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Influence of biomass cofiring on the optimal coefficient of the cogeneration share in a district heating system

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Abstract The paper presents a modified algorithm for choosing the optimal coefficient of the share of cogeneration in district heating systems taking into account additional benefits concerning the promotion of high-efficiency cogeneration and biomass cofiring. The optimal coefficient of the share of cogeneration depends first of all on the share of the heat required for preparing the hot tap water. The final result of investigations is an empirical equation describing the influence of the ratio of the heat flux for the production of hot tap water to the maximum flux for space heating and ventilation, as well as the share of chemical energy of biomass in the fuel mixture on the optimal value of the share of cogeneration in district heating systems. The approach presented in the paper may be applied both in back-pressure combined heat and power (CHP) plants and in extraction-condensing CHP plants.

Keywords: Cogeneration; Combined heat and power; District heating systems; Guarantees of origin; Biomass cofiring

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Nomenclature

- b – share of the chemical energy of biomass in the fuel mixture
 c – unit cost, PLN/unit
 C – cost, PLN
 E – production or consumption of energy, MWh or GJ
 G – amount of substance, Mg
 \dot{G} – flux of substance, kg/s
 I – capital cost, PLN
 m – ratio of heat flux for the production of hot tap water in the heating season to the maximum heat flux for space heating and ventilation
 P – profit, PLN
 t – temperature, °C
 Q – heat, GJ
 \dot{Q} – rate of heat, kW

Greek symbols

- α – coefficient of the share of cogeneration
 β – rate of repairs and maintenance costs
 δ – coefficient of the costs of auxiliary materials
 ρ – rate of fixed costs
 τ – time, h

Subscripts

- a – ambient or annual
 bio – biomass
 cer – certificates (guarantees of origin)
 $coal$ – hard coal
 E – energy
 el – electrical
 h – space heating and ventilation
 htw – hot tap water (hot water for domestic use)
 o – heating season
 s – start of heating season
 sh – space heating
 t – top water
 T – turbine
 v – ventilation

Abbreviations

- CHP – combined heat and power
 DHS – district heating systems
 HEC – high-efficiency cogeneration
 LHV – lower heating value
 PES – primary energy savings
 PLN – Polish currency
 RES – renewable energy sources

1 Introduction

The coefficient of the share of cogeneration is defined as follows:

$$\alpha_{CHP} = \frac{\dot{Q}_{T\max}}{\dot{Q}_{\max}}, \quad (1)$$

where $\dot{Q}_{T\max}$ defines the maximum heat flux transmitted by the cogeneration unit (back-pressure turbine or extraction-condensing turbine), and \dot{Q}_{\max} defines the maximum flux of heat which depends on the duration curve of the demand for heat. In district heating systems the demand for heat in the heating season, is determined by the duration curve of ambient temperature and the demand for hot tap water (hot water for domestic use). The ratio of the heat demand required for the preparation of hot tap water to the maximum flux of heat for space heating decreased in the latest two decades due, first of all, to the improvement of insulating the buildings thanks to thermomodernization. The growing share of hot tap water in the maximum demand for heat is accompanied by an increasing value of the coefficient of the share of cogeneration.

Up to now the coefficient of the share of cogeneration in district heating systems cooperating with combined heat and power (CHP) plants has been assumed to be on a rather low level, e.g., 0.45 [1]. This result has been achieved using the objective function basing on the mean annual profit resulting from the difference between the costs of the separate production of heat and electricity and the cost of CHP operation without taking into consideration additional benefits concerning the promotion of high-efficiency cogeneration, and as in the presented case the promotion of electricity production from renewable energy sources (biomass). The rather low value concerns also those cases when the ratio of heat demand for preparing hot tap water to the maximum heat flux in district heating does not exceed 10%. In contemporary district heating systems the share of the heat demand for the production of hot tap water increases, whereas the share of the heat consumption for space heating decreases [2,3]. This may lead to considerable changes in the share of cogeneration in district heating systems.

