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ENERGY EFFICIENCY – ECOLOGICAL AND ECONOMIC PROFITABILITY

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Abstract
The aim of the article is to draw attention to both the average annual savings in the costs of consumed fuels and energy, as well as the possibility of obtaining additional funds in the case of implementing projects aimed at improving energy efficiency. On the example of an implemented investment in a cement industry company, the achieved energy savings and obtained economic savings in the form of reduction of fuel and energy costs were analysed. Moreover, it was shown what additional support can be obtained in the form of energy efficiency certificates, the so-called "White certificates", issued by the President of the Energy Regulatory Office, and the resulting property rights become an exchange commodity and are traded on Towarowa Giełda Energii SA. The purpose of this article is to estimate how much money will be financed from the certificates.

Keywords: **Energy efficiency; "white certificates"; Cement industry.**

1. INTRODUCTION

The mechanisms promoting energy efficiency in Poland were initiated by the introduction of the Act of April 15, 2011 on energy efficiency [1], as amended by introducing a new the Act of May 20, 2016 on energy efficiency [2]. Pursuant to these regulations, an entrepreneur who has implemented / plans to implement an undertaking or undertakings of the same type aimed at improvement, obtained the possibility to apply for an energy efficiency certificate, the so-called "White certificates".

Energy efficiency certificates are issued by the President of the Energy Regulatory Office at the request of the entity where the project or projects of the same type aimed at improving energy efficiency will be implemented or authorized by this entity.

Then, in accordance with Art. 24 sec. 2 [3] of the applicable act, the President of the ERO informs the entity referred to in Art. 30 sec. 3 [4] of the Act, i.e. an entity operating a commodity exchange or a regulated market and organizing trading in property rights resulting from energy efficiency certificates (currently the entity organizing the trading of the above-mentioned property rights is Towarowa Giełda Energii SA) with an energy efficiency certificate issued for the entity indicated in this certificate. However, according to the content of Art. 30 sec. 2 of the Act, upon saving – on the basis of the above-mentioned information provided by the President of the ERO to Towarowa Giełda Energii SA about the issuance of an energy efficiency certificate to the entity indicated therein – an energy efficiency certificate for the first time on an account in the register of energy efficiency certificates, property rights arising from the energy efficiency certificate are created, which are entitled to the account holder. The property rights resulting from the energy efficiency certificate are a stock exchange commodity within the meaning of the Act of 29 July 2006 on Commodity Exchanges [1] and they are marketable [4]. It follows from the above provisions that the possibility of trading in property rights resulting from the issued energy efficiency certificates or using these certificates for the fulfilment by the obliged entities of the obligation to obtain them and submit them to the President of the ERO for redemption, depends on obtaining the status of a member of the Certificates of Origin of the Commodity Exchange. Energy SA Detailed information on the conditions for obtaining membership in the Certificate of Origin Register can be found in https://www.tge.pl/pl/51/czlonkstwo-w-rsp [2].

The basic document that is necessary when applying for "white certificates" is the energy efficiency audit technical or installation, as well as the assessment of their economic profitability and possible energy savings, understood as the amount of energy constituting the difference between the energy potentially consumed by an object, technical device or installation in a given period before the implementation of one or more projects to improve energy efficiency, and energy consumed by this object, technical device or installation in the same period, after the completion of these projects and taking into account standardized external conditions that affect energy consumption. Profitability is presented on the example of a project carried out in one of the large cement companies. The effectiveness of this measure is presented as the level of support in the form of energy efficiency certificates that can be obtained [1, 3].

2. PURPOSE OF THE ARTICLE

The aim of the article is to draw attention to the benefits that can be obtained as a result of the implementation of projects aimed at improving energy efficiency, both ecological and economic benefits. Each pro-efficiency action contributes to measurable savings in fuel and energy consumption, and thus not only reduces the current costs of business operations, but also contributes to environmental protection through, for example, reduced carbon dioxide emissions.

In addition, the aim of the article is to encourage entrepreneurs and other legal entities to take advantage of the opportunities provided for in the Energy Efficiency Act, consisting in applying to the President of the Energy Regulatory Office for issuing energy efficiency certificates, white certificates. The property rights resulting from these certificates may constitute a significant financial income and may constitute an incentive to implement another project aimed at improving energy efficiency.

