# Thermodynamical motivation of the Polish energy policy

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**Abstract**   Basing on the first and second law of thermodynamics the fundamental trends in the Polish energy policy are analysed, including the aspects of environmental protection. The thermodynamical improvement of real processes (reduction of exergy losses) is the main way leading to an improvement of the effectivity of energy consumption. If the exergy loss is economically not justified, we have to do with an error from the viewpoint of the second law analysis. The paper contains a thermodynamical analysis of the ratio of final and primary energy, as well as the analysis of the thermo-ecological cost and index of sustainable development concerning primary energy. Analyses of thermo-ecological costs concerning electricity and centralized heat production have been also carried out. The effect of increasing the share of high-efficiency cogeneration has been analyzed, too. Attention has been paid to an improved efficiency of the transmission and distribution of electricity, which is of special importance from the viewpoint of the second law analysis. The improvement of the energy effectivity in industry was analyzed on the example of physical recuperation, being of special importance from the point of view of exergy analysis.

**Keywords:** Energy policy; Energy effectiveness; Cogeneration; Waste-heat recovery; Exergy; Thermo-ecological cost; Exergy losses

## Nomenclature

$B, b$  –  exergy
$E$  –  energy

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| | | |
|---|---|---|
| $LHV$ | – | lower heating value |
| $Q$ | – | heat |
| $r$ | – | index if sustainable development |
| $R^2$ | – | index of determination |
| $T$ | – | temperature |

**Greek symbols**

| | | |
|---|---|---|
| $\delta$ | – | losses |
| $\Delta$ | – | increase |
| $\eta$ | – | efficiency |
| $\mu$ | – | multiplier of energy savings |
| $\rho$ | – | index of thermo-ecological cost |
| $\sigma$ | – | ratio of cogeneration |

**Subscripts**

| | | |
|---|---|---|
| $a$ | – | ambient |
| $B$ | – | exergy |
| $c$ | – | coal |
| $CHP$ | – | combined heat and power |
| $E$ | – | energy |
| $el$ | – | electricity |
| $f$ | – | fuel, final |
| $h$ | – | heated |
| $hp$ | – | heating plant |
| $m$ | – | mean |
| $p$ | – | primary |
| $pp$ | – | power plant |
| $Q$ | – | heat |
| $r$ | – | recuperation |
| $ref$ | – | reference |
| $s$ | – | substrates |
| $sep$ | – | separate |

# 1   Introduction

According to paragraph 15 of the Polish Energy Law the assumption of the
energy policy of the country must agree with the principle of sustainable
development and should contain, among others, an assessment of the secu-
rity of energy supply, a forecast of the demand for fuels and energy, and the
policy of rationalizing the consumption of energy, as well as activities con-
cerning environment protection. In compliance with the definition quoted
in the report on our common future, put forward by the commission of Mrs
Bruntland, the former prime minister of Norway, sustainable development
denotes such an exploitation of natural resources at present which would
ensure also the possibility of using these resources by future generations [1].

From the view-point of energy policy the sustainable development means:

- rational utilization of nonrenewable resources of primary energy,
- reduction of the hazards for the environment and warranting ecological security,
- honest conditions of competition of the availability of limited resources and the possibility of depositing contaminations.

The rationalization of the consumption of energy (including the environment) comprises, first of all, an improvement of the thermodynamic imperfections of production processes in energy engineering. Thermodynamic imperfections involve the devaluation of energy. And although in actual processes this is inevitable, it should be restricted, as far as possible, within the frame of technical possibilities and economical profitability. Exergy analysis and the observance of the 20 rules of improving the thermodynamic imperfections are adequate tools to achieve this purpose [2,3].

The crucial elements of the Polish energy policy, initiated on the turn of the 80s to the 90s of the former century together with the transformation of the political system have principally not undergone any changes. They comprise, first of all, the security of energy supply and the protection of the natural environment against negative effects of energy processes, as well as the improvement of competitiveness of the producers of energy on the Polish and international markets.

The main aims of the energy policy of the European Union (EU) are: security of the energy supply, environmental protection and ensuring the conditions of competition on energy markets. The priorities comprise the development of a common energy market, the promotion of effective utilization of energy, an increase of the competitiveness of renewable energy resources and mitigation of climatic changes (reduction of $CO_2$ emission). A comparison of these aims indicates a convergence of the energy policy of Poland and the EU.