2 Heat demand in district heating systems

The basis for calculations of the demand for heat for space heating purposes and ventilation is the duration curve of external temperature in the heating

season. An adequate approximation of changes of the relative external temperature is provided by the Raiss's equation [4], which may be applied in various climatic zones and is expressed by the following expression

$$\frac{t_{as} - t_a}{t_{as} - t_{a \min}} = 1 - \sqrt[3]{\frac{\tau}{\tau_0}} + \left(\frac{\tau}{\tau_0}\right)^2 \left(1 - \sqrt{\frac{\tau}{\tau_0}}\right), \quad (2)$$

where:

- t_{as} – external temperature when the heating season starts (mostly assumed as 10–12 °C), °C;
- $t_{a \min}$ – lowest calculated external (ambient) temperature characteristic for any given climatic zone, °C;
- τ_0 – duration of the heating season, h;
- τ – time, h.

In the steady state the heat demand for heating rooms (space heating) is equal to the losses of heat through all external walls

$$\dot{Q}_{sh} = \sum_i A_i k_i (t_{in} - t_a), \quad (3)$$

where:

- \dot{Q}_{sh} – current value of the rate of heat for space heating, kW;
- A_i – surface of external walls of the building, m²;
- k_i – coefficient of heat transfer, kW/(m²K);
- t_{in} – internal temperature, °C;
- t_a – current external (ambient) temperature, °C.

The heat demand for the purpose of space heating reaches its maximum when the external temperature is at its lowest, $t_{a \min}$, characteristic for the given climatic zone, is

$$\dot{Q}_{sh \max} = \sum_i A_i k_i (t_{in} - t_{a \min}), \quad (4)$$

where $\dot{Q}_{sh \max}$ denotes maximum demand for heat for concerning space heating, ($t_a = t_{a \min}$) in kW.

Dividing both sides of Eqs. (3) and (4) and assuming that the coefficient of heat transfer may be considered as independent of the ambient temperature, we get the relative characteristic of the demand for heat required for space heating

$$\frac{\dot{Q}_{sh}}{\dot{Q}_{sh \max}} = \frac{t_{in} - t_a}{t_{in} - t_{a \min}}. \quad (5)$$

The heat flux required for ventilation, \dot{Q}_v , depends on the multiplicity of the exchange of air per unit of time and the volume of ventilated rooms is calculated by means of the equation

$$\dot{Q}_v = e n_v (M c_p) \Big|_{t_a}^{t_{in}} (t_{in} - t_a) , \quad (6)$$

where:

- \dot{Q}_v – rate of heat required for ventilation, kW;
- e – multiplicity of the exchange of air per unit of time, 1/s;
- n_v – amount of air in the ventilated rooms, kmol;
- $(M c_p) \Big|_{t_a}^{t_{in}}$ – mean specific molar heat capacity at a constant pressure within the range of the external and internal temperature, kJ/(kmol K);

and

$$n_v = \frac{p_{in} V_{in}}{R_u T_{in}} , \quad (7)$$

where:

- p_{in} – pressure inside the ventilated rooms, kPa;
- T_{in} – temperature inside the ventilated rooms, K;
- V_{in} – volume (cubature) of the ventilated rooms, m³;
- R_u – universal gas constant, kJ/(kmol·K).

The multiplicity of the exchange of air is settled by special sanitary regulations.

Applying Eq. (6) in the case of minimum external temperature (similarly as in case of space heating) and designating the maximum heat flux for ventilation, assuming also the mean specific molar heat capacity of ventilated air to be constant ($(M c_p) \Big|_{t_a}^{t_{in}} = \text{idem}$), we get the relative characteristic for the demand of heat required for ventilation

$$\frac{\dot{Q}_v}{\dot{Q}_{v \max}} = \frac{t_{in} - t_a}{t_{in} - t_{a \min}} . \quad (8)$$

Taking into account the relative characteristic of the demand for heat required for space heating (Eq. (5)) and the relative characteristic of the demand for heat required for ventilation (Eq. (8)), we get the combined relative characteristic of the demand for heat required for space heating and ventilation:

$$\frac{\dot{Q}_h}{\dot{Q}_{h \max}} = \frac{t_{in} - t_a}{t_{in} - t_{a \min}} . \quad (9)$$

Equation (9) results from the sum of heat demand for space heating and ventilation $\dot{Q}_h = \dot{Q}_{sh} + \dot{Q}_v$ and from the assumptions concerning the coefficient of heat transfer and specific heat capacity in the process of preheating the ventilating air.