3. LITERATURE ANALYSIS

The 2030 climate and energy policy framework include EU-wide policy objectives and targets for 2021–2030 [6]. The most important goals for 2030:

- reduction of greenhouse gas emissions by at least 40% (compared to 1990 levels)
- increasing the share of energy from renewable sources in total energy consumption to at least 32%
- an increase in energy efficiency by at least 32.5%

In October 2014, the policy framework was adopted by the Council. The targets for renewable energy and energy efficiency were increased in 2018. To achieve this target:

- Sectors covered by the EU Emissions Trading System (ETS) have to reduce emissions by 43% (compared to 2005) – therefore the ETS has been changed to the post-2020 period.
- Sectors not covered by the ETS must reduce emissions by 30%. (compared to 2005) – this target has been translated into individual binding targets for individual Member States.

As part of the European Green Deal, the Commission intends to propose to increase this EU target to at least 50% and even aim for 55% [7].

4. AN UNDERTAKING AIMED AT IMPROVING ENERGY EFFICIENCY CONSISTING IN THEMODERNIZATION OF THE CLINKER BURNING PROCESS

The energy efficiency improvement project that is the subject of this audit was carried out at Cement, a producer of Portland Slag, Portland Compound, Lime Portland and blast furnace cements [8]. Until the project was completed, the clinker was burnt in three rotary kilns using the dry method. The furnaces were fired with coal dust, light alternative fuels (from high-energy waste) and, to a small extent, with dry sewage sludge. The fuel was fed to the furnaces by a system of belt conveyors and, through buffer tanks, is weighed on dosing scales. The weighed fuel was pneumatically transported to the burners. It allowed to keep the installation tight, and the whole process was carried out automatically [9]. The alternative fuel directly reduced the amount of coal to the furnace, thus saving the primary fuels. Process fuel based on coal dust was a product obtained from grinding fine coal (fine coal) in a ball coal mill, while alternative fuel was a special product from an external supplier, it was stored and fed to the rotary kiln using separate technological lines [10].

4.1. Purpose and scope of modernization

The main objective of the modernization was to intensify production and reduce the energy consumption and emissivity of the clinker burning process (Fig. 1). This goal was achieved by replacing the existing three rotary kilns with one kiln and reduction of specific heat consumption and creation of technological conditions to reduce coal consumption by replacing it with alternative fuels [11]. The basic effects of modernization include:

- reduction of production costs resulting from the reduction of heat demand

for burning and the use of alternative fuels,

- reduction of electricity consumption due to the intensification of the production process,
- improvement of process stability – improvement of clinker quality [4–7].

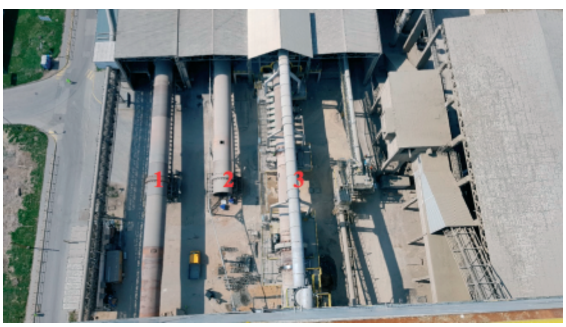

Figure 1.
Rotary kilns (top view) (1. One of the three old rotary kilns – currently out of service, intended for demolition; 2. One of the three old rotary kilns – currently being demolished; 3. New rotary kiln)

4.2. Primary energy consumption before modernization

Chemical energy of fuels intended for clinker burning and clinker production before modernization were compared to the base year [12]. According to production data, clinker production in this period amounted to 381,890 Mg. The amount of fuels and their calorific value in the base year are presented in Table 1. Data on the amount of fuels and their calorific value come from the actual consumption data of a given type of fuel, and their calorific value is constantly monitored in the laboratory located at the cement plant [13]. The balance limit for the calculation of fuel consumption and the energy consumption index for clinker production was determined for three clinker burning furnaces [14].