## 2  Analysis of the possibilities of decreasing the thermodynamic imperfections of energy processes and the fundamentals of methodology

The utilization of the limited resources of nonrenewable energy ought to comply with the principle of sustainable development. This means rational utilization, keeping in mind future generations. Rationalization of the use of energy consists, first of all, in the improvement of the thermodynamic imperfections of phenomena occurring in thermal and cooling processes. Thermodynamic imperfections involve the devaluation of energy (losses of exergy). The Gouy-Stodola law determines internal exergy losses [2,4]:

$$\delta B = T_a \sum \Delta S \; , \tag{1}$$

where $T_a$ is the ambient temperature, $\sum \Delta S$ is the sum of the entropy increase values of all the kinds of matter taking part in the process.

Internal exergy losses determined in compliance with Gouy-Stodola's law are irrevocable losses and cannot even be partly recovered. Thus, in the case of processes consisting of several parts the internal exergy losses can be calculated by summing up the internal exergy losses of the particular parts. Every exergy loss contributes to an increased consumption of input energy in the process if the useful effect is constant or to a decrease of useful effect providing the input energy remains constant.

Although in real processes exergy losses are inevitable, they should be restricted as far as technically possible and economically profitable. Losses of exergy are admissible only if they are indispensable to set down the investment costs. If the loss of exergy is economically not justified, it is an error in the art of engineering from the view-point of second law. The idea of second law errors is of fundamental importance in the design of energy systems [5]. The elimination of these errors influences positively the financial effects of the project, often resulting in savings both in performance and investments. Every design which does not contain second law errors may be considered to be an optimal design. Thus, instead of requiring one global economical optimum of design, which is usually flat, and the input data (mainly the price of fuels) are uncertain, multivariant optimal designs may be taken into consideration [5].

Twenty rules concerning the ways of the improvement of thermodynamical imperfections can be applied according to [2] and [3]. Some important ones are:

- accept only those exergy losses which are indispensable for the reduction of investment costs,

- all counter-current processes are generally thermodynamically more efficient than parallel ones,

- exergy losses due to the hydraulic friction or irreversible heat transfer are the greater, the lower the temperature in the process,

- try to introduce cogeneration processes producing simultaneously two or more useful effects,

- try to reduce exergy losses in places where they are the greatest and in places where they are most expensive.
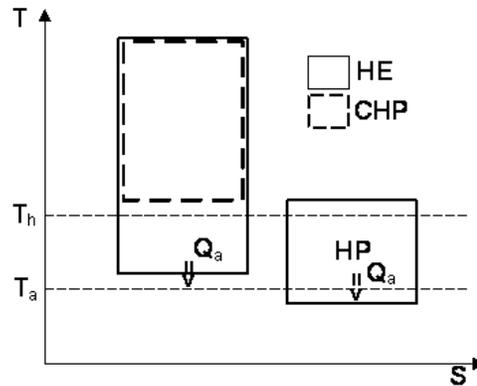


Figure 1. The idea of heat and power cogeneration; $T_h$ – temperature of the heated room; $T_a$ – ambient temperature; $Q_a$ – heat exchange with the environment; HE – heat engine; HP – heat pump; CHP – combined heat and power.

Thanks to the application of cogeneration, the chain of irreversible thermodynamic processes occurring in the separate production of heat and electricity is shortened. Figure 1 presents the idea of heat and power cogeneration basing on theoretical cycles of a heat engine and heat pump. In the case of separate heat and power production (heat pump and heat engine) two irreversible processes of heat transfer are taking place between the media in both thermal cycles and the environment. The heat $(Q_a)$ is transferred from the heat engine cycle to the environment, whereas in the heat pump the heat $(Q_a)$ is taken over from the environment. Both these irreversible phenomena may be eliminated if the expansion in the heat engine ends on the level of upper isotherm of the heat pump. In this way a combined

heat and power cycle is formed which replaces the separate production of heat and power. In combined heat and power (CHP) plants boilers with higher thermal parameters can be applied, attaining a higher exergy efficiency. A decrease of irreversibility thanks to cogeneration leads to savings in the consumption of primary fuels. Such a cycle is practically realised in
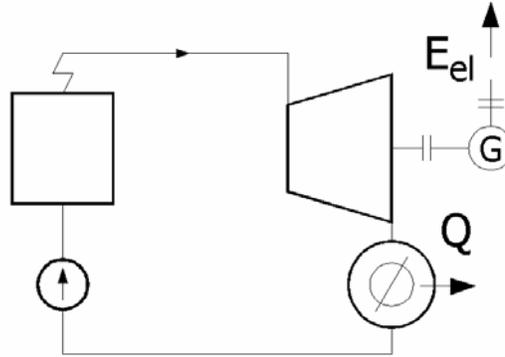


Figure 2. Diagram of a classical CHP with a back-pressure turbine. Q – ????, $E_{el}$ – ??, G – generator.

