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Thermo-ecological cost of electricity from renewable energy sources

Wojciech Stanek, Lucyna Czarnowska*, Wiesław Gazda, Tomasz Simla

Institute of Thermal Technology, Silesian University of Technology, Konarskiego 22, 44-100 Gliwice, Poland

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ABSTRACT

Nowadays, the society faces the challenge of continuous supply of electricity. Energy from two different sources of origin such as renewable and non-renewable is used to meet the needs of modern humankind. The paper presents the findings concerning the thermo-ecological cost assessment of renewable energy sources defining their total impact on the environment. Biogas, wind and photovoltaic power plants were evaluated to present the results of cumulative environmental impact based on the thermo-ecological cost methodology. Polish law regulations and the prediction of the future energy mix structure are described to emphasize the importance of selected technologies. The measurements data of real renewable energy units in Poland and the characteristics of components were used to calculate thermo-ecological cost of electricity originating from renewable sources. Moreover, different phases of the production chain are considered to present results in total life cycle of the respective technologies. In the calculations, continuous availability of conventional power plants for stabilizing the current electricity needs is taken into account. Finally, the results of this study prove that biogas power plants cause lower environmental impact than wind and photovoltaic technologies.

1. Introduction

In this section, the statistical, economic and political background is presented for renewable and non-renewable resources. It is provided to show the importance of application of scientific methodology in the policy regarding renewable energy sources (RES). Continuous aspirations for further global economic growth accelerate the consumption of limited stock of non-renewable resources. Their lifetime defined as ratio of proven reserves of resources to their production, further referred to as R/P[1] ratio, in the case of fossil fuels is now significantly limited [1]: natural gas – 54.1 years, oil – 52.5 years in relation to total word resources. In the case of coal, during the last decade an extremely rapid decrease of R/P ratio has been observed: in the year 2000 the ratio was estimated at the level of 220 years; whereas after 14 years – in 2014, it was estimated as only at the level of 110 years [1]. These numbers are not precise as they depend on many changing factors, yet it is clear that sooner or later the resources of these fuels will deplete, and we should promote sustainable development to minimalize the risks tied to that depletion.

Electricity is one of the most important energy carriers for many manufacturing processes, for this reason power sector plays a significant role in consumption of resources. Moreover, electricity generation in fossil fuel based power plants is strongly connected with rejection of harmful wastes as well as greenhouse gases to the natural environment. Consumption of hard coal and lignite dominates in the fuel structure of Polish electricity generation. In the years 2006–2014, the share of chemical energy of hard coal was equal to 50–58%, while lignite consumption was equal to 36–40%. Fig. 1 presents the average (gross and net) energy efficiency of electricity generation in Polish fossil fuel based power plants within the years 2006–2014. Efficiency is defined as generated electric power (either gross or net) divided by the rate of chemical energy of fuel used in the power plant. Gross power is the output of electric generator. Net power is obtained by subtracting the power for own needs of the power plant.

The improvement of electricity generation efficiency and the increase of RES in energy mix are crucial issues from the sustainability point of view. According to the Polish Energy Policy [3], a significant increase of renewable sources with simultaneous decrease of coal consumption are planned for electricity generation (Fig. 2). Energy mix based on both non-renewable and renewable

* Corresponding author.
E-mail addresses: wojciech.stanek@polsl.pl (W. Stanek), lczarnowska@polsl.pl (L. Czarnowska), wieslaw.gazda@polsl.pl (W. Gazda), tomasz.simla@polsl.pl (T. Simla).

[1] Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.

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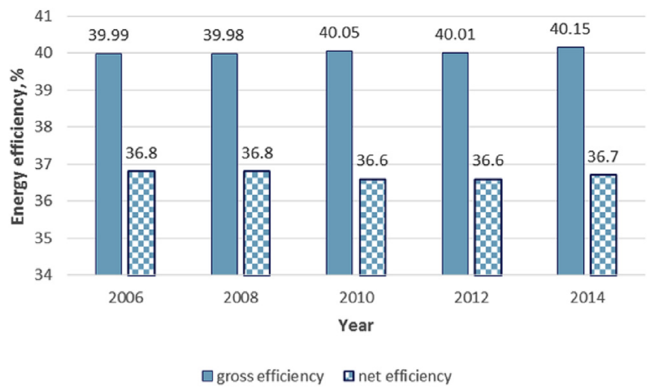

Fig. 1. Energy efficiency of electricity generation by conventional power plants [2].

