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Exemplary application of energy substitution efficiency and marginal cost analysis

In this paper the economic efficiency and the marginal cost of energy substitution (EEES and MCES) have been introduced. The EEES and analysis are applied in order to satisfy individual living and municipal requirements of inhabitants by means of different kinds of energy production and utilization appliances. The applied form of energy influences not only its cost (purchase energy prices) but also requires different investment and maintenance costs and, above all, it determines the final environmental impact. That is why described indicators are different for final energy production while using different types of energy carriers and methods of energy conversion. However, there are different utilization effects for each of the considered forms of energy in its final application. It may be particularly significant when the analyzed form of energy is the one that does not commonly occur. In the final part of this paper, the method of EEES and MCES along with a few examples of efficiency of energy substitution and its evaluation have been presented.

Nomenclature

e	–	unit costs of energy, PLN/GJ
$EEES$	–	economic efficiency of energy substitution
$\dot{G}$	–	rated input, W
i	–	rate of return
I	–	investment cost of purchasing equipment, PLN/GJ
j	–	future value per unit of energy

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k	–	unit costs, PLN/GJ
$MCES$	–	marginal costs of energy substitution
n	–	number of period
$\dot{U}$	–	rated output, W

Greek symbols

η	–	unit quantity of final energy effect related to unit of basic energy (thermal efficiency)
ε	–	part of basic energy in overall energy consumption
ρ	–	uniform-series present-worth factor
τ	–	annual time of exploitation rated output

Subscripts

d	–	auxiliary
e	–	operating, maintenance and environmental
eff	–	effective
i	–	i-final energy product ($i = 1, 2, \ldots, n$)
j	–	j-type of energy carriers and methods of its conversion (j=1,2,...,n)
o	–	reference
s	–	analyzed

1 Introduction

The same final energy effect can be produced with application of different types of energy carriers and methods of energy conversion. The methods of energy supply are comprehended as a kind of fuel, energy carriers and their parameters or the type of energy itself. Particular methods of final energy conversion affect costs of energy which include cost of fuel, investment cost of purchasing equipment, operating and maintenance cost, inter alia cost of materials and labor, environmental cost and others [1]. In this connection, there are varied economic effects of producing the same final energy by means of different types of energy carriers and methods of energy conversion. In order to determine efficiency of energy substitution, different indicators are used.

Application of the economic efficiency and marginal cost of energy substitution for economic assessment (EEES and MCES) has been proposed in [2,5]. In those articles also general rules for the calculation of the indicators and methods of estimation of particular examples for the production effects have been given. In this paper, application of the foregoing indicators as an effective method of efficiency assessment of energy substitution by produced final energy (central heating and domestic hot water in a distribute appliances) has been suggested.

2 Definition of the economic efficiency and marginal cost of energy substitution in final energy generation

The economic efficiency of energy substitution was defined as a difference between the incurred production costs of final useful energy effect in case where this energy is used in the reference way, as well as with respect to the analyzed forms of its use. By the reference way is meant the manner which is locally the most prevalent and either is based on fuels or on energy carriers which close the energy balance [4]. The considered methods of final energy production can be compared if their characteristic parameters, i.e. rated output, annual exploitation time, and so on, have the same values or at least are comparable. There can be difference of energy consumption in production of the same amount of final energy. It results from using fuel and energy of diverse quality as well as of different thermal efficiency. In this article, the economic efficiency reffers to the considered method of final energy production. The calculations of EEES have been introduced for the amount of final energy effect which can be obtained for the unit of energy applied in the analyzed method. In some cases, for example, while heating water for domestic use by solar collectors, application an auxiliary heat source is obligatory.