CHP plants. Figure 2 presents the diagram of a classical CHP unit with a back-pressure turbine. The energy effects of cogeneration are savings of the chemical energy of fuels, the measure of which is the index of primary energy savings (PES) [6]:

$$PES = \frac{E_{sep} - E_{CHP}}{E_{sep}} \, , \tag{2}$$

where consumption of the chemical energy of fuel concerning separate production of heat and electricity, $E_{sep}$, and in CHP plant, $E_{CHP}$, are given respectively

$$E_{sep} = Q \left( \frac{1}{\eta_{ref\,hp}} + \frac{\sigma}{\eta_{ref\,pp}} \right) \, , \tag{3}$$

$$E_{CHP} = \frac{(1 + \sigma)Q}{\eta_{E\,CHP}} \tag{4}$$

hence

$$PES = 1 - \frac{1 + \sigma}{\eta_{E\,CHP} \left( \frac{1}{\eta_{ref\,hp}} + \frac{\sigma}{\eta_{ref\,pp}} \right)} \, , \tag{5}$$

where:

| | | |
|---|---|---|
| $Q$ | – | production of heat, |
| $\sigma$ | – | ratio of cogeneration (electricity to heat), |
| $\eta_{ref\,hp}$ | – | energy efficiency of reference heating plant, |
| $\eta_{ref\,pp}$ | – | energy efficiency of reference power plant, |
| $\eta_{E\,CHP}$ | – | energy efficiency of CHP plant. |

Figure 3 illustrates the dependence of *PES* on the ratio of cogeneration and energy efficiency of CHP plants. According to the EU Directive [6] the condition $PES \geq 10\%$ is the criterion of classifying the CHP plant as high-efficiency cogeneration and assigning the certificate of origin for production of electricity in cogeneration.
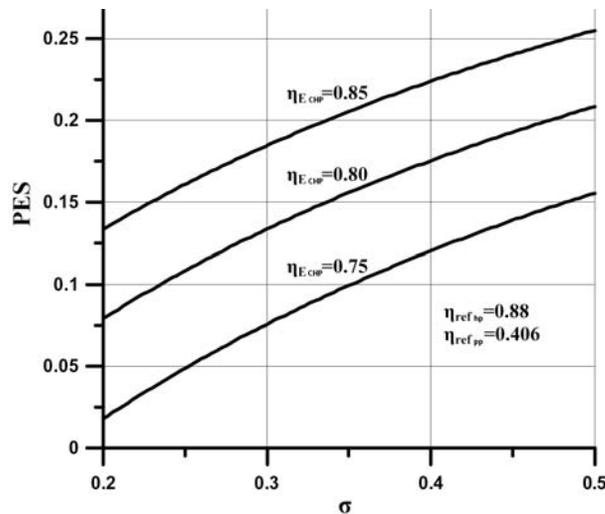


Figure 3. Index of primary energy savings (PES) of a CHP with a back-pressure turbine: $\eta_{ref\,hp}$ – energy efficiency of reference heating plant, $\eta_{ref\,pp}$ – energy efficiency of reference power plant; $\eta_{E\,CHP}$ – energy efficiency of CHP plant.

Considerable exergy losses are also due to the heat transfer between the heaters and the heated rooms. They can be reduced by the application of low-temperature (low-exergy) heating systems. In district heating cooperating with CHP, low-exergy heating systems permits to decrease the pressure of the heating steam and thus to increase the ratio of cogeneration. The application of renewable energy sources (solar energy, geothermal energy and biofuels) leads to a reduction of the losses of nonrenewable primary exergy in district heating systems. Large investments for these installations decrease the competitivity of these enterprises [7].

Every technology of electricity production has a determined potential of improvement. An increase of the thermal parameters of live steam aiming at supercritical or ultra supercritical parameters is only one factor influencing the improvement of the energy efficiency of power units. The improvement of the construction of boiler and turbine, the application of the second degree of interstage reheating, a decrease of pressure in the condenser and more intensive utilization of the enthalpy of flue gases in the boiler are other factors leading to an increase of the energy efficiency of the power unit. The technology, which in the latest thirty years attained a large progress, comprises gas cycles and mainly combined steam and gas cycles. The latter ones, making use of the advantages of the gas cycle (high upper isotherm) and steam cycle (low bottom isotherm), permit to achieve an energy efficiency of the power unit up to 60%.

