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ALICJA ULIASZ-BOCHEŃCZYK[1], EUGENIUSZ MOKRZYCKI[2]

The use of waste in cement production in Poland – the move towards sustainable development

Introduction

A circular economy aims to rationalize the use of resources, limit the negative environmental impact of manufactured products, and minimize the generation of waste. Waste recovery is an important element of a circular economy. Industrial symbiosis turns waste or by-products from one industry sector into raw materials for another. This reduces the waste that needs to be disposed of.

In a circular economy, waste is recovered and used as a raw material, contributing to the conservation of natural resources in the spirit of sustainable development.

An industry that is an example of implementing a circular economy is the cement industry, which has been using waste for many years as part of material recycling and energy recovery.

✉ Corresponding Author: Alicja Uliasz-Bocheńczyk; e-mail: aub@agh.edu.pl

[1] AGH University of Science and Technology, Faculty of Civil Engineering and Resource Management, Kraków, Poland; ORCID iD: 0000-0002-0977-9028; Scopus iD: 6506969347; Researcher iD: F-6400-2018; e-mail: aub@agh.edu.pl

[2] Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Kraków, Poland; ORCID iD: 0000-0003-4080-3660

Cement production is an energy-intensive process (Usón et al. 2013).

The cement industry is a significant emitter of CO_2 (Deja et al. 2010). Extensive urbanization in countries has led to an increase in the demand for cement and, therefore, to an increase in CO_2 emissions, which is related to the specificity of the technological production process (Miller et al. 2018). The main measures to reduce CO_2 emissions are (Zhaurova et al. 2021):

- increasing the use of renewable fuels from waste,
- reducing the ratio of clinker to cement through waste recovery.

The co-processing of secondary raw materials is seen as a winning option to reduce greenhouse gas emissions and reduce the extraction of natural resources and is an element of integrated waste management (Supino et al. 2016) for industry, society, and local governments. The cement industry can co-process waste with a high calorific value and high mineral components. Some of the waste used enables both energy and material recovery (Cembureau 2016). The co-processing of waste in the cement industry should ensure the maximum replacement of natural resources with waste that is not recyclable for technological reasons or the recycling of which is not economically or ecologically viable. In this way, cement plants use waste that, according to the hierarchy of waste management methods, should be subjected to other recovery processes or neutralized.

In cement production, waste is used as raw materials and fuels (Rahman et al. 2013). For many years, the cement industry has used waste as fuel or raw material in plants around the world, for example, in Korea (Lim et al. 2020), Germany (VDZ 2020), Japan, Taiwan (Hong et al. 2017), Australia (Mohammadi et. al. 2015), the Czech Republic (CzCA 2020), Austria (Mauschitz 2020), Italy (Supino et al. 2016), and Brazil (Natalli et al. 2021).

The waste products most frequently used as raw materials for cement production are fly ash, slag (Giergiczny 2019), cement kiln dust (Osmanovic et al. 2018), and reagypsum (Caillahua and Moura 2018). Waste such as bottom ash from municipal solid-waste incineration (Kleib et al. 2021) is also being increasingly used (VDZ 2020).

Fuels are mainly high-calorific waste, such as plastics and tires, but also include waste classified as biomass, such as sewage sludge or wood waste (Uliasz-Bocheńczyk et al. 2021).

However, not all waste can be used as raw materials in the cement industry, and the types of waste used depends on the possibility of obtaining them in a given country. The decision to use a given type of waste in a cement plant depends on many individual factors for a given plant. However, the waste used must always be of added value for the plant (Cembureau 2016), whether as part of energy recovery (R1 – use principally as a fuel or other means to generate energy) or material recovery (R5 – recycling/reclamation of other inorganic materials). Of course, the waste used in the cement industry must meet the requirements for the raw materials that they replace in the production process.

The article presents the activities of the cement industry in the recovery of waste in production processes, as well as activities aimed at reducing CO_2 emissions, as an example of industrial symbiosis.

Analysis of the literature on waste management in the cement industry revealed the lack of a comprehensive study in this area. Publications focus on the specific types of waste used as components of raw material mix or fuels. No comprehensive case study was found on the use of waste as raw materials and fuels.

This article summarizes the issue of the use of waste for cement production in terms of waste management and the reduction of CO_2 emissions, which is an innovative approach to the implementation of waste management in the cement-production sector.

The purpose of the article is to provide the reader with an in-depth analysis with regard to the waste used in cement production in Poland. The cement industry in Poland is a clear example of a positive trend in the fulfilment of sustainable development objectives. There are many reasons why it was worth choosing the cement industry in Poland for the case study analysis. First of all, there has been a relatively short period of rapid increase in the amount of waste used, without a negative impact on the quality of cement, which is reflected in the upward trend in cement production and sales.

1. Materials – cement industry data

Currently, the Polish cement industry has twelve cement plants (PCA 2010–2022).

CEM I Portland cement, CEM II Portland-composite cement, CEM III Blast furnace cement, CEM IV Pozzolanic cement, CEM V Composite cement, and other types of cement are produced (PCA 2010–2022).