Taking this into account, the EEES for analyzed energy sources (s) and methods of its conversion used to produce (i) final energy effect can be written as follows [2]:

$$EEES = \frac{\eta_{si}}{\varepsilon_{si}} \left(k_{oi} - k_{si} \right) . \tag{1}$$

The unit cost of produced final energy effect (i) by application of type of energy carriers (j) and methods of its conversion can be determined as

$$k_{ji} = \frac{1}{\eta_{ji}} = \left[\varepsilon_{ji} e_{ji} + (1 - \varepsilon_{ji}) e_{dji} + k_{eji} + \frac{\sum_j \rho_{ji} I_{ji}}{\dot{U}_{ji} \tau_{ji}} \right] \tag{2}$$

(in further equations the i index has been ignored). Thus, by comparison of Eqs. (2) and (1) one can obtain:

$$EEES = \frac{1}{\varepsilon_{si}} \left\{ \frac{\eta_{si}}{\eta_{oi}} \left[\varepsilon_{oi} e_{oi} + (1 - \varepsilon_{oi}) \, e_{doj} + k_{eoi} + j_{oi} \right] - \left[\varepsilon_{si} e_{si} + (1 - \varepsilon_{oi}) \, e_{dsj} + k_{esi} + j_{si} \right] \right\} , \tag{3}$$

provided that

$$j_{ji} = \frac{\sum_j \rho_{ji} I_{ji}}{\dot{G}_{ji}\tau_{ji}} , \tag{4}$$

where

$$\rho_{ji} = \frac{(1+i_{eff})^n - 1}{i_{eff}(1+i_{eff})^n} . \tag{5}$$

In Eq. (3) index j has been replaced by index o or s. The term $(1+i_{eff})^n$ is referred to the single payment compound amount factor.

The marginal cost of energy substitution has been defined as unit cost of energy for which no economic losses are incurred. The marginal cost was determined in comparision to the reference method of final energy generation. The formula of MCES can be written as follows [2]:

$$MCES = EEES + e_s . \tag{6}$$

3 Example of economic efficiency and marginal cost of energy substitution calculation

The example refers to determining the EEES and MCES for heat and domestic hot water production in a multifamily building. The values of economic efficiency and marginal costs of energy substitution have been determined for methods of energy supply using fuel deficient systems and renewable energy resources. In order to calculate the EEES and MCES for heat and domestic hot water production, data including the branched price list and scale of charges have been used. In both cases, the reference fuel is pea coal. The chosen reference method of energy supply was based on a boiler with a retort burner which is fed by the reference fuel – pea coal. The cost of fuel and heat values calculations are shown in Tab. 1.

The following heat sources have been taken into consideration:

1.	Eco pea coal, t	solid fuel fired boiler with retort burner
2.	Coal-fired heat plant	district heating house substation
3.	Chestnut coal, t	solid fuel fired boiler
4.	Natural gas, m^3	gas fired condensing boiler
5.	Heating oil, l	oil fired condensing boiler
6.	Biomass/ wood pellet, t	biomass fired boiler
7.	Electricity-G12, kWh	electric storage heating system
8.	Electricity-G11, kWh	electric storage heating system

Table 1. Cost and low heating value of fuel [3].

Fuel, unit of the fuel	Unit costs, PLN/unit of the fuel	Low heating value, W_d, MJ/unit of the fuel
Natural gas, Nm^3	1.32	30
Eco pea coal, kg	0.75	27
Chestnut coal, kg	0.65	20
Heating oil, l	3.63	42
Biomass/ wood pellet, kg	0.70	19
Electricity-G11, kWh	0.49	–
Electricity-G12, kWh	0.47	–

For domestic hot water production the following methods of energy supply have been taken into consideration:

1.	Coal-fired heat plant	district heating house substation
2.	Natural gas, m^3	flow gas water heater
3.	Eco pea coal, t	hot water storage tank in conjuction with solid fuel fired boiler with retort burner
4.	Chestnut coal, t	hot water storage tank in conjuction with solid fuel fired boiler
5.	Natural gas, m^3	storage water heater in conjuction with gas fired condensing boiler
6.	Biomass/ wood pellet, t	hot water storage tank in conjuction with biomass boiler
7.	Solar energy – with surcharge	vacuum collector and gas fired condensing boiler
8.	Solar energy – with surcharge	flat plate collector and gas fired condensing boiler
9.	Solar energy	vacuum collector and gas fired condensing boiler
10.	Solar energy	flat plate collector and gas fired condensing boiler
11.	Electricity-G11, kWh	electric hot water storage
12.	Electricity-G12, kWh	electric flow-water heater
13.	Heating oil, l	hot water storage tank in conjuction with oil fired condensing boiler

In the analysis, the best of currently accessible technologies of energy utilization for each fuel have been compared. The reference year for the data is 2011. The time of exploitation and the rate of return used in estimating the uniform-series present-worth factor are respectively 20 years and 3% . The results of the economic efficiency and the marginal cost of energy substitution calculations have been presented in Figs. 1–4. These graphs show the relationship between these indicators and methods of energy utilization for heat and domestic hot water production.