The 'pinch' method may be treated as a special kind of exergy analysis. This technique permits to determine the maximum regenerative heat flux which may be exchanged between the process media, which leads to a minimum of heat fluxes which must be introduced into to the heat exchanger networks from outside. The only parameter which must be defined in the course of the 'pinch' analysis is the minimum difference of temperature between the process media (hot stream and cold stream).

In many industrial heating processes there are waste energy carriers (flue gases, technological fuel gases, vapours), which may be utilized profitably, thus decreasing the external losses of exergy. The utilization of waste energy allows to save primary fuels (coal, natural gas, fuel oil), whose rationalization often requires lower expenditures than gaining fundamental fuels. The depletion of nonrenewable natural resources is a real hazard in the global scale. Therefore, the minimization of the consumption of nonrenewable natural resources may be in near future the most important criterion in designing and the exploitation of production processes accompanied by the emission of noxious wastes, which lead to losses in the environment, whose compensation requires an additional consumption of nonrenewable natural resources. The improvement of the energy effectiveness leads to a decrease of harmful substances emitted to the environment. The overall effects of the depletion of limited nonrenewable resources used for the production of final energy carriers and compensation of the negative results of the emission of harmful substances are assessed by the index of thermo-ecological cost based on exergy analysis [2,8,9]. In order to assess various natural resources and consequently their depletion, a common measure of their quality is in-

dispensable. As far as the features characterizing the natural resources are concerned, viz. composition and concentration differing from those commonly occurring in the environment, the measure of their quality may be exergy.

Generally the indices of thermo-ecological costs should be calculated from the set of equations describing the balance of thermo-ecological costs of all goods produced in the country. But in the case of some goods (e.g., energy carriers) produced in the network of processes characterized by weak connections, the thermo-ecological cost may be calculated by means of equation [8,9]:

$$\rho = e_f(\gamma_f + \sigma_f) , \qquad (6)$$

where:
$\rho$ – index of thermo-ecological cost of considered product (e.g., heat),
$e_f$ – unit consumption of fuel,
$\gamma_f$ – ratio of the thermo-ecological cost of fuel to the chemical energy,
$\sigma_f$ – component of thermo-ecological cost concerning harmful emissions.

The thermo-ecological cost may be used to determine the coefficient of sustainable development (ratio of the thermo-ecological cost of the product to its specific exergy) [2]. The higher the value of the coefficient of sustainable development exceeding 1, the more unfavourable is the effect of the considered product on the depletion of nonrenewable natural resources. From the point of view of the depletion of nonrenewable natural resources it should be tried to decrease the coefficient of sustainable development. Such an aim should, however, be economically justified.

## 3 Polish energy policy up to 2030

The aim of the Polish energy policy is to increase the energy safety of the country complying with the principle of sustainable development [10]. Presently the Polish energy system depends to a large extent on the import of natural gas and a nearly complete external supply of crude oil. Poland's own resources of hard coal and lignite warranted up to now the electroenergy security of the country and also ensured to a large extent both the centralized and individual supply of heat. However, the obligations put upon Poland by the climatic-energy packet, accepted in 2008 by EU countries, restrict the application of coal in the Polish energy economy. Therefore, in future the Polish energy policy will be the so called 'energy mix' (similarly as the 'energy mix' of EU15), allowing to apply both large energy

systems and distributed energy systems, of course in adequate proportions. The Polish electroenergy mix ought to be based on coal and nuclear energy. Both these options do not exclude, but even supplement each other (coal-nuclear synergy). Nowadays natural gas is taken into account in the power engineering system in the peak units and stand-by units in the case of wind power plants, as well as in high-efficiency cogeneration.

Among the priority trends of the Polish energy policy the first position is taken by the improvement of the energy effectiveness, particularly:

- increase of the efficiency in the production of electricity,

- a twice as large increase of electricity production in highly efficient cogeneration technologies,

- reduction of losses in the transformation and transmission of electricity,

- higher effectiveness of the final utilization of energy, including waste energy recovery.