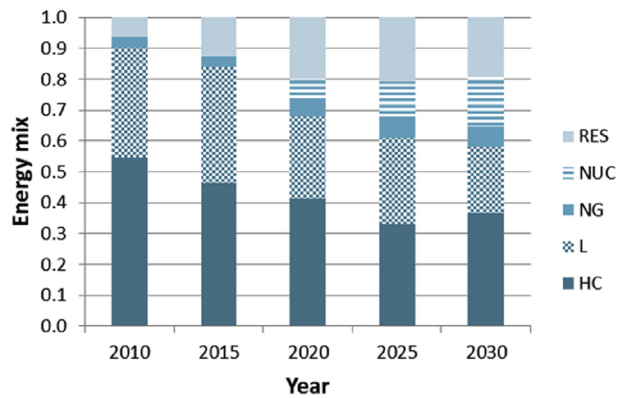

Fig. 2. Structure of Polish energy mix according to Polish energy policy (based on [4]) (HC – hard coal; L – lignite, NG – natural gas; NUC – nuclear energy, RES – renewable energy sources).

primary energy resources requires consequent evaluation at the level of extraction of natural resources. The analysis should include interactions of non-renewable and renewable power plants within the national energy system. These interactions result mainly from the existing regulations, as well as from random accessibility of primary renewable energy.

In Polish conditions, due to the policy [4], renewable electricity has ensured the priority in the national energy market. With such regulations, random generation of electricity based on RES leads to changing operation of fossil fuel power plants, which finally leads to work with decreased efficiency. Concluding, random operation of RES induce specific losses in utility non-renewable power plants fed with fossil fuels. This effect has to be included in the evaluation of RES, however, very often it is neglected or ignored. These issues have been addressed in some international studies, in most cases with focus on the emission of carbon dioxide [5–10].

The influence of any production technology, including power technologies, on the depletion of resources has to be evaluated using the methods that let to: 1) take into account the whole cycle, 2) evaluate the resources quality by one common measure, as well as 3) take into account the influence on the depletion resulting from generation of wastes. Such approach is possible due to the application of the Thermo-Ecology methodology [11]. The theory of the Thermo-Ecological Cost (TEC) has been presented e.g. in Refs. [12–16]. The evaluation by means of TEC, in other words the investigation of the technology's influence on the global non-renewable resources consumption is especially important in the case of renewable power technologies such as biomass, biogas, wind or solar energy. The comparison of these processes e.g. with non-renewable power plants is only possible at the level of primary resources. It is also proposed in simplified way e.g. by legal regulations devoted to RES supporting system [17] or to energy consumption in buildings [18]. To evaluate the influence on primary resources consumption the following approach is proposed:

$$E_p = w_i E_f \tag{1}$$

where E_p and E_f denote consumption of primary and final energy and w_i denotes the coefficient of primary energy consumption necessary for final energy generation. Very similar coefficient c_i was used in proposal of Polish regulations [17]. Both coefficients for different power technologies are collected from the literature [18,19] and presented in Table 1. The coefficients c_i and w_i presented in Table 1 are not scientifically determined ecological costs of a given process. These values are just simple conversion factors used in current policy regulations to convert final energy to primary energy extracted from nature. One of the goals of this article is to propose methods to evaluate these factors based on solid scientific ground.

These numbers are presented here to discuss the fact, that they are chosen arbitrarily and are lacking rigor in their definition. The lack of consequence seems to be evident. According to [18,19], in the case of photovoltaics (PV) once $w_{PV} = 0.0$ and 3 years later $w_{PV} = 0.70$. It seems also not justified that for all non-renewable technologies based on primary energy the coefficient is at the level of 1.1, while these fuels are extracted and processed with very different burden on the environment [20,21].

One of the proposals of Polish regulations towards RES support introduced “coefficients of support”. The level of support in this proposal was directly proportional to the c_i coefficient. It is difficult to explain in physical ways why PV ($c_i = 2.85$) would be almost three times better than wind ($c_i = 0.9$) or about 2 times better than biogas ($c_i = 1.40$).

It can be concluded that the evaluation of RES as well as comparison with non-RES requires comprehensive, objective and based on physical laws methods. Such approach is possible thanks to the introduction of TEC indices for their comparison. Taking into account the random operation of RES, the classic TEC approach has to be supplemented with an additional part due to the compensation and induced losses.

2. Thermo-ecological cost (TEC) – fundamentals

The physical, as well as ecological cost of any product should take into account the total consumption of natural resources at the level of their extraction from nature. Moreover, it has to be calculated using the common measure of resources quality. Such cost can

Table 1
Coefficients for RES.

System	c_i [17]	w_i [18]	w_i [19]
Renewable Natural Resources			
PV	2.85	0.00	0.70
Biogas	1.40	0.50	N/A
Hydro	1.90	N/A	N/A
Wind	0.90	0.00	N/A
Biomass	N/A	0.20	0.20
Nonrenewable Natural Resource			
Oil	–	1.10	1.10
Natural gas	–	1.10	1.10
LPG	–	1.10	1.10
Hard coal	–	1.10	1.10
Lignite	–	1.10	1.10