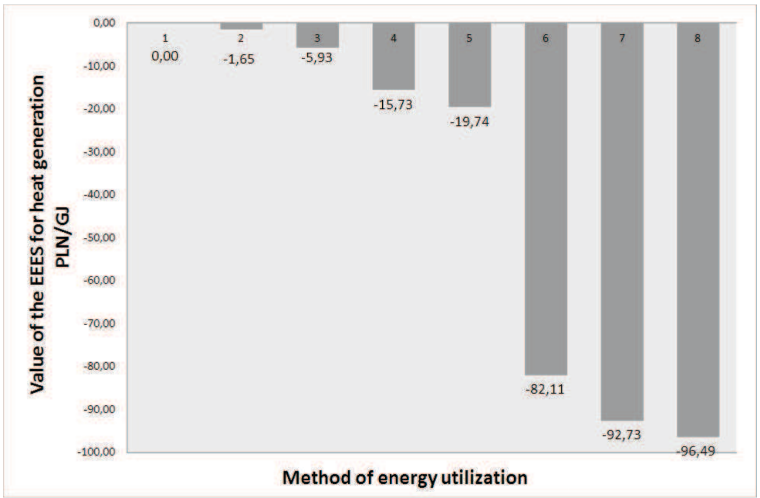

Figure 1. Economic efficiency of energy substitution for heat generation with different method of energy supply.

4 Summary

In this paper the preliminary calculations of *EEES* and *MCES* for heat and domestic hot water have been presented. From the analysis performed the undermentioned conclusions can be drawn. Values of the *EEES* and *MCES* indicators have been dependent on the output of final energy production, actual structure of fuel, as well as investment, operating and maintenance costs, which include environmental costs. The presented method of determining these indicators allows to determine the value of emission charges which enable positive efficiency of exploitating particular energy carriers and methods of their conversion. The economic efficiency of energy substitution enables evaluation of priority of use

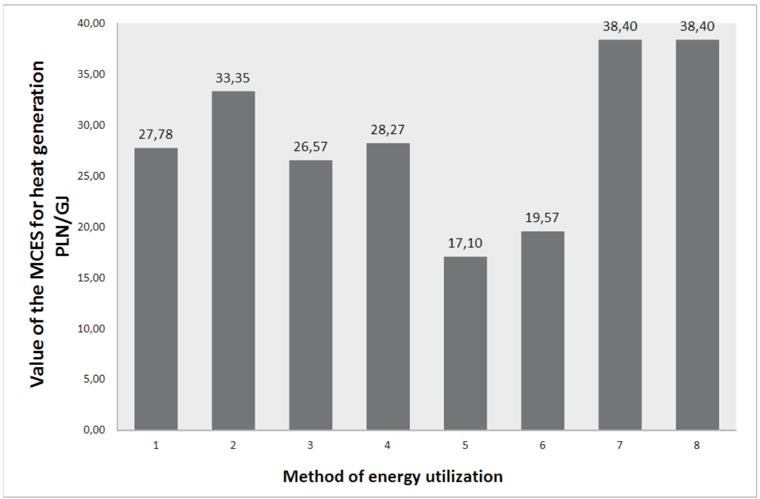

Figure 2. Marginal cost of energy substitution for heat generation with a different method of energy supply.