In the document of November 10, 2009 [10] it was stressed that rational energy management will effect essentially the improvement of the economy and its competitivity. It was also stressed that the energy security, i.e., the continuous supply of fuels and energy on a level warranting the meeting of the needs of processes accepted by producers and consumers, realized making optimally use of domestic energy resources and the improvement of the diversification in the supply of hydrocarbon fuels. When this document was issued the matter of shale-gas was not precisely settled yet.

The Polish energy policy for the years up to 2030 assumes that the development of renewable energy engineering will be one of its fundamental goals [10]. The fact that the degree of independence of the import of primary energy will not grow and that the share of renewable energy resources will increase, will involve a reduction of the thermo-ecological cost of primary energy. In spite of doubtless advantages of renewable energy resources we must keep in mind that their potential, as far as Polish conditions are concerned, is limited.

## 4  Is 'the energy policy of Poland up to the year 2030' thermodynamically motivated?

The structure of the demand for primary energy indicates in the perspective of the year 2030 a distinctly decreasing share of the chemical energy of solid fuels (about 60% in the year 2006 and about 40% in 2030) with a simultaneously increasing share of hydrocarbon fuels (about 30% in the year 2006 and about 40% in 2030), particularly renewable energy sources (about 5% in the year 2006 and about 14% in 2030). In the structure of primary energy after the year 2020 nuclear fuel will be used, the share of which will in the year 2030 reach the level of about 7%.

The growing improvement in the structure of primary energy is proven by the ratio of the final energy to the primary energy which may, with a good approximation, be identified as the efficiency of primary energy conversion. The ratio of the final energy to the primary energy presented in Fig. 4 illustrates a growing tendency from about 67% in the year 2006 to more than 71% in the last decade of forecasting, in which this ratio will stabilize. This is proven by lower curve in Fig. 4, presenting the ratio of final exergy to primary exergy. The growing tendency indicates a progressing decrease of exergy losses in the conversion of primary energy.
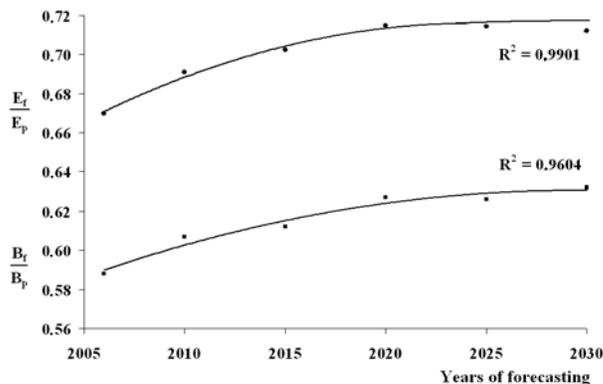


Figure 4. The ratio of the final energy $(E_f)$, and exergy $(B_f)$, to the primary energy $(E_p)$ and exergy $(B_p)$, $R^2$ – index of determination.

Figure 5 shows the thermo-ecological cost of primary energy in the course of the considered time of forecasting. Due to the growing share of renewable energy sources and imported hydrocarbon fuels, the thermo-ecological cost of primary energy will reach the value of about 37 PJ/Mtoe

in the last decade of forecasting in comparison with the basic value of 41.6 PJ/Mtoe in the year 2006.
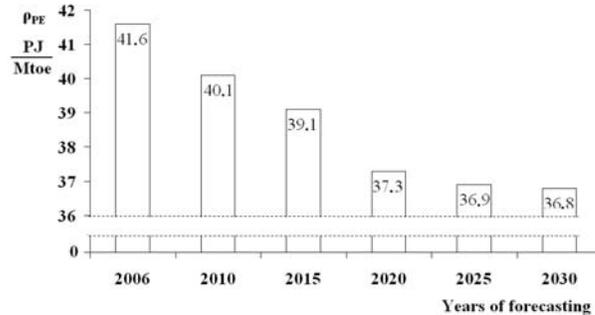


Figure 5. The thermo-ecological cost of the primary energy.