Based on the above data, the following values were calculated:

Primary energy consumption in the base year
1,918 768.145 GJ/year

Amount of clinker produced in the base year
381,890 Mg/year

WE energy intensity index before modernization
5.024 GJ/Mg

CO2emissions 172,575.002 Mg CO_2/year

Analysing the nominal capacity of three furnaces, i.e. over 1,900 Mg/day and production data in the base year [15] it can be assumed that the cement plant, theoretically (assuming a large sales market and production days per year at the level of 92%), was able to produce over 600,000 Mg of clinker/year. That's why in further calculations using the index method, the production value from the period "after modernization" will be used to calculate final energy savings "after modernization". The production volume indicated above was possible due to the nominal efficiency of three furnaces in the base year and their technical parameters.

In accordance with the technical and operational documentation and the operating manual for old furnaces, the furnace capacity is 28 Mg/day, which, with three furnaces per year, allows for the maximum production of 676,972 Mg of clinker.

The value was calculated as follows:

Max production before modernization: =28 Mg/day * 3 * 24h * 365 days * 0.92 = 676,972 Mg/year

Table 1.
Fuel and energy consumption for clinker production in the base year [cement plant data]

Type of fuel	Fuel consumption [Mg / year]	Calorific value [kJ / kg]	Fuel chemical energy [GJ / year]	Emission factor [Mg CO_2 / GJ]	CO_2 emissions [Mg / year]
Coal	27,922.161	30.511*	851,933.054	93.080	79,297.928
RDF alternative fuel	55 306.338	18.561	1,026,540.940	87.400	89,719.678
Dry sewage sludge	2,840.095	13.512	38,375.364	89.000	3,415.407
Heating oil	45.149	42.499	1,918.787	74.000	141.989
Sum	**86,113.743**		**1,918,768.145**		**172,575.002**

* calorific value of dry coal dust

4.3. Saving primary energy in fuel

Due to the unstable clinker firing process during the technological start-up of the new furnace (and several days of technological breaks, process optimization and stabilization), the final energy savings "after modernization" were calculated using the data for a full month, from September 17 to October 20 [16]. During this period, the furnace system was stable, which allowed for continuous feeding of all types of fuel – coal dust, alternative fuel RDF [17], dry sewage sludge and small amounts of fuel oil [18]. The calorific value of light fuel oil is provided by its supplier.

Based on the data on the quantity and calorific value of fuels used for burning clinker on September 17 – October 20, the following values were calculated in the period after the modernization of the furnace installation:

Primary Energy consumption 183,577.799 GJ

Clinker production 47,563.080 Mg

Energy intensity index WEam (after modernization) 3.860 GJ/Mg clinker

(WE_{am} was calculated as the quotient of primary energy consumption and clinker production).

Primary energy savings ΔEp, calculated according to the formula:

$$\Delta Ep = (WE_{bm} - WE_{am}) * P_{am} \quad (1)$$

where:

WE_{bm} – energy intensity index before modernization

P_{am} – energy consumption after modernization

It should be pointed out here that P_{am}, i.e. the volume of clinker production after modernization of the furnace installation, it was calculated proportionally, according to the relationship:

47,563,080 Mg of clinker was produced in the period of 34 days (from September 17 to October 20), and therefore in the full year after the modernization, the production may amount to 510,603.653 Mg (47,563.080 Mg * 365 days) / 34 days = 510,603.653 Mg/year).

ΔEp = (5.024 GJ / Mg - 3.860 GJ / Mg) *
* 510,603.653 Mg/year (1)

ΔEp = 594,342.652 GJ/ year.

Such a calculation of the production data P after the modernization results from the fact that the new furnace is still in the phase of optimization and stabilization of operation [19] and efficiency in relation to the values provided by the manufacturer (2000 Mg/day) [20]. The average daily value of clinker production in the period in question is 1,398.914 Mg and is 70% of the efficiency assumed by the manufacturer of the furnace installation [21].

In accordance with the Regulation of the Minister of Energy of October 5, 2017 on the detailed scope and method of preparing an energy efficiency audit and methods for calculating energy savings, the coefficient of non-renewable primary energy input for hard coal, heating oil, alternative fuel and sewage sludge is 1.1 [1, 8].