The level of cement consumption in a country is commonly associated with its economic growth (Subiyanto 2020). In Poland, the level of cement production remained at comparable levels in the years 2006–2017. The increase in cement production was especially visible in 2011. The development of housing, roads, and highways as well as stadiums for EURO 2012 contributed to it. Since 2018, there has been an increase in cement production due to further investments in housing and road infrastructure. The negative impact of the COVID-19 pandemic on the economy has had little impact on the construction market in Poland, which is one of the strongest segments of the economy. The continuation of road construction and housing construction is indicated as a key factor (Cembureau 2020).

The cement industry, due to the nature of the applied technological processes, consumes significant amounts of electricity and heat energy (Figure 1). The Polish cement industry mainly uses the less energy-consuming dry method of cement production (Figure 1). In this method, the raw materials are crushed and then dried. The dry raw flour is fed into the kiln. In the wet method, the raw materials are ground with water. Raw sludge formed in this way is fed to the sludge dryer or directly to the kiln. Until 2009, both cement production methods were used in Poland, but the high energy consumed in the wet process resulted in this method being abandoned (PCA 2010–2022). Currently, more than 90% of furnaces in Europe are operated using the dry method (Cembureau 2022).

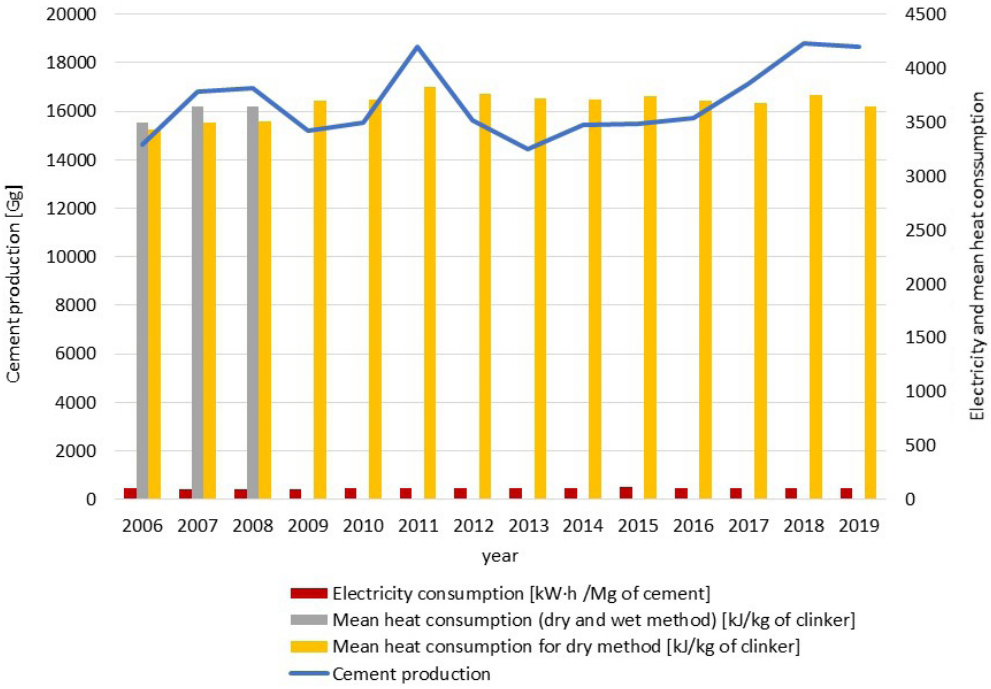

Fig. 1. Heat and electricity consumption in the cement industry in Poland (1990–2018), based on the data from PCA 2010–2022

Rys. 1. Zużycie ciepła i energii elektrycznej przez przemysł cementowy w Polsce (1990–2018)

In 2019, the average unit heat consumed was 3,649.0 kJ/kg of clinker, and the energy consumed was 103.8 kW·h/ton of cement (Figure 1).

The Polish energy industry uses bituminous coal as the main fuel because of the conditions of raw materials (Olkuski et al. 2021). However, in recent years, waste fuels have become increasingly important in the fuel economy of the cement industry. Initially, these activities were primarily related to the increasing prices of conventional fuels. However, after Poland's accession to the European Union, environmental and energy aspects of the use of energy obtained from renewable sources and waste management have become factors with a significant impact on increasing the energy recovery from waste in cement plant production processes (Uliasz-Bocheńczyk et al. 2021).

The combustion conditions in the cement kilns predispose them to using waste fuel. The temperatures in the kilns are high, and the alkaline environment of the kilns allows them to neutralize and capture acid gas components. The combustion of waste fuel in cement kilns is a waste-free process; all metallic and non-metallic incineration products undergo complete absorption (Mokrzycki and Uliasz-Bocheńczyk 2003).

2. Methods

A quantitative and qualitative analysis of the waste used in cement plants in Poland is presented in relation to material and energy recovery in cement plants.