This becomes more evident in Fig. 6 illustrating the index of sustainable development in the course of the subsequent years of forecasting. From about 0.9 (in the year 2006) this index drops to the level of about 0.82 in the last decade of forecasting. This proves a more favourable structure of gaining primary energy from the view-point of the depletion of nonrenewable natural resources.
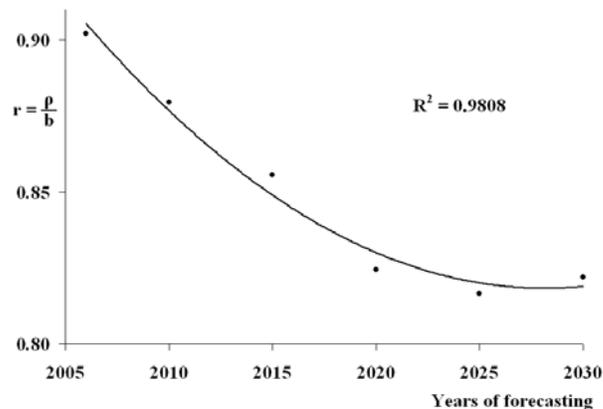


Figure 6. The index of sustainable development of primary energy: $\rho$ – thermo-ecological cost, $b$ – specific exergy.

In the structure of final energy the favourable growing tendency of the share of electricity becomes evident, which grows from 14.5% in the year 2006 to 17.5% in 2030. The level of consumption of electricity per person marks the standard of life in the given country. It is also to be observed

that the fuel component of the thermo-ecological cost of electricity decreases radically from the level of about 3.2 J/J (in the year 2006) to about 2 in the last five years of forecasting (Fig. 7). This proves a more favourable struc-
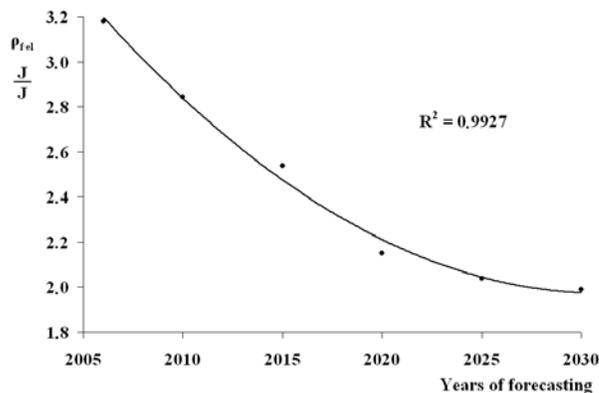


Figure 7. The fuel component of the thermo-ecological cost of electricity.

ture of input energy in processes of electricity generation in the domestic electroenergy system. Also in the transmission of electricity an improvement of its efficiency is to be observed, reaching about 2 p.p. (Fig. 8). This coincides with one of the rules of diminishing the thermodynamical imperfection, which says that the exergy of energy carriers is most expensive in the last part of process generation. This is where these processes should be improved first.
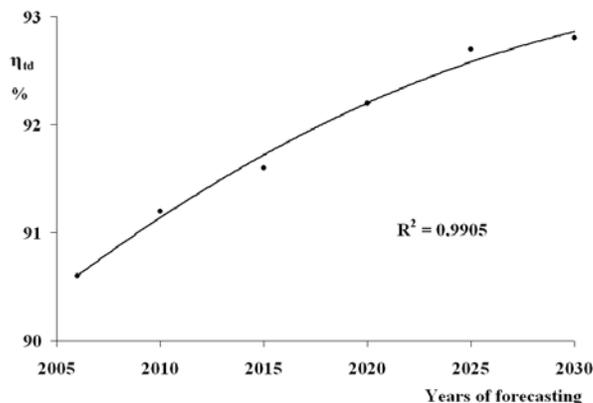


Figure 8. The efficiency of the transmission and distribution of electricity.

Figure 9 presents the course of incrementing savings of the chemical

energy of fuels achieved thanks to the increased share of electricity production in cogeneration during the period of forecasting. Up to the year 2030 a twofold increase of the share in the cogenerating production of electricity in comparison with the basic year 2006 is predicted. In result of this, the savings of cumulated energy consumption of the chemical energy of primary fuels amount to 2 Mtoe; in relation to the demand for primary energy in the year 2030, this is 1.7%.
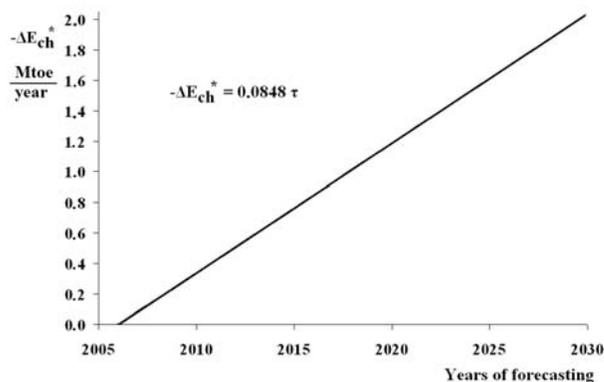


