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# The implementation of Circular Economy Concept in the Polish Coal Combustion Products Sector – selected problems

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**Abstract:** The EU economy is currently losing a significant amount of potential secondary raw materials which are present in waste streams (particular numerical data are presented in the paper). In the total amount of generated waste, the share of Coal Combustion Products (CCPs) and Coal Mining Products (CMPs) is particularly high, which is generated mainly by Central and Eastern European Countries (CEECs), where we come to deal with high consumption of energy produced by coal combustion and coal mining processes. The problem concerns, in particular, the Polish economy. Consequently, the European Commission (EC) has developed a closed-loop (circular) economy concept (CEC), whose implementation should contribute to reducing CCPs negative impact on the economy, not only in the ecological, but also in social and economic aspects. Closed-loop (circular) economy keeps products, parts and materials in economic circulation, as long as possible, using as little resources as possible. This concept was presented in the document published by the European Commission: Circular Economy Package, which also includes *the Communication of the Commission: Closing the Loop – An EU Action Plan for the Circular Economy (2015)*. Recent trends suggest that further progress in resource efficiency is possible and it can bring major economic, environmental and social benefits. Turning waste, especially CCPs, into a resource is an essential part of increasing resource efficiency and closing the loop in a circular economy. There are four key areas of CCPs use: construction, road construction, energy and road maintenance. Increasing the use of CCPs can be achieved by granting a legal status to waste products and convincing consumers and business of the following benefits of using them: decreasing production costs by substituting natural aggregate with waste aggregates (based on CCPs), reducing greenhouse gas emissions, and increasing energy efficiency. As a result,

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CCPs must comply with certain technical standards set by the EU and implemented in the Polish economy. The study attempts to estimate, using comparative analysis, the economic, social and environmental benefits of implementation of CEC in the CCPs sector of the Polish economy.

***Keywords:*** Circular Economy Concept (CEC) implementation, Coal Combustion Products (CCPs), the EU and the Polish economies.

**JEL codes:** Q31, Q32, Q53.

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## 1. Introduction

The EU economy is currently losing a significant amount of potential secondary raw materials which are present in waste streams. In 2013, the total waste generation in the EU amounted to approximately 2.5 billion tons of which 1.6 billion tons were not reused or recycled and therefore are considered a loss for the European economy. It is estimated that an additional 600 million tons could be recycled or reused (Stopińska, 2015). By the way of example, only a limited share (43%) of the municipal waste generated in the EU was recycled, with the rest being landfilled (31%) or incinerated (26%). The EU thus misses out on significant opportunities to improve resource efficiency and create a more circular economy. With respect to waste management, the EU also faces large differences amongst its Member States. In 2011, while six Member States landfilled less than 3% of their municipal waste, 18 landfilled over 50%, with some exceeding 90%. This uneven situation needs to be redressed as a matter of urgency. The proposals to amend Directive 2008/98/EC on waste, Directive 94/62/EC on packaging and packaging waste, Directive 1999/31/EC on the landfill of waste, Directive 2000/53/EC on end-of-life vehicles, Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators and Directive 2012/19/EU on waste electrical and electronic equipment (COM(2014)397 Final) form part of *a Circular Economy Package (CEP)* (EP, 2016) which also includes *European Commission Communication: Closing the Loop – An EU Action Plan for the Circular Economy* ((COM)2015a; (COM)2015b).

Every year around 700 million tons of anthropogenic minerals (AM) are generated in Europe, including about 150 million tons of Coal Combustion Products (CCPs) in the power industry. More than 100 million tons are produced in 28 Member States of the European Union, of which more than 20 million tons in Poland (Stopińska, 2015).

The main way of obtaining electricity in Poland is burning coal. This process is related to CCPs, also called anthropogenic minerals from the power industry. CCPs are very widely used, mainly in: construction, road construction, mining technology, land reclamation

(especially post-industrial), agriculture and winter maintenance of roads. Due to the European Union's raw material policy strategy it is assumed that for the development of an efficient economy it is necessary to maximize the use of recyclables, minimizing the consumption of raw materials. The development of AM from energy and heating is in line with the idea of a circular economy. Due to the predominant role played by coal, especially stone, in the Polish power industry and restrictive European Union environmental legislation, there is a need to draw attention to the use of CCPs. The introduction of appropriate legislation and numerous studies in this direction have rendered useless waste in today's technology a valuable resource, not only economically, but also socially and environmentally (Stopińska, 2015).