It can be proved that

$$\frac{\dot{Q}_h - \dot{Q}_{h \min}}{\dot{Q}_{h \max} - \dot{Q}_{h \min}} = \frac{t_{as} - t_a}{t_{as} - t_{a \min}}, \quad (10)$$

where:

- \dot{Q}_h – current value of the rate of heat (both space heating and ventilation), kW;
- $\dot{Q}_{h \max}$ – maximum demand for rate of heat (both space heating and ventilation), kW;
- $\dot{Q}_{h \min}$ – minimum demand for rate of heat (both space heating and ventilation), kW;
- t_{as} – initial temperature of the beginning of the heating season, °C.

Applying Raiss's Eq. (2) describing the universal duration curve of ambient temperature, we may write

$$\frac{\dot{Q}_h - \dot{Q}_{h \min}}{\dot{Q}_{h \max} - \dot{Q}_{h \min}} = 1 - \sqrt[3]{\frac{\tau}{\tau_0}} + \left(\frac{\tau}{\tau_0}\right)^2 \left(1 - \sqrt{\frac{\tau}{\tau_0}}\right). \quad (11)$$

Finally, after joining Eqs. (10) and (11) we get

$$\dot{Q}_h = \dot{Q}_{h \max} \frac{t_{in} - t_{as} + (t_{as} - t_{a \min}) \left[1 - \sqrt[3]{\frac{\tau}{\tau_0}} + \left(\frac{\tau}{\tau_0}\right)^2 \left(1 - \sqrt{\frac{\tau}{\tau_0}}\right)\right]}{t_{in} - t_{a \min}}. \quad (12)$$

The average flux of heat required to preheat tap water is calculated by means of the relation

$$\dot{Q}_{htw} = \dot{G}_{htw} c_w (t_{htw} - t_{tw}), \quad (13)$$

where:

- \dot{Q}_{htw} – rate of heat required to preheat tap water, kW;
- \dot{G}_{htw} – flux of hot tap water, kg/s; c_w – specific heat of water, kJ/(kgK);
- t_{htw} – temperature of hot tap water, °C;
- t_{tw} – temperature of tap water, °C.

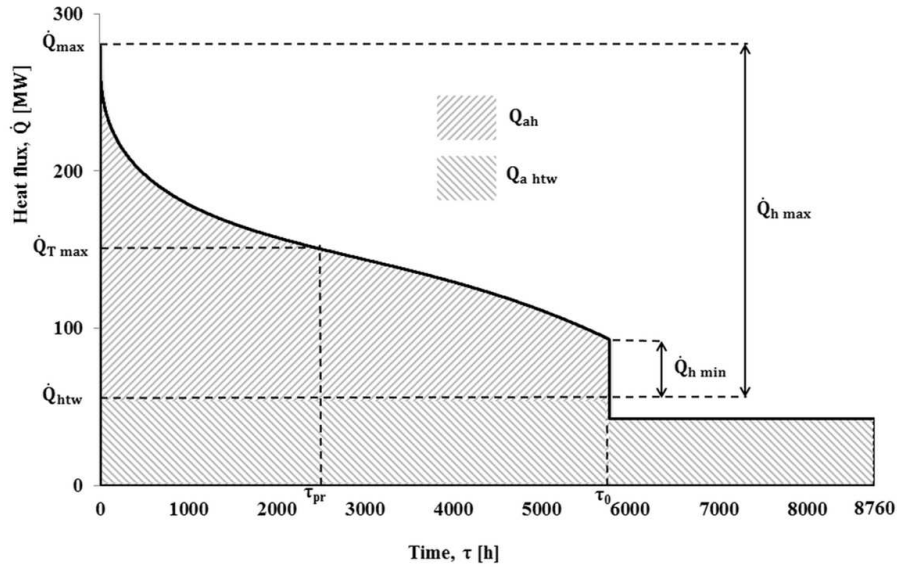


Figure 1. Duration curve of the demand for heat in the district heating system: Q_{ah} – annual demand for heat for space heating and ventilation, $Q_{ah tw}$ – annual demand for heat required to get hot tap water.

