants, in which the optimal cogeneration nominal coefficient varies by changing the loan's annual interest:

1) the investment in the CHP plant is fully covered from a bank loan and the loan period is t_{imp} = 18 years;
2) the investment in the CHP plant is fully covered from a bank loan and the loan period is t_{imp} = 9 years
3) the loan period is t_{imp}=18 years and the investment in the CHP plant is covered:
   - 50% by a bank loan;
   - 50% by own funds.
4) the loan period is t_{imp}=9 years and the investment in the CHP plant is covered:
   - 50% by a bank loan;

- 50% by own funds.



a) The investment in the CHP plant is covered 100% by a bank loan



b) The investment in the CHP plant is covered 50% by a bank loan and 50% by own funds

Fig. 3.10 The influence of the specific variables used when it accesses bank loans over the optimal cogeneration nominal coefficient

In the calculation example presented in Fig. 3.10, has been shown the loan's annual interest modification and its influence over the optimal cogeneration nominal coefficient. The manner influence is different, depending by the loan size and time length for witch was made the loan. Thus, it appears three specific variables of a bank loan (k_{ip}, d_{imp}, t_{imp}) which are interconnected; the changing of one variable can change the influence manner of the other variables both over the NPV^{max} and $(\alpha_{cg}{}^{n})_{opt}$.

Also, from the Fig. 3.10 results that, for values of the annual interest between [5%, 30%], decreasing the period for granting the loan from 18 years to 9 years, determines modification of the optimal cogeneration nominal coefficient; the modification sense of its value (comparing these two cases) being given by the size of the annual interest and of the bank loan. Thus, at a decreasing of the bank loan from 18 years to 9 years, under the conditions in which the total investment in the CHP plant is given:

- totally from a bank loan (Fig. 3.10 a)) results that:
    - $\left(\alpha_{cg}^{n}\right)_{opt}$ decreases for $d_{imp} \in [5\%; 14\%)$;
    - $\left(\alpha_{cg}^{n}\right)_{opt}$ increases for $d_{imp} \in [14\%; 30\%]$.
- 50% by a bank loan, the rest being covered by own funds (Fig. 3.10 b)), results that:
    - $\left(\alpha_{cg}^{n}\right)_{opt}$ decreases for $d_{imp} \in [5\%; 11\%]$;
    - $\left(\alpha_{cg}^{n}\right)_{opt}$ increases for $d_{imp} \in (11\%; 30\%]$.

4 Conclusions

Since the investment in the cogeneration plants with gas-steam combined cycle for small and medium power plays an important role in the decision of its implementation, it was watched the investment influence over their economic efficiency. For this purpose there were considered variations of the investments in ICG and in the auxiliary equipment associated to the CHP plant, and there was watched the role of the investment made in the peak thermal installations.

Thus, at the variation of the specific investment in ICG, under the conditions in which the CHP plant sells electricity through:

- regulated contracts, it was demonstrated that:
  - NPV^{max} increases with decreasing the specific investment in ICG; the decrease of i_{ICG} by 5% determines an increase of NPV^{max} by 113.7% ;
  - the CHP plant is at breakeven point, $NPV^{max} = 0$, for an increase of i_{ICG} by 4,5%;
  - the optimal value of the cogeneration nominal coefficient increase with decreasing of the specific investment in ICG.
- bilateral contracts, it was demonstrated that the CHP plant becomes cost efficient for a higher specific investments in ICG, being cost effective for an increases of i_{ICG} to a maximum of 7,9% (where the CHP plant is at the breakeven point, $NPV^{max} = 0$), offering great advantages in choosing of more efficient cogeneration equipments, which are more expensive.

The share of the investment in ITV from the total investment in the CHP plant, I_{ITV} / I_{CCG}, is decreasing with increasing of the cogeneration nominal coefficient, and compared with I_{aux} / I_{CCG} and especially with I_{ICG} / I_{CCG}, it is significantly less for the most values which it can take α_{cg}^{n}. From this point of view, the effect of the investment in ITV over the economic efficiency of the CHP plant is very small.

Increasing the investment share in the auxiliary equipment simultaneously decreases the maximum net present value and the optimal cogeneration nominal coefficient.

Analyzing the financing manner of the total investment over the economic efficiency of the CHP plant, when it was used the amounts from bank loans to cover partially or totally the investment in the CHP plant, it was found that:

- ✓ a higher loan's annual interest and/or a longer time period of the bank loan, always drives to lower values of NPV^{max};
- ✓ depending by the loan's annual interest and/or the time length of the bank loan, there may be situations where the use of a bank loan to cover totally or partially the total investment, will lead to more profitable cogeneration solutions;
- ✓ for annual interest values between [5%, 30%], decreasing the grant duration of the bank loan from 18 years to 9 years, determines the modification of the optimal cogeneration nominal coefficient; the modification sense of its value (comparing these two cases) being given by the size of the annual interest and of the bank loan.

In conclusion, whether for the total or partial coverage of the investment in the cogeneration plants with gas-steam combined cycle for small and medium power, if it is desired to use some amounts from bank loans, for sizing, it should:

- ✓ to consider the amount that can be covered by own funds;
- ✓ to prospect the bank market and to establish the annual interest with which can be taken a loan from a bank;
- ✓ to fix a time length for which will make the bank loan.

REFERENCES

[1] *V. Athanasovici,* Tratat de inginerie termică – Alimentări cu căldură Cogenerare, Ed. Agir Publishing, Bucureşti, 2010 (Treaty of thermal engineering. Heat supply. CHP., Agir, Bucharest, 2010)
[3] Meherwan P. Boyce, Handbook for cogeneration and combined power plants", 2002
[4] ***, Gas Turbine World Handbook", 2009
[5] *M. Boyce,* Handbook for Cogeneration and Combined Cycle Power Plants, 2004
[6] *J.L. Silveira, C.E. Tuna,* Thermoeconomic analysis method for optimization of combined heat and power systems, 2003
[7] *Structural Funds, Cohesion Fund and Instrument for Pre-Accession*, Guide to cost-benefit analysis of investment projects, 2008
[8] *WECC, Northwest Power Planning Council,* „New Resource Characterization for the Fifth Power Plan: Natural Gas Combined-cycle Gas Turbine Power Plants", 2002
[9] *Zhang Beihong, Long Weiding*, An optimal sizing method for cogeneration plants, 2005
[10] *M.C. Hoară,* Eficienţa tehnico-economică a ciclului mixt gaze-abur aplicat la soluţiile de cogenerare de mică şi medie putere, Raport ştiinţific nr. 2, UPB, 2011 (The technical and economic efficiency of the gas steam combined cycle applied to the cogeneration solutions for small and medium power, Scientific Report no. 2, UPB, 2011)