As a result, CCPs must comply with certain technical standards set by the EU and be implemented in the Polish economy. The present study attempts to estimate, using comparative analysis, the economic, social and environmental benefits of implementation of *the Circular Economy concept* to the CCP sector of the Polish economy.

## 2. Circular Economy Concept (CEC) and possibilities of its implementation in the EU economy

### 2.1. The origin and the essence of CEC, its importance for sustaining the socio-economic development

The term *Circular Economy* (CE) appeared to be formally used in an economic model for the first time by Pearce and Turner (1990). They took a critical look *at the traditional linear economic system's approach and developed a n*ew opposed economic model, called the *Circular Economy*, based mainly on the principles of the first and second laws of thermodynamics.

Over the past decades, a considerable corpus of literature has emerged, which has influenced the present understanding of *the Circular Economy Concept (CEC)* (Lieder; Rashid, 2016). Industrial ecology is a research discipline underpinned by a system approach and involving a holistic perspective on economic activity and sustainability (Garner; Keoleian, 1995). The main conclusion from these considerations is that the natural ecosystem and man-made industrial system operate in a similar way and they are both characterized by flows of materials, energy and information (Erkman, 1997; Ehrenfeld, 2007).

In subsequent years there have been many further attempts to define the CE. They were influenced by several important concepts. Many of their authors have provided resource-oriented definitions and/or interpretations, underlining the need to create closed loops of

material flows and to reduce consumption of scarce and/or non-renewable resources and their negative environmental impacts.

Sauvé et al. (2016: 49), state that the CEC applies to the 'production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution).' In their opinion, the principal focus of the CE is tending to the limitation of resource consumption, pollution and waste at each stage of the life cycle of the product. According to Preston (2012: 1), '*Circular Economy* is an approach that would transform the function of resources in the economy. Waste from factories would become a valuable input to another process – and products could be repaired, reused or upgraded instead of thrown away.' In a similar way, EEA (2014: 11) states that CE 'refers mainly to physical and material resource aspects of the economy – it focuses on recycling, limiting and re-using the physical inputs to the economy, and using waste as a resource leading to reduced primary resource consumption.' Moreover, WRAP (2015) emphasizes the importance in the scope of CEC of keeping resources in use for as long as possible, as well as extracting the maximum value from products and materials through using them for as long as possible by recovering and reusing them. CEPS Research Report (2017) identified the following processes that can be classified into three categories: i) using less primary resources (realized through: recycling, efficient use of resources and utilization of renewable energy sources), ii) maintaining the highest value of materials and products (realized through: remanufacturing, refurbishment, re-use of products and components and product life extension) and iii) changing utilization patterns (realized through: treating product as service, sharing models and shifting in consumption patterns). The categories of circular processes are not mutually exclusive. Many of their elements are often interlinked. In some cases businesses can adopt a strategy involving multiple circular processes (see, for example, Rizos et al., 2016).

The CEC keeps products, parts and materials in economic circulation, as long as possible, using as little resources as possible. Ideally, this implies a direct secondary use of the products, preserving both the deliberately constructed nature of the product and its functional function. Products can be prepared for longer service life, i.e., business models involving product leasing, or transition from product delivery to functional delivery. Where a product needs repairing before it can be reused or reassembling, it retains most of its original value. These are the strictest 'loops' in the CE. Another of the best paths is recycling: it is ideally a closed loop, converting products into materials that are used to recreate the products from which they were recovered. Otherwise, open loop recycling, or descending recycling, creates materials

that are less valuable. A less developed but potentially large part of the future closed-loop economy is a bio-economy where waste biological products are re-used to capture energy or create new products, such as using agricultural waste to produce biogas or bioplastics.