Figure 1 presents the duration curve of the demand for heat needed for heating, ventilation and the production of hot tap water. This duration curve is characterized by the following indices:

- ratio of the rate of heat for the production of hot tap water in the heating season to the maximum rate of heat for heating and ventilation purposes

$$m = \frac{\dot{Q}_{htw}}{\dot{Q}_{h \max}}, \quad (14)$$

- degree of fluctuations in the heat demand for heating and ventilation [4]:

$$m_o = \frac{\dot{Q}_{h \min}}{\dot{Q}_{h \max}}. \quad (15)$$

The ratio m will be a parameter used in further considerations. In the case of district heating the degree of fluctuations in the heat demand may be assumed to be constant.

The equations presented in this section concerning calculations of the heat demand in district heating systems (DHS) were used to construct a mathematical model (based on the duration curve of the demand for heat) of the district heating system. This model was later integrated with the mathematical model of the CHP plant and used to calculate the annual values of heat and electricity production in dependence of the parameter m [5].

3 Objective function in the algorithm of the choice of the optimal share of cogeneration in DHS

The objective function in the algorithm concerning the choice of the optimal share of cogeneration in DHS cooperating with CHP plants is the mean annual profit. This profit results from the following effects connected with the construction and operation of the CHP plant:

- construction of a heating plant became superfluous,
- power of the turbogenerator in a CHP plant replaces the equivalent power in the system power station,
- it may increase the annual costs of the heating networks due to the larger range of transporting the heat in comparison with the heating plant,
- on the other hand, however, the cost of the power grid may be reduced, because the consumers of electricity are nearer to the CHP plant producing electricity,
- in comparison with the separate production of heat and electricity in the same amounts savings in the consumption of the chemical energy of fuels can be achieved.

Moreover, the mean annual profit should include profits achieved by getting certain guarantees of origin (so called certificates) for electricity produced:

- in high-efficiency cogeneration according to the Directive 2004/8/EC [6],
- from renewable energy sources according to the Polish Direction [7],

the CHP plant gets a bonus in form of exchangeable certificates (in Poland they are called, respectively 'red certificates' and 'green certificates').

Benefits resulting from cogeneration are well known and have been confirmed by many analyses performed over the last decade. As several authors have stressed, the replacing of separate electricity and heat production by cogeneration leads to a significant reduction in the consumption of the chemical energy of fuels [8–11].

Thus, the objective function in the algorithm concerning the choice of the optimal share of cogeneration in district heating systems is expressed by the relation

$$P_a = Q_a c_{rh} + E_{ela} c_{rel} + \sum_i P_{cera i} + \Delta C_{pga} - I_{CHP}(\rho_{CHP} + \beta_{CHP}) - (\sum_j E_{cha j} c_{ch j})(1 + \delta) - C_{ea} - \Delta C_{hna} \Rightarrow \max, \quad (16)$$

where:

- P_a – mean annual profit resulting from the realization of cogeneration, PLN/a;
- Q_a – annual demand for heat, GJ;
- c_{rh} – unit cost of heat from the replaced heating plant, PLN/GJ;
- E_{ela} – net production of electricity in a CHP plant, MWh;
- c_{rel} – unit cost of electricity from the replaced power plant, PLN/MWh;
- $P_{cera i}$ – annual profit resulting from i th guarantees of origin, PLN/a;
- ΔC_{pga} – increased annual costs of the power grid if no CHP plant is constructed, PLN/a;
- I_{CHP} – investment outlay of the CHP plant, PLN;
- ρ_{CHP} – annual rate of fixed costs concerning a CHP plant;
- β_{CHP} – annual rate of costs of repairs and maintenance;
- $E_{cha j}$ – annual consumption of the chemical energy of j th fuels in a CHP plant, GJ;
- $c_{ch j}$ – unit cost of the chemical energy of j th fuel, PLN/GJ;
- δ – coefficient of the cost of auxiliary materials;
- C_{ea} – other annual costs of the exploitation of a CHP plant, PLN/a;
- ΔC_{hna} – increased annual costs of the heating network connected with the construction of the CHP unit, PLN/a.