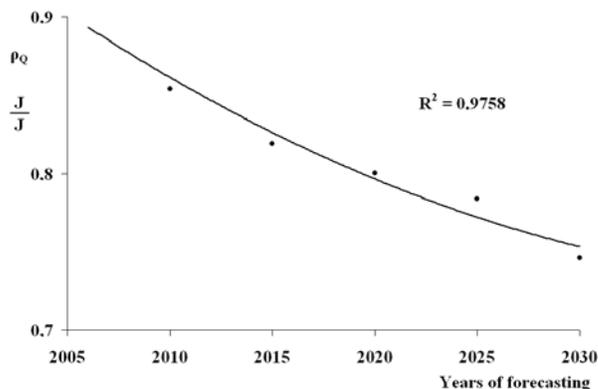Figure 9. Cumulative energy savings due to cogeneration.



Figure 10. Thermo-ecological cost of centralized heat production.

Figure 10 illustrates the change of the thermo-ecological cost of the heat supplied by district heating networks. These changes result from the thermodynamically favourably increased share of cogenerated production of heat and electricity. The thermo-ecological cost of heat produced in

cogeneration ($\rho_Q$) is calculated basing on the principle of avoided fuel input:

$$\rho_Q = \frac{1}{Q} \left( \frac{E_{el} + Q}{\eta_{E\,CHP}} - \frac{E_{el}}{\eta_{ref\,pp}} \right) (\gamma_c + \sigma_c) , \qquad (7)$$

or denoting $\sigma = E_{el}/Q$

$$\rho_Q = \left( \frac{1 + \sigma}{\eta_{E\,CHP}} - \frac{\sigma}{\eta_{ref\,pp}} \right) (\gamma_c + \sigma_c) , \qquad (8)$$

where
$E_{el}$ – production of electricity,
$Q$ – production of heat,
$\gamma_c$ – ratio of the thermo-ecological cost of hard coal to its specific chemical energy,
$\sigma_c$ – component of the thermo-ecological cost due to harmful emissions resulting from the combustion of hard coal.

Assuming the energy efficiency of the CHP plant fired with hard coal as $\eta_{E\,CHP} = 0.8$ and the cogeneration ratio as $\sigma = 0.45$, as well as the ratio of the thermo-ecological cost of hard coal to its specific chemical energy as $\gamma_c = 1.13$ J/J and the components of the thermo-ecological cost due to harmful emissions resulting from the combustion of hard coal $\sigma_c = 0.0175$ J/J we get $\rho_Q = 0.65$ J/J. The thermo-ecological cost of the remaining part of heat supplied by district heating networks was assumed to amount to 1.4 J/J like in the case of heat produced in water heating boilers [8]. Figure 10 presents the thermo-ecological costs determined as the weighted mean of both these values. As is to be seen, in the course of forecasting the thermo-ecological cost of heat is reduced by more than 15%.

Among the ways of improving the exergy effectivity of industrial processes one of the most important is the physical recuperation. Figure 11 presents the relative savings of the chemical energy of fuel thanks to preheating the combustion air. Relative savings of the chemical energy of fuels are defined as follows:

$$\omega_E = \frac{-\Delta P \cdot LHV}{(P \cdot LHV)_0} , \qquad (9)$$

where
$-\Delta P$ – savings of fuel,
$LHV$ – lower heating value,
$(P \cdot LHV)_0$ – consumption of the chemical energy of fuels in a process without recuperation.
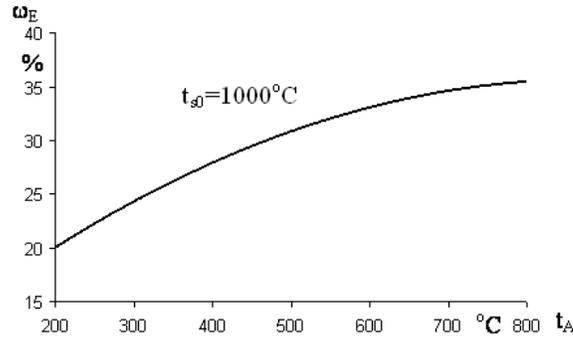
Figure 11. Relative savings of the chemical energy of fuels versus the temperature of preheated air: $t_{s0}$ – temperature of flue gases without recuperation.