This analysis use a qualitative case study approach (Eisenhardt 1989). We chose this method because, to quote K.M. Eisenhardt (Eisenhardt 1989): *The case study is a research strategy which focuses on understanding the dynamics present within single settings.* Authors such as Merriam (Merriam 1998), followed by Mahzouni (Mahzouni 2019), point out that *an in-depth study of a particular instance or case will illuminate that interest* thereby increasing interest in a topic that is important from an industrial, social and environmental point of view in the case of waste recovery described in the article.

The analysis is made up of two parts:

1. An analysis of the activities of cement plants in Poland in the field of using alternative fuels from waste.
2. An analysis of the use of waste in cement plants in Poland as a component of the raw material set.

The dataset covers the period 2006–2019.

The methodology focused on collecting data to compile and characterize the waste used in the cement-manufacturing sector at the national level.

For a comprehensive overview of the waste flows, annually updated publications and official statistics were reviewed (PCA 2010–2022).

The aim of this approach was to analyze the situation with respect to waste use in cement production, providing information on the possibility of obtaining secondary raw materials.

3. Results

3.1. Waste as fuels

The use of alternative fuels from waste should not be analyzed only in terms of the energy economy and fossil fuel savings. First, attention should be paid to the participation of cement plants in broadly understood waste management (Uliasz-Bocheńczyk et al. 2021).

The potential for energy recovery from waste in cement plants, carried out using the R1 energy efficiency formula and according to the limits for the landfilling of waste with a gross calorific value above 6 MJ/kg by Regulation of the Minister of Economy of 16 July 2015 on the acceptance of waste to landfills (Journal of Laws, 2015, item 1277), makes them an important element of the waste management system in Poland that help reduce expenditure on the construction of incineration plants (Uliasz-Bocheńczyk et al. 2021).

The introduction of waste landfilling limits (waste classified as groups 19 and 20) and the limited number of municipal waste-incineration plants are the reason why cement plants have become an essential part of efficient waste management favoring energy recovery carried out in accordance with a hierarchy of waste management methods (Uliasz-Bocheńczyk et al. 2021).

The combustible fractions of municipal and industrial waste are a prospective fuel for the cement industry. The experiences of the cement plants in Poland prove that the use of fuels from waste is ecological and economically justified (Mokrzycki and Uliasz-Bocheńczyk 2003). The cement industry in Poland has been successfully using this kind of fuel for many years (Figure 2), helping lower the cost of production, thus increasing competitiveness. Use of fuels made out of waste is really important for society because of economic reasons and the fact that conventional fuels can be saved, which significantly limits the negative impact on the environment (Uliasz-Bocheńczyk et al. 2021).

In the years 1998–2005, increases in the use of fuels from waste were as follows: 1998 – 1.39%, 1999 – 1.15%, 2000 – 2.07%, 2001 – 1.97%, 2002 – 4.00%, 2003 – 6.50%, 2004 – 9.90%, and 2005 – 14.0% (PCA 2010–2022; Uliasz-Bocheńczyk et al. 2021).

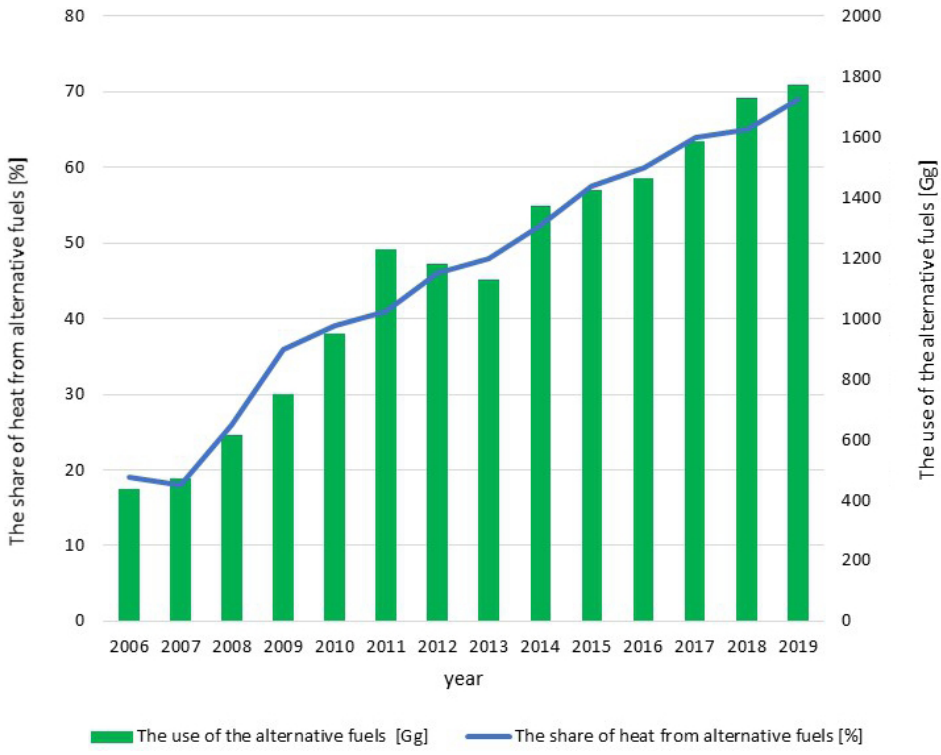

Fig. 2. The use of the alternative fuels in the cement industry (2006−2019), based on the data from PCA 2010–2022 and Uliasz-Bocheńczyk et al. 2021