The objective function (Eq. 16) may be simplified by eliminating those items which do not depend at all or only slightly on the coefficient of the share of cogeneration in DHS. Firstly, the term $Q_a c_{rh}$ is constant because

the annual demand for heat expressed by the duration curve (Fig. 1), as well as the unit cost of heat from the replaced heating plants are constant. Secondly, the influence of the coefficient of the share of cogeneration on the term C_{ea} concerning other annual costs of the operation of the CHP plant may be neglected, too. Thirdly, the increase of the investment outlay and exploitation costs of the heating network and the reduction of these costs concerning the power grid may also be left out of account. Thus, the variable part of the objective function depending on the value of the coefficient of the share of cogeneration was used for the purpose of optimization and it takes the following form:

$$P_a = E_{ela}c_{rel} + \sum_i P_{cera_i} - I_{CHP}(\rho_{CHP} + \beta_{CHP}) - \left(\sum_j E_{cha_j}c_{ch_j} \right) (1 + \delta) \Rightarrow \max. \quad (17)$$

Guarantees of origin – red certificates – are awarded when electricity is produced in high-efficiency cogeneration. The criterion of qualification concerning high-efficiency cogeneration depends on the value of the primary energy savings (PES) index [6] defined as

$$PES = 1 - \frac{1}{\frac{\eta_h}{\eta_{ref\ hp}} + \frac{\eta_{el}}{\eta_{ref\ ps}}}, \quad (18)$$

where:

- $\eta_{ref\ hp}$ – reference value of the energy efficiency of separate production of heat (heating plant);
- $\eta_{ref\ ps}$ – reference value of the energy efficiency of separate production of electricity;
- η_h, η_{el} – partial arithmetical efficiency of heat and electricity production in a CHP plant.

If $PES \geq 10\%$ the cogeneration unit is considered to be a high-efficiency CHP plant. The annual amount of electricity produced in a high-efficiency CHP unit (E_{HECa}) is calculated basing on [6].

Guarantees of origin – green certificates – are awarded when electricity is produced from renewable energy sources. The amount of electricity produced by renewable energy sources is related to the share of the chemical energy of biomass, and is calculated basing on [7]. The share of the chemical

energy of the biomass in the fuel mixture is defined as follows:

$$b = \frac{\sum_{i=1}^n G_{bio\ i} LHV_{bio\ i}}{\sum_{i=1}^n G_{bio\ i} LHV_{bio\ i} + \sum_{j=1}^m G_{coal\ j} LHV_{coal\ j}}, \quad (19)$$

where

- $G_{bio\ i}$ – amount of the i th kind of biomass, Mg
- $G_{coal\ j}$ – amount of some other fuels than biomass (e.g. coal), Mg
- $LHV_{bio\ i}$ – lower heating value the i th kind of biomass, MJ/Mg
- $LHV_{coal\ j}$ – lower heating value of some other fuels than biomass, MJ/Mg

The amount of electricity produced by renewable energy sources is defined in [6] and takes the following form:

$$E_{RES\ a} = b E_{el\ a}, \quad (20)$$

where:

- $E_{RES\ a}$ – annual amount of electricity produced by renewable energy sources, MWh;
- $E_{el\ a}$ – annual production of electricity, MWh.

Thus, the part of the objective function describing the annual profit resulting from i th guarantees of origin $\sum_i P_{cer\ a\ i}$ can be further written as

$$\sum_i P_{cer\ a\ i} = E_{HEC\ a} \cdot c_{cer\ HEC} + E_{RES\ a} \cdot c_{cer\ RES}, \quad (21)$$

where:

- $E_{HEC\ a}$ – annual amount of electricity produced in high-efficiency cogeneration, MWh;
- $c_{cer\ HEC}$ – unit cost of the guarantees of origin for the electricity produced in high-efficiency cogeneration, PLN/MWh;
- $c_{cer\ RES}$ – unit cost of the guarantees of origin for the electricity produced from renewable energy sources, PLN/MWh.