The high effectivity of preheating the combustion air is still more stressed by the so-called energy and exergy multipliers of savings of the chemical energy $(\mu_E)$ (exergy $(\mu_B)$) of fuel which are defined as follows:

$$\mu_E = \frac{-\Delta P \cdot LHV}{Q_r} > 1 \ , \tag{10}$$

$$\mu_B = \frac{-\Delta P b_f}{\Delta B_s} \tag{11}$$

where

$$\Delta B_s = Q_r \frac{T_m - T_a}{T_m} \tag{12}$$

hence

$$\mu_B = \mu_E \frac{b_f}{LHV} \frac{T_m}{T_m - T_a} > \mu_E \ , \tag{13}$$

where
$Q_r$      –   heat of recuperation,
$b_f$      –   exergy of fuel,
$\Delta B_s$   –   exergy of preheated substrates,
$T_a$      –   ambient temperature,
$T_m$      –   thermodynamic mean temperature of substrates.

This energy multiplier takes a value exceeding 1 (Fig. 12), due to the super-position of useful effects, viz. a decrease of the temperature of flue gases, as well as their flux caused by the reduction of input fuel. This effectivity is still more proved by the exergy multiplier (Fig. 12), whose values exceed the value of the energy multiplier. This effect results from the favourable

influence of preheating the substrates on the exergy losses in combustion processes.
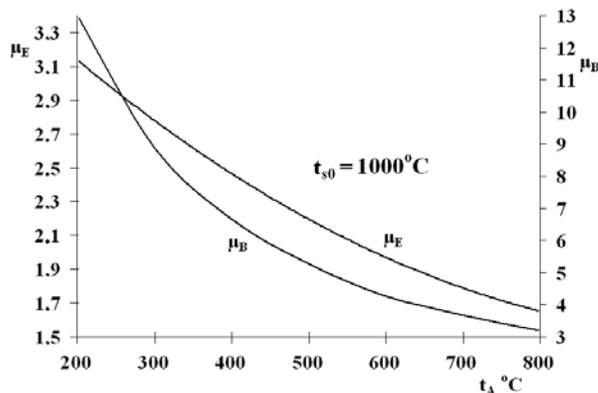


Figure 12. Energy and exergy multipliers of energy (exergy) savings.

## 5    Conclusions

According to knowledge in the year 2009, when the Document *The energy policy of Poland up to the year 2030* was published, the Polish 'energy mix' ought to be based on coal and nuclear energy engineering. The application of coal is justified by its resistance to external disturbances. Its drawbacks are emissions of $CO_2$ and other pollutants. Nuclear energy is characterised by the availability of fuels on the competitive international market, an inconsiderable effect of the price of fuels and the lack of direct $CO_2$ emission. The coal and nuclear options do not exclude each other (coal-nuclear synergy). Natural gas, if it must be mainly imported, is not resistant to political disturbances. The situation might change if the expectations concerning shale-gas come true. The availability of renewable energy sources is in Poland rather limited and, what more, excluding hydro- and biomass energy, their other forms applied for electricity generation (e.g., wind) require considerable power-rating reserves in the electroenergy system.

Generally, the answer concerning the question, put forward in Section 4, is — yes, and particularly:

- The favourable tendency of the improvement of the primary energy structure becomes evident when the ratio of the final energy to the primary energy is analyzed. In the considered range of forecasting

this ratio increases, by about 3.5 p.p. Also the ratio of final exergy to primary exergy increases which proves a favourable effect of the reduction of exergy losses during the conversion of primary energy.

- The favourably changing structure of primary energy is also confirmed by the results of thermo-ecological analysis. The thermo-ecological cost of primary energy, amounting at the beginning to about 42 PJ/Mtoe is reduced to about 37 PJ/Mtoe at the end of forecasting. Simultaneously, the index of sustainable development is reduced from 0.9 to about 0.82.

- The structure of the primary energy consumption for the production of electricity and centralized heat is also thermodynamically justified, as has been proved by the analysis the thermo-ecological costs of electricity and centralized heat production. In the first case the fuel component of the thermo-ecological cost decreases from about 3.2 to about 2. In the latter case the thermo-ecological cost decreases from about 0.9 to about 0.75, which first of all results from the twofold increase of electricity production in high-efficiency cogeneration.

- The thermo-ecological motivation of the improvement of the energy effectivity in industry was analyzed as an example of physical recuperation. The energy multiplier of savings and particularly the exergy multiplier, prove the high effectivity of preheating the substrates in combustion processes making use of waste heat recovery.

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