Rys. 2. Wykorzystanie paliw alternatywnych w przemyśle cementowym (2006−2019)

In 2016, thermal energy substitution rates by alternative fuel in cement plants in Poland was 60%, which was higher than the global average (16.7%), Europe (44.2%), North America (15.8%), Latin America (14.2%), Asia and Oceania (9.0%), and Africa and The Middle East (6.3%) (GIZ-LafargeHolcim 2020) but was lower than Germany (64.8%) (VDZ 2020) and Austria (78.3%) (Mauschitz 2020).

The share of alternative fuels from waste in the production of cement in Poland increased (Figure 2) from 1.34% in 1997 to about 70% in 2019 and was higher than in the EU (50.0%) (PCA 2010–2022). Waste products used as alternative fuels are tires, waste fuel (19 12 10 – combustible waste (alternative fuel)), rubber waste, plastics, woodworking-industry waste, coal enrichment by flotation waste, power-plant waste, sewage sludge, and others (Table 1).

In 2019, 1,753.4 Gg of alternative fuels from waste was used (RDF – *Refuse Derived Fuel*) – 1,579.7 Gg (90.0%); tires – 89.7 Gg (5.0%); plastics and rubber – 44.3 Gg (3.0%); sewage sludge – 13.2 Gg (1.0%); others – 26.5 Gg (1.0%)) (Table 1) and only 595.9 Gg of coal (PCA 2010–2022).

Thanks to the use of biomass, the cement industry has reduced its total CO_2 emissions. The use of waste fuels may also reduce indirect CO_2 emissions because in the majority of cement plants in Poland, they are transported over shorter distances compared to conventional fuels (Uliasz-Bocheńczyk et al. 2021).

Table 1. The waste fuels used (%) in the cement industry (2009−2019)

Tabela 1. Paliwa z odpadów stosowane w przemyśle cementowym (2009–2019)

Specification	The use of the waste fuels										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
RDF	78.3	75.2	75.4	83.8	85.1	79.5	82.7	86.0	84.9	88.02	90.0
Tires and rubber scraps	8.6	9.1	9.1								
Tires				7.6	6.4	6.0	5.5	5.7	5.5	6.75	5.0
Rubber waste				1.5	1.3	2.5	2.9	4.3	4.6	2.72	
Plastics	1.8	1.7									
Plastics and rubber											3.0
Woodworking industry waste	1.6	0.7	0.1								
Coal enrichment by flotation waste	1.8	4. 1	4.0	2.4	1.8	2.1	2.1	2.1			
Power plant wastes			8.3	3.0	3.1	6.0	6.0	2.6	2.1		
Sewage sludge	0.3	1.2	1.3	0.8	0.6	0.4	0.7	0.6	0.6	0.88	1.0
Others	7.6	8.0	1.8	0.9	1.7	2.2	0.1	0.0	0.2	1.62	1.0

Source: PCA 2010–2022.

The type of alternative fuel used depends on the local conditions of waste availability. The type and amount of waste used primarily depends on the technological conditions of the plant that uses it (Uliasz-Bocheńczyk et al. 2021).

In Poland, the alternative fuel used in the largest amount is RDF, which is also used in large amounts in Germany (VDZ 2020) and in small amounts in Japan (Hong et al. 2017) but not in the Czech Republic (CzCA 2020). Tires are used in cement plants in Poland (Table 2), the Czech Republic (CzCA 2020), Germany (VDZ 2020), and Japan (Hong et al. 2017).

In the European Union countries, the use of biomass is important in terms of the European Union Emission Trading System (EU ETS). According to the Commission Implementing Regulation (EU) 2018/2066 art. 38.2 – the emission factor of biomass combustion should be zero (Commission Implementing Regulation (EU) 2018).

The price of emission allowance (EUA) in April 2022 (83.99 EUR (KOBIZE 2022) makes biomass an attractive fuel for the cement industry in the EU.

Waste such as bone meal, sewage sludge, woodworking industry waste, the biodegradable fraction of RDF (19 12 10 waste), and biodegradable waste other than municipal waste classified as 06 and 19 groups are classified as biomass (Table 1).

Fuels from biomass are used by, among others, European countries such as the Czech Republic (CzCA 2020), Germany (meat and bone meal and animal fat, waste wood, mixed fractions of municipal waste, sewage sludge (VDZ 2020), Italy (combustible waste (RDF), sewage sludge) (AITEC 2022), Bulgaria, France, Ireland, Spain, Sweden, and Portugal (Beer et al. 2017).

3.2. Waste as raw materials

The cement industry has been using waste as raw materials for the production of cement for many years (Scrivener et al. 2018).

Waste from other industries, mainly from the power industry and metallurgy, is recovered and the idea of a circular economy is implemented. It is also an important element in reducing CO_2 emissions. However, the use of waste as a component of raw material composition is limited by the standard PN-EN 197-1:2012 Cement – Part 1: Composition, specifications and conformity criteria for common cements (Giergiczny 2019).