The variable part of the objective function together with the set of balance equations constituting a descriptive mathematical model of the CHP unit, is an optimizing mathematical model of choosing the optimal coefficient of the share of cogeneration in DHS. It has been used to develop a computer code by means of the Engineering Equation Solver.

4 Description of the computer code

The mentioned computer software is based on implemented equations describing the individual elements of the system by mass and energy balances. For a proper operation of the program the parameters ought to be determined at the characteristic points of the simplified model of a CHP plant (Fig. 2), including steam pressure in the turbine bleeds, temperature limitations in the heat exchangers, nominal efficiencies, etc. The regeneration system consists of three low-pressure regenerative heat exchangers (RH3, RH4 and RH5) and two high-pressure regenerative heat exchangers (RH1, RH2) in order to preheat the condensate prior to feeding it into the boiler (B). The heat exchanger (HE) covers the basic heat demand resulting from the characteristics of the district heating network. The peak heat demand is covered by oil-fired peak boilers (PB).

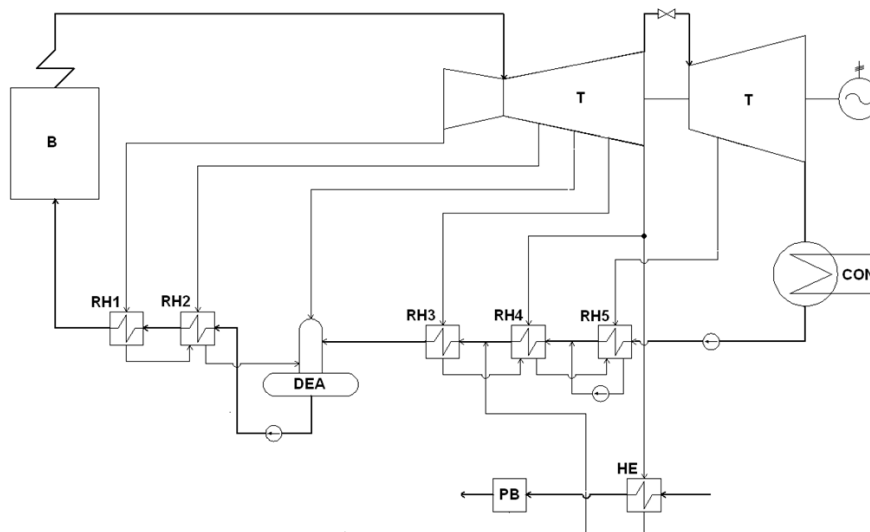


Figure 2. Simplified model of a CHP plant: B – boiler, RH1, RH2 – high-, RH3, RH4, RH5 – low-pressure regenerative heat exchangers, HE – heat exchanger, DEA – deaerator, PB – peak boiler, CON – condenser, T – turbine.

Empirical equations characterizing the change of the isentropic and electromechanical efficiency of the turbine depending on the load were introduced into the model [5]. Also the influence of biomass cofiring on the energy efficiency of the boiler has been taken into account [12]. In the case

of biomass co-fired with hard coal it takes the following form:

$$\frac{\eta_{Eb}}{\eta_{Eb0}} = 1 - 0.1515 b, \quad (22)$$

where

η_{Eb} – energy efficiency of a boiler in which biomass is co-fired,

η_{Eb0} – energy efficiency of a boiler fired only with coal.

The described model of the CHP plant was included into the already existing district heating system, for which the thermal characteristics of the heating network had been preset [5]. Also the economical model, based on the objective function, has been implemented into the computer code, which allows to calculate the values of the objective function for each set of input data, in the assumed range of the parameters m and b .

Some of the input data concerning the district heating network, CHP plant and economic data have been presented in Tab. 1. The analyzed mathematical model of the CHP plant is based on typical CHP configuration used in Polish conditions (BC-100) [1].

Table 1. Characteristic values of the CHP plant.