Therefore, the final energy savings after modernization ΔE_f will amount to:

$$\Delta E_f = \frac{\Delta E_p}{1.1} = \frac{594{,}342.651\ GJ/year}{1.1} = 540{,}311.502\ GJ/year \quad (2)$$

After conversion, the final energy savings resulting from the reduction of primary energy consumption are:

ΔE_{ff} = 12,905.119 toe (tonne of oil equivalent)

4.4. Saving final energy in electricity

By replacing three furnaces with one furnace installation, savings were also made of electricity for auxiliary and accompanying devices of the new furnace installation [22]. After modernization, it was possible to reduce electricity consumption, among others, by thanks to the elimination of three old main-drive furnaces with a rated power of 315 kW each [23]. The current main drive of the new rotary kiln is 261 kW [24].

Electricity consumption data before and after modernization are counted data and are collected and analysed by the internal services of the cement plant [25]. The devices that are part of the furnace system have an ION 7330 meter. ION meters from individual fields are read using the ION Enterprise program, while the states of the main 110 kV billing meters are read using the DIALOG program [26]. The meters are compiled with each other and sent for further, official reports [27, 28].

The resulting electricity savings ΔE_{fe} in the clinker burning process from replacing three furnaces with one furnace, it was calculated as the difference between energy consumption indices before and after modernization and the product of the annual clinker production after modernization.

Table 2.
Electricity consumption data for the furnace installation in the base year (before modernization)

	kWh	t Kl.	kWh/t
January	1,223,212.0	30,625.2	39.9
February	597,631.4	13,412.2	44.6
March	1,143,617.9	32,926.0	34.7
April	1,191,783.2	32,393.8	36.8
May	1,287,485.2	37,446.9	34.4
June	1,255,544.9	35,243.6	35.6
July	1,291,080.6	34,320.0	37.6
August	1,239,850.6	33,623.7	36.9
September	1,267,597.4	32,423.8	39.1
October	1,151,178.0	29,759.8	38.7
November	1,256,302.0	34,130.7	36.8
December	1,324,375.0	35,584.2	37.2
average	-	-	37.7
sum	14,229,658.2	-	-

Table 3.
Electricity consumption data for a new furnace installation

	kWh	t Kl.	kWh/t
September	838,118.4	27,850.4	30.1
October	1,088,692.6	33,979.1	32.0
average	963,405.5	-	31.1

Table 4.
Fuel prices in the base year

Fuel type	Fuel cost before modernization PLN/t	Fuel cost after modernization PLN/t
Coal	471.50	350.00
Heating oil	2,521.09	2,587.77
RDF	55.35	30.67
Sewage sludge	38.37	48.46

$$\Delta E_{fe} = (37.7 \text{ kWh / Mg} - 31.1 \text{ kWh / Mg}) * 510{,}603.653 \text{ Mg / year} \quad (3)$$

ΔE_{fe} = 3,369.984 MWh = 289.766 toe.

According to the above-mentioned regulation, the coefficient of non-renewable primary energy input for electricity from mixed production is 2.5.

Therefore, the primary energy ΔE_{pe} savings after modernization will amount to:

$$\Delta E_{pe} = \Delta E_{fe} * 2.5 = 3{,}369.984 \text{ MWh / year} * 2.5 = 8{,}424.96 \text{ MWh / year} \quad (4)$$

4.5. Economic effect of the project

The following data and values were included in the economic analysis:

1. Clinker production after modernization 510,603.653 Mg/year
2. Capital expenditure on the construction of a new furnace PLN 100,000,000 [29]

For the calculation of the economic effect for electricity, its consumption was taken into account before and after modernization as well as its average value.

To obtain a reliable electricity price in the analysed periods (for cement plants, electricity is purchased at different tariffs, voltage levels, etc.), the average

Table 5.
Fuel consumption before and after modernization

Fuel type	Fuel consumption before modernization [Mg]	Fuel consumption after modernization [Mg]
Coal	27,922.161	22,363.27
Heating oil	45.149	136.20
RDF	55,306.338	63,483.48
Sewage sludge	2,840.095	864.63

Table 6.
Fuel consumption before and after modernization

Fuel type	before modernization PLN/year	after modernization PLN/year
Coal	13,165,298.91	7,827,144.50
Heating oil	113,824.69	352,454.27
RDF	3,061,205.81	1,947,038.33
Sewage sludge	108,974.45	41,899.97
Sum	16,449,303.86	10,168,537.08