The use of raw materials from waste, as in the case of fuels, depends primarily on their availability.

Wastes from power plants and combined heat and power plants used for cement production are: fly ash (1,505.1 Gg in 2006 and 1,863.2 Gg in 2019), reagypsum/phosphogypsum (288.7 Gg in 2006 and 702.0 Gg in 2019), fluidized-bed combustion fly ash (48.5 Gg in 2006 and 25.8 Gg in 2019), and fluidized bed combustion bottom ash (30.2 Gg in 2012 and 27.5 Gg in 2019) (PCA 2010–2022) (Table 2). The use of coal in energy-production processes produces combustion by-products that are used successfully by the cement industry (Table 2).

Table 2. Use of waste (Gg) as additives in clinker and cement production in 2006–2018

Tabela 2. Wykorzystanie odpadów [Gg] jako dodatków do produkcji klinkieru i cementu w latach 2006–2018

Specification	The use of the waste as additives in clinker and cement production													
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Fly ash	1,505.1	1,949.9	1,965.4	1,781.8	1850.9	2,007.2	1,864.3	1,601.5	1,360.5	1,437.9	1,476.8	1,468.4	1,578.4	1,863.2
Granulated blast furnace slag	1,767.7	2,058.8	2,038.2	1,328.0	1,523.9	1,614.8	1,399.1	1,263.6	1,395.9	1,672.0	1,801.8	2,017.4	2,124.3	1,939.4
Reagypsum/phosphogypsum	288.7	281.9	342.9	410.0	447.6	470.9	485.5	482.6	543.7	538.1	555.0	628.0	718.4	702.0
Iron bearings						151.8	311.8	124.0	157.2	167.8	170.9	192.7	249.9	241.2
Fluidized bed combustion fly ash	48.5	85.0	74.0	42.1	23.5	32.8	31.9	22.2	24.1	28.8	28.3	28.3	23.6	25.8
Cement kiln dust + by-pass kiln dust						24.8	12.9	11.3	9.0	13.9	15.0	N/A	13.6	28.5
Burned slate						23.9	31.3	24.9	39.2	165.3	30.0	203.1	44.7	227.8
Fluidized-bed combustion bottom ash							30.2	27.0	35.1	2.4	N/A	N/A	24.3	27.4
Others	482.5	549.6	762.6	749.7	225.4	42.5	72.8	4.1	14.7	77.3	14.1	70.8	74.3	59.4

Source: PCA 2010–2022.

Countries that burn coal in the energy sector use fly ash in cement production, such as Poland, Germany (VDZ 2020), Austria (Mauschitz 2020), Italy (Supino et al. 2016) and Australia (Mauschitz 2020). Brazil and Italy also use energy waste in the form of fly ash from peat and untreated wood, calcium-based reaction wastes from flue-gas desulfurization in solid form, silica fume and rice-husk ash (Natalli et al. 2021). The cement industry in Austria also uses reagypsum (Mauschitz 2020).

The second quantitatively used waste group as raw materials in the cement industry is waste from metallurgy. In Poland, these are granulated blast furnace slag (1,767.7 Gg in 2006 and 1,939.4 Gg in 2019) and iron bearings (151.8 Gg in 2011 and 241.2 Gg in 2019) (PCA 2010–2022) (Table 2).

Granulated blast furnace slag is used in Poland, Germany (VDZ 2020), Austria (Mauschitz 2020) and Brazil (Natalli et al. 2021). In Germany, they also use roasted pyrite, contaminated ore, iron-oxide fly-ash blends, dust from steel plants, and mill scale (VDZ 2020).

A clean form of circular economy is the use of waste generated in cement production (cement kiln dust and by-pass kiln dust (24.8 Gg in 2011 and 28.5 Gg in 2019) (PCA 2010–2022) as raw materials in the primary process.

Discussion and conclusions

For a more complete characterization of the use of alternative fuels, the physical indicator, SAFs (Specific Alternative Fuels) proposed in Hong et al. (Hong et al. 2017) was calculated (Figure 3):

$$SAFs = \text{the amount of specific alternative fuels/total clinker production} \quad (1)$$

The calculated index (SAFs) for the cement industry in Poland is 125.86 and is lower than the index calculated for Germany (136.0) but much higher than the index for Japan (33.4) (Hong et al. 2017).

The increase in the consumption of alternative fuels is particularly visible through the analysis of the SAFs indicator, which increased from 39.07 kg AFs/Mg clinker in 2006 to 125.86 kg AFs/ton clinker in 2019.

Using the formula proposed in Hong et al. (Hong et al. 2017), the physical indicator of the use of waste as raw materials in cement production was calculated (Figure 3):

$$SWRM = \text{the amount of specific waste raw materials/total cement production} \quad (2)$$

The amount of specific waste raw materials/total cement production (Figure 3) was 280.0 Gg waste raw material/Gg cement in 2006 and 270 Gg waste raw material/Gg cement in 2019.