Input data	Value	Unit
maximum heat flux	280	MW
initial temperature at the beginning of the heating season	12	°C
lowest calculated external (ambient) temperature	- 20	°C
assumed internal temperature	20	°C
temperature of hot tap water	65	°C
temperature of hot water for heating purposes	135	°C
temperature of return water for heating purposes	65	°C
pressure of live steam in the CHP plant	13	MPa
temperature of live steam in the CHP plant	535	°C
unit cost of electricity from the replaced power plant	200	PLN/MWh
unit cost of the guarantees of origin for electricity produced in high-efficiency cogeneration	24	PLN/GJ
unit cost of the guarantees of origin for electricity produced from renewable energy sources	270	PLN/GJ
unit cost of the chemical energy of hard coal	12	PLN/GJ
unit cost of the chemical energy of biomass	29	PLN/GJ
unit cost of the chemical energy of oil (in the peak boiler)	58	PLN/GJ
annual rate of fixed costs concerning a CHP plant	0.1	-
annual rate of costs of repairs and maintenance	0.04	-
coefficient of the cost of auxiliary materials	0.1	-

The investment outlay for the CHP plant (I_{CHP}) results from the relation obtained within the frame of the research project CHP Strateg, based

on the literature review. It takes the following form [13]:

$$I_{CHP} = 12902395 N_{elB}^{0.6354}, \quad (23)$$

where the N_{elB} is expressed in MW and the I_{CHP} in EUR₂₀₁₁. Certain economic data, including the investment outlay for the CHP plant, were later taken into account in the sensitivity analysis.

5 Results of calculations and sensitivity analysis

As a result of calculations based on the mathematical model comprising DHS, CHP plant and economic the values of the objective function have been obtained in relation to the parameters m and b . Thus the optimal values of the coefficient of the share of cogeneration could then be estimated.

Practically, the share of chemical energy of the biomass in the fuel mixture applied in the co-combustion process in the boilers does not exceed the value of 0.2. Hence the assumed range concerning the value b is 0–0.2. The low value of the parameter m results from the traditional building practice. Higher values of this parameter are due to thermomodernization of buildings leading to a reduction of the demand for heating purposes.

Figure 3 presents the results of the analysis concerning the influence of the share of chemical energy of biomass in the fuel mixture on the optimal value of the coefficient of the share of cogeneration. Cofiring with biomass involves an increased value of the coefficient of the share of cogeneration by about 0.03 due to the increasing share of the chemical energy of biomass in the fuel mixture by 0.1.

An empirical equation has been derived (based on the obtained set of data) expressing the influence of biomass cofiring and the share of heat for the preparation of hot tap water on the optimal value of the share of cogeneration in district heating systems. It takes the following form:

$$\alpha_{CHP\ opt} = 0.2818m + 0.2888b + 0.6058. \quad (24)$$

The empirical Eq. (24) has been obtained basing on the results of calculations concerning the optimal values of the coefficients of cogeneration by changing the parameters m and b . The presented empirical equation may be applied in designing CHP plants co-fired with biomass and cooperating with district heating systems.

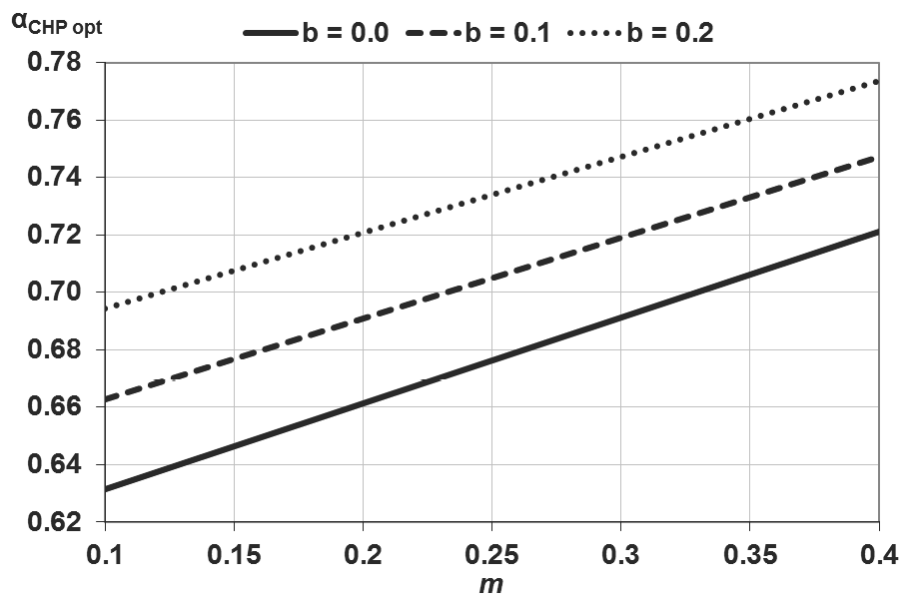


Figure 3. Dependence of $\alpha_{CHP\ opt}$ on the value m characterizing the share of heat for the production of hot tap water and on the value b characterizing the share of the chemical energy of biomass in the fuel mixture.