Table 7.
Electricity consumption by a cement plant in the base year

Parameters	Fee	Consumption
Unit	MWh	PLN
The morning peak	12,319.004	3,385,212.31 zł
Afternoon peak	7,059.223	2,347,205.31 zł
The rest of the day	71,444.776	12,451,814.95 zł
Overall	90,823.003	18,184,232.57 zł
Contract power	-	2,746,800.00 zł
Variable transmission fee	-	2,516,384.48 zł
Power exceeded (PDG)	-	- zł
Reactive power exceeded	-	1,416.81 zł
Capacitive reactive power	-	341.54 zł
Subscription fee	-	5,280.00 zł
Including fixed fees	-	2,752,080.00 zł
Including transmission fees	-	2,518,142.84 zł
Including Energy charges	-	18,184,232.57 zł
Average price of energy	258.24	-
Energy consumption	90,823.003	23,454,455.40 zł

Table 8.
Electricity consumption by a cement plant in September and October after modernization

Parameters	Fee	Consumption
Unit	MWh	PLN
The morning peak	12,319.004	3,385,212.31 zł
Afternoon peak	7,059.223	2,347,205.31 zł
The rest of the day	71,444.776	12,451,814.95 zł
Overall	90,823.003	18,184,232.57 zł
Contract power	-	2,746,800.00 zł
Variable transmission fee	-	2,516,384.48 zł
Power exceeded (PDG)	-	- zł
Reactive power exceeded	-	1,416.81 zł
Capacitive reactive power	-	341.54 zł
Subscription fee	-	5,280.00 zł
Including fixed fees	-	2,752,080.00 zł
Including transmission fees	-	2,518,142.84 zł
Including Energy charges	-	18,184,232.57 zł
Average price of energy	258.24	-
Energy consumption	90,823.003	23,454,455.40 zł

price of 1 kWh in the period before and after modernization was calculated.

Electricity consumption in the base year was 90,823 MWh and its total cost was PLN 23,454,455.40, hence, the average price of 1 kWh in the analysed period was 0.258243 PLN/kWh.

In turn, in the analysed period of two months after the modernization, they were purchased 15,843.21 MWh at the price of PLN 4,717,766.99, hence the average price of 1 kWh was 0.297779 PLN/kWh.

The costs of electricity used by the furnace installation were compared to the data from the above tables and to their average prices before and after modernization.

For the base year, the total electricity consumption by three furnaces was 14,229.658 MWh/year. The cost of electricity consumed by three furnaces in the base year it amounted to 14,229.658 MWh/ear * *258.243 PLN/MWh = PLN 3,674,717.556.

For the year after the modernization, the total electricity consumption by the new furnace installation was calculated as the average consumption for the months of September and October and the reference of this value to the whole year (963,405.5 MWh * 12 months). The average electricity consumption for the year after the modernization is 11,560.865 MWh.

The cost of electricity consumed by the new furnace installation in the year after the modernization will be: 11,560.865 MWh * 297.779 PLN/MWh = 3,442,583.043 PLN.

The difference in the cost of electricity consumption by furnace installations will be

232,134.513 PLN.

Average annual savings resulting from the reduction of fuel consumption will amount to

6,280,766.78 PLN/year.

4.6. Total energy saved

The energy effect ΔE_{ft} of a furnace installation modernization is the sum of energy savings:

$$\Delta E_{ft} = \Delta E_{ff} + \Delta E_{fe} = 12{,}905.119 \text{ toe} + 289.766 \text{ toe} = 13{,}194.885 \text{ toe} \qquad (4)$$

5. CALCULATION SUMMARY

The expenditure on this large investment amounted to approx. PLN 100 million, but the annual savings in fuel and energy costs alone amounted to PLN 6.5 million. In addition, the energy efficiency certificate, with the above-mentioned Final energy savings, according to the current prices of property rights resulting from the certificates, amount to an additional approx. PLN 20 million – it is not enough, as it is 20% of the expenditure incurred.

6. CONCLUSIONS

The above-described example of an implemented project aimed at improving energy efficiency in a large Polish cement plant shows how large ecological and economic benefits can be obtained as a result of the investment, benefits not only in the form of lower fuel and energy costs, which costs in this type of enterprises constitute a very large share of costs in general, but also in the form of additional funds obtained as a result of trading in property rights from the energy efficiency certificate.

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