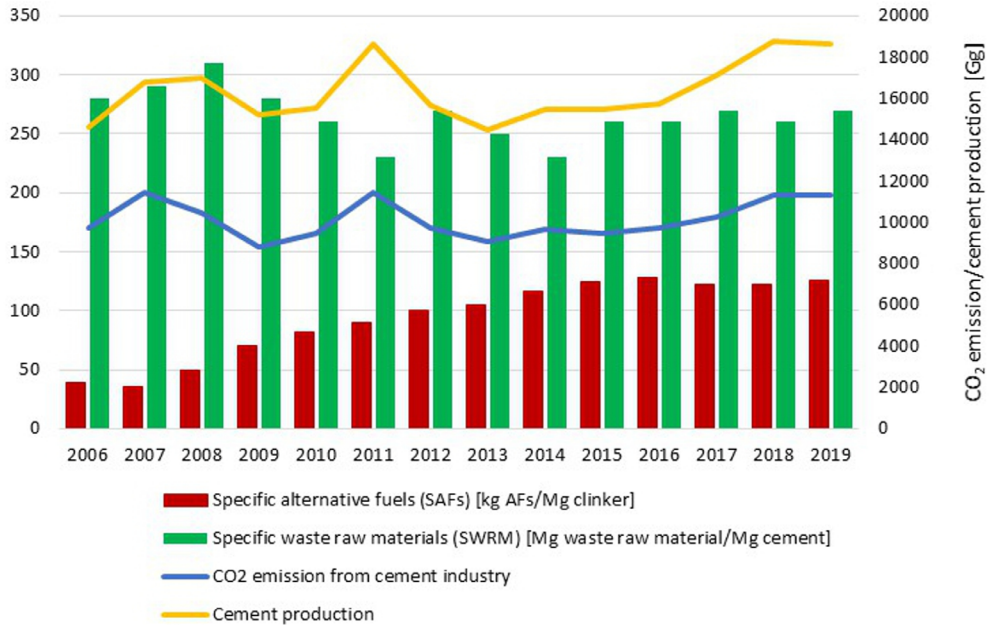

Fig. 3. Dependence of CO_2 emissions on the use of fuels from waste and waste raw materials and cement production – CO_2 emissions and cement production based on the data from PCA 2010–2022

Rys. 3. Zależność emisji CO_2 od zużycia paliw z odpadów oraz surowców odpadowych do produkcji odpadów i cementu – emisje CO_2 i produkcja cementu

The maintenance of the index at a comparable level is mainly related to the standard limitations in the composition of cement.

The factor that will influence the increase in the use of biomass is the increasing price of allowances.

The cement industry has a significant role to play in the implementation of a circular economy in Poland. This industry recovers municipal and industrial waste generated in the production process. The activities of the cement industry in the field of waste recovery are in line with the concept of a circular economy on the way to achieving sustainable development and the climate neutrality goals set out in the Green Deal.

In addition, many European countries have increased the range of waste and reduced the clinker content in cement to reduce the consumption of natural resources, while reducing direct and indirect CO_2 emissions.

Industrial waste from metallurgy, power plants, heat and power plants, wastewater treatment plants, and municipal waste is used as the raw material and fuels for the cement industry, leading to industrial symbiosis.

The example of the cement industry in Poland shows that within 20 years, the amount of waste used in cement production can be considerably increased, contributing significantly to closing the circulation of raw materials. This study has illustrated how waste recovery

has contributed to coming closer to achieving the sustainable development that the cement industry in Poland has been experiencing.

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REFERENCES

AITEC 2022 − Associazione Italiana Tecnico Economica del Cemento 2022. *Recupero di energia*. [Online:] https://www.aitecweb.com/Sostenibilità/Economia-circolare/Recupero-di-energia [Accessed: 2022-05-17].

Beer et. al. 2017 – Beer, J. de, Cihlar, J., Hensing, I. and Zabeti, M. 2017. *Status and prospects of co-processing of waste in EU cement plants*.

Caillahua, M.C. and Moura, F.J. 2018. Technical feasibility for use of FGD gypsum as an additive setting time retarder for Portland cement. *Journal of Materials Research and Technology* 7(2), pp. 190–197, DOI: 10.1016/j.jmrt.2017.08.005.

Cembureau 2016 – *Cement, concrete & the circular economy*. [Online:] https://circulareconomy.europa.eu/platform/en/knowledge/cement-concrete-circular-economy [Accessed: 2022-06-19].

Cembureau 2022 – *The role of CEMENT in the 2050 LOW CARBON ECONOMY*. [Online:] https://lowcarboneconomy.cembureau.eu/ [Accessed: 2022-06-19].

Cembureau 2020 – *Activity Report 2020*. [Online:] https://cembureau.eu/library/reports/ [Accessed: 2022-05-13].

Commission Implementing Regulation (EU) 2018 – *Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601*.

CzCA 2020 − Czech Cement Association 2021. *Data 2020 . Svaz výrobců cementu České republiky Czech Cement Association*.