The influence of the main economical terms of the objective function has been assessed by means of the sensitivity analysis which consists in quantitative investigations of changes in the objective function assuming changes of these main terms in the range of $\pm 10\%$. The main terms of the objective function are: unit cost of electricity, chemical energy of hard coal and biomass, guarantees of origin (certificates) and the investment outlay of the CHP plant.

Figure 4 presents the results of the sensitivity analysis concerning the CHP unit with biomass cofiring ($m = 0.2$ and $b = 0.1$). The influence of the change of unit costs of several main elements of the objective function on the optimal value of the coefficient of the share of cogeneration has been shown. The greatest impact can be proved concerning the change of the unit cost of electricity from the replaced power plant. The second most influential parameters, are the unit cost of the chemical energy of hard coal and the investment outlay of the CHP plant. On the other hand, the influence of changes of the unit cost of guarantees of origin for high-efficiency cogeneration, can be neglected.

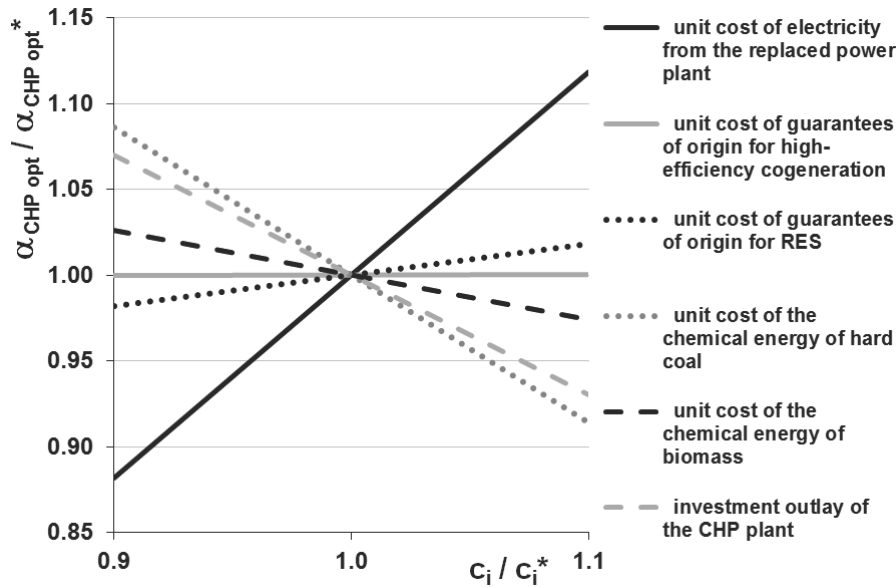


Figure 4. Results of the sensitivity analysis for the case of the parameters $m = 0.2$ and $b = 0.1$ value; upscript * denotes basic value.

6 Summary

The cogeneration part of CHP plants cooperating with district heating systems is not chosen with respect to the maximum demand for heat. The flux of heat from the cogeneration part is determined by the optimal value of the share of cogeneration, depending first of all on the share of the demand for heat concerning the preparation of hot tap water. The benefits from the certificates of origin, achieved thanks to cofiring of biomass, increase the coefficient of the share of cogeneration. The paper presents the results of the analysis of the influence of the share of biomass cofiring in the range of 0.0–0.2 in the chemical energy of the fuel mixture on the coefficient of the share of cogeneration in district heating systems. The empirical equation expressing the influence of the share of hot tap water and biomass cofiring on the optimal coefficient of the share of cogeneration has been derived. This dependence may be used in designing extraction-condensing CHP plants cooperating with district heating systems.

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