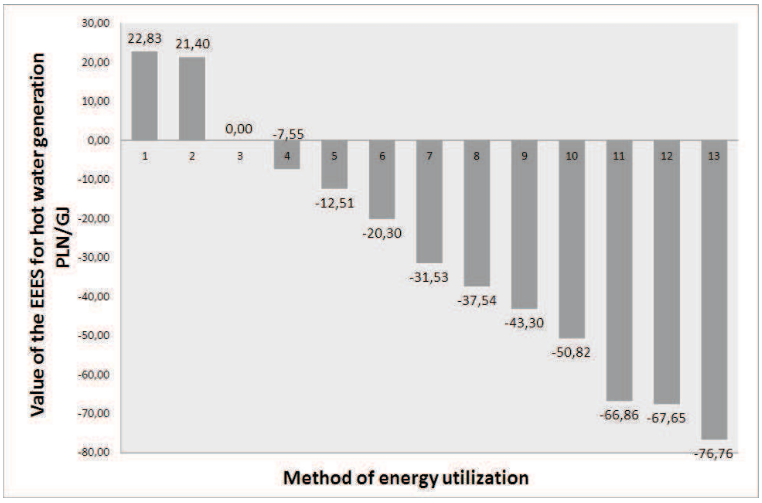

Figure 3. Economic efficiency of energy substitution for domestic domestic hot water production with different method of energy supply.

of some methods of energy supply over other ones, in considered localization, as well as evaluation of advisability of the chosen schemes of energy supply in other localization. The value of the *EEES* and *MCES* can be positive, negative or equal zero. The greater is the *EEES* in comparision with the reference, the

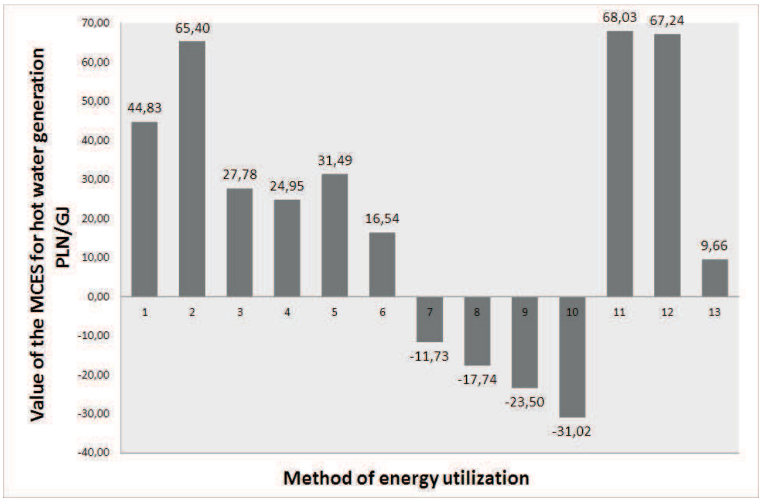

Figure 4. Marginal cost of energy substitution for domestic hot water production with different method of energy supply.

more economically reasonable is to use the analyzed metod. The negative value can determine minimal surcharge which allows to avoid economic losses.

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Przykładowe zastosowanie analizy efektywności substytucji energii i kosztów granicznych

S t r e s z c z e n i e

Wykorzystując pojęcia wskaźnika efektywności substytucji oraz kosztu granicznego paliwa substytucyjnego, przeprowadzono ocenę efektywności różnych sposobów wykorzystania tego samego źródła energii (paliwa lub nośnika) w różnym zastosowaniu oraz porównano efektywność wykorzystania różnych źródeł energii w tym samym zastosowaniu. Te same produkty użyteczne można uzyskać przy stosowaniu różnych sposobów energetycznego zasilania procesów ich wytwarzania. Przez sposób energetycznego zasilania należy rozumieć zastosowane paliwo, nośnik energetyczny i jego parametry lub rodzaj energii. Poszczególne sposoby zasilania wpływają na koszty paliwowe, koszty pozapaliwowe, nakłady inwestycyjne na urządzenia i instalacje, straty środowiskowe oraz inne. Zróżnicowane są, w związku z tym, efekty ekonomiczne wytwarzania tych samych produktów użytecznych lub zaspokajania takich samych potrzeb, przy korzystaniu z różnych sposobów energetycznego zasilania. W pracy zaproponowano wykorzystanie powyższych wskaźników do oceny efektywności substytucji energii przy pozyskaniu komunalno-bytowych produktów użytecznych: ciepła oraz ciepłej wody użytkowej.