Deja et al. 2010 − Deja, J., Uliasz-Bocheńczyk, A. and Mokrzycki, E. 2010. CO_2 emissions from Polish cement industry. *International Journal of Greenhouse Gas Control* 4(4), pp. 583–588, DOI: 10.1016/j.ijggc.2010.02.002.

Eisenhardt, K.M. 1989. Building Theories from Case Study Research. *The Academy of Management Review* 14(4), pp. 532–550.

Natalli et al. 2021 − Natalli, J.F., Christo Silveira Thomaz, E., Castro Mendes, J., André Fiorotti Peixoto, R.S., Thomaz, E.C., Mendes, J.C. and Peixoto, F.R.A. 2021. A review on the evolution of Portland cement and chemical admixtures in Brazil. *Revista IBRACON de Estruturas e Materiais* 14(6), DOI: 10.1590/S1983-41952021000600003.

Giergiczny, Z. 2019. Fly ash and slag. *Cement and Concrete Research* 124, DOI: 10.1016/j.cemconres.2019.105826.

GIZ-LafargeHolcim 2020 – *GIZ-LafargeHolcim, Guidelines on Pre- and Co-processing of Waste in Cement Production – Use of waste as alternative fuel and raw material*. 2020. [Online:] https://www.giz.de/en/html/index.html [Accessed: 2022-06-19].

Hong et. al. 2017 – Hong, G.B., Huang, C.F., Lin, H.C. and Pan, T.C. 2017. Strategies for the utilization of alternative fuels in the cement industry. *Carbon Management* 9(1), pp. 95–103, DOI: 10.1080/17583004.2017.1409044.

Kleib et. al. 2021 – Kleib, J., Aouad, G., Abriak, N.E. and Benzerzour, M. 2021. Production of Portland cement clinker from French Municipal Solid Waste Incineration Bottom Ash. *Case Studies in Construction Materials* 15, DOI: 10.1016/j.cscm.2021.e00629.

KOBIZE 2022 − The National Centre for Emissions Management (KOBiZE) 2022. *CO_2 market report*. [Online:] https://www.kobize.pl/pl/category/id/92/aktualnosci–2022 [Accessed: 2022-06-19].

Lim et. al. 2020 – Lim, C., Jung, E., Lee, S., Jang, C., Oh, C. and Nam Shin, K. 2020. Global Trend of Cement Production and Utilization of Circular Resources. *Journal of Energy Engineering* 29(3), pp. 57–63, DOI: 10.5855/ENERGY.2020.29.3.057.

Mauschitz, G. 2020. *Emissionen aus Anlagen der österreichischen Zementindustrie Berichtsjahr 2020*.

Mahzouni, A. 2019. The role of institutional entrepreneurship in emerging energy communities: The town of St. Peter in Germany. *Renewable and Sustainable Energy Reviews* 107, pp. 297–308, DOI: 10.1016/j.rser.2019.03.011.

Merriam, S.B. 1998. *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education"*. Jossey-Bass Publishers, 350 Sansome St, San Francisco, 275 p.

Miller et. al. 2018 – Miller, S.A., John, V.M., Pacca, S.A. and Horvath, A. 2018. Carbon dioxide reduction potential in the global cement industry by 2050. *Cement and Concrete Research* 114, pp. 115–124, DOI: 10.1016/j.cemconres.2017.08.026.

Mohammadi et. al. 2015 − Mohammadi, J., South, W., Chalmers, D., 2015. *Towards a More Sustainable Australian Cement and Concrete Industry*. Proceedings of the concrete 2015 conference: 27th biennial national conference of the concrete institute of Australia in conjunction with the 69th RILEM week conference, 2015, pp. 596–603.

Mokrzycki, E. and Uliasz- Bocheńczyk, A. 2003. Alternative fuels for the cement industry. *Applied Energy* 74(1), pp. 95–100, DOI: 10.1016/S0306-2619(02)00135-6.

Olkuski et al. 2021 – Olkuski, T., Suwała, W., Wyrwa, A., Zyśk, J. and Tora, B. 2021. Primary energy consumption in selected EU Countries compared to global trends. *Open Chemistry* 19(1), DOI: 10.1515/chem-2021-0046.

Osmanovic et. al. 2018 – Osmanovic, Z., Haračić, N. and Zelić, J. 2018. Properties of blastfurnace cements (CEM III/A, B, C) based on Portland cement clinker, blastfurnace slag and cement kiln dusts. *Cement and Concrete Composites* 91, pp. 189–197, DOI: 10.1016/j.cemconcomp.2018.05.006.

PCA 2010–2022 − The Polish Cement Association 2010–2020. *Bulletin of The Polish Cement Association 2010–2022*. [Online:] http://www.polskicement.pl/l/Informatory-112 [Accessed: 2022-06-19].

Rahman et. al. 2013 – Rahman, A., Rasul, M.G., Khan, M.M.K. and Sharma, S. 2013. Impact of alternative fuels on the cement manufacturing plant performance: An overview. *Procedia Engineering* 56, pp. 393–400, DOI: 10.1016/j.proeng.2013.03.138.

Regulation of the Minister of Economy of 16 July 2015 on the acceptance of waste to landfills *(Journal of Laws*, 2015, item 1277).

Scrivener et. al. 2018 – Scrivener, K.L., John, V.M. and Gartner, E.M. 2018. Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. *Cement and Concrete Research* 114, pp. 2–26, DOI: 10.1016/j.cemconres.2018.03.015.

Subiyanto, E. 2020. The Relationship of Cement Consumption and Economic Growth: An Updated Approach. *European research studies journal* 23(3), pp. 280–295, DOI: 10.35808/ersj/1638.

Supino et al. 2016 − Supino, S., Malandrino, O., Testa, M. and Sica, D. 2016. Sustainability in the EU cement industry: the Italian and German experiences. *Journal of Cleaner Production* 112, pp. 430–442, DOI: 10.1016/j.jclepro.2015.09.022.

Uliasz-Bocheńczyk et. al. 2021 − Uliasz-Bocheńczyk, A., Deja, J. and Mokrzycki, E. 2021. The use of alternative fuels in the cement industry as part of circular economy. *Archives of Environmental Protection* 47(4), pp. 109––117, DOI: 10.24425/aep.2021.139507.

Usón et. al. 2013 − Usón, A., López-Sabirón, A.M., Ferreira, G. and Llera Sastresa, E. 2013. Uses of alternative fuels and raw materials in the cement industry as sustainable waste management options. *Renewable and Sustainable Energy Reviews* 23, pp. 242–260, DOI: 10.1016/j.rser.2013.02.024.

VDZ 2020 − Verein Deutscher Zementwerke e.V. 2020. *Umweltdaten der deutschen Zementindustrie Environmental Data of the German Cement Industry. 2020*.

Zhaurova et. al. 2021 − Zhaurova, M., Soukka, R. and Horttanainen, M. 2021. Multi-criteria evaluation of CO_2 utilization options for cement plants using the example of Finland. *International Journal of Greenhouse Gas Control* 112, DOI: 10.1016/j.ijggc.2021.103481.

THE USE OF WASTE IN CEMENT PRODUCTION IN POLAND – THE MOVE TOWARDS SUSTAINABLE DEVELOPMENT

Keywords

case study, cement industry, alternative fuels, mineral waste, industrial symbiosis

Abstract

The cement industry has been using waste as a raw material for many years. Waste is also used as alternative fuel. Cement plants are an important element of the waste management system and fit the idea of a circular economy. When waste is recovered in the cement production process, direct and indirect CO_2 emissions are partially avoided. This article discusses the cement industry in Poland. The current situation in terms of the use of alternative fuels and raw materials in Poland, the different types of waste and the amount of waste used is discussed. The article discusses changes in the amount of waste (the increase in the amount of waste used as raw materials from the year 2006 to the year 2019) and the types of waste recovered in the cement production process and the possibility of closing material cycles on the plant scale (recycling to the primary process – cement kiln dust) and industry (using waste from other industries: metallurgy – granulated blast furnace slag, iron bearings; energy production – fly ash, reagypsum/phosphogypsum, fluidized bed combustion fly ash, and fluidized bed combustion bottom ash; wastewater treatment plants – sewage sludge, etc.). The analysis shows that the role of cement plants in waste management and the circular economy in Poland is important. Industrial waste from metallurgy, power plants, heat and power plants, wastewater treatment plants, and municipal waste is used as the raw material for the cement industry, leading to an industrial symbiosis.

ODPADY W PRODUKCJI CEMENTU W POLSCE – W KIERUNKU ZRÓWNOWAŻONEGO ROZWOJU

Słowa kluczowe

case study, przemysł cementowy, paliwa alternatywne, odpady mineralne, symbioza przemysłowa

Streszczenie

Przemysł cementowy od wielu lat wykorzystuje odpady przemysłowe i komunalne jako surowce mineralne oraz energetyczne. prowadząc do symbiozy przemysłowej. Cementownie są ważnym elementem systemu gospodarki odpadami i wpisują się w ideę gospodarki o obiegu zamkniętym. Odzysk odpadów w procesie produkcji cementu przekłada się na częściowe uniknięcie bezpośredniej i pośredniej emisji CO_2.

W artykule omówiono zmiany ilościowe stosowanych odpadów (wzrost ilości odpadów wykorzystywanych jako surowcew latach 2006–2019), jak również rodzaje odpadów poddanych odzyskowi w procesie produkcji cementu oraz możliwość zamknięcia obiegów materiałowych na skalę zakła-

dową (recykling w ramach procesu pierwotnego – pył z pieca cementowego) i przemysłową (wykorzystywanie odpadów z innych gałęzi przemysłu: hutnictwo – granulowany żużel wielkopiecowy, dodatki żelazonośne; produkcja energii – popiół lotny, reagips/fosfogips, popioły fluidalne; oczyszczalnie ścieków – osady ściekowe itp.). Przeprowadzona w artykule analiza wskazuje na istotną rolę cementowni w systemie gospodarki odpadami i gospodarce o obiegu zamkniętym w Polsce.