The concept of developing a framework of business model for the Circular Economy were presented on Figure 1. The CEC was presented in the above-mentioned document: Closing the Loop – An EU Action Plan for the Circular Economy (COM2015). The transition to the circular economy entails four fundamental building blocks:

- materials and product design,
- new business models,
- global reverse networks,
- enabling conditions.

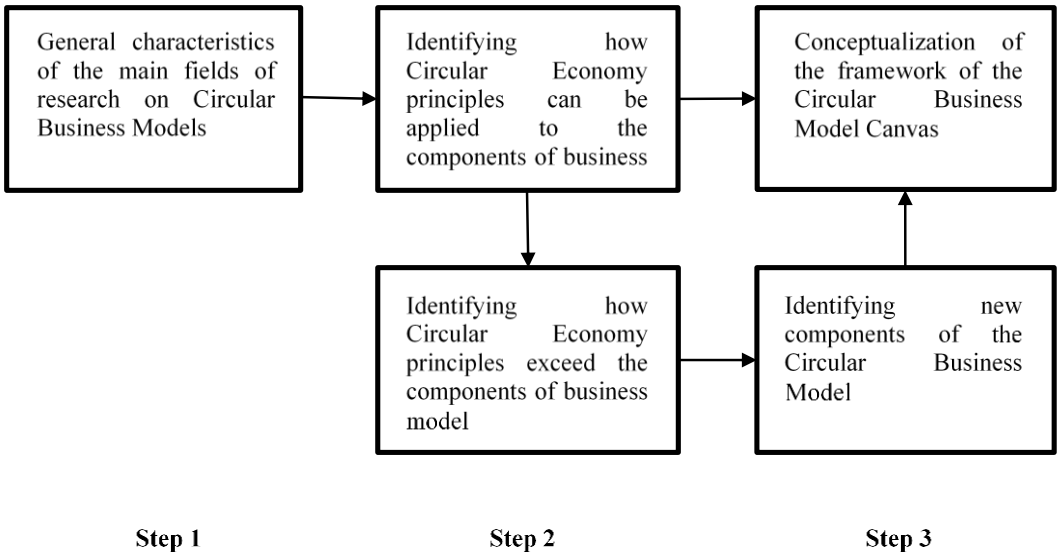


**Figure 1.** The concept of developing a framework of business model for the Circular Economy
Source: Lewandowski, 2016: 2.

Switching an economy to a circular one depends, on the one hand, on policymakers and their decisions; on the other hand, it depends on introducing circularity into their business models by business entities.

## 2.2. Problems of the CEC implementation in the EU economy

### 2.2.1. Grounds for and objectives of the CEC implementation in the EU economy

Persistent long-term recession trends in the EU economy suggest that further progress on resource efficiency is possible and that it can bring major economic, environmental and

social benefits. Turning waste into a resource is an essential part of increasing resource efficiency and closing the loop in a circular economy. The legally binding targets in the EU waste legislation have been a key driver to improve waste management practices, stimulate innovation in recycling, limit the use of landfilling, and create incentives to change consumer behavior. Taking waste policy further can bring significant benefits: sustainable growth and job creation, reduced greenhouse gas emissions, direct savings linked with better waste management practices, and a better environment. The proposal to amend Directive 2008/98/EC responds to the legal obligation to review the waste management targets in that Directive. The proposals which form part of the Circular Economy Package and amend the six Directives mentioned above build in part on the proposal that the Commission tabled in July 2014 and subsequently withdrew in February 2015. They are in line with the objectives of the Resource Efficiency Roadmap (COM(2011)571 Final) and the 7th Environment Action Programme (Decision No 1386/2013/EU), including full implementation of the waste hierarchy in all Member States, decline in absolute and per capita waste generation, ensuring high quality recycling and the use of recycled waste as a major, reliable source of raw materials for the Union. They also contribute to the implementation of the EU Raw Materials Initiative (COM(2008)699 Final) and the EU Review of the List of Critical Raw Materials (COM(2014)297 Final) to address the need to prevent food waste. In addition, these proposals simplify the reporting requirements included in all six EU Directives which were amended by Proposal for a Directive of the European Parliament and of the Council (COM(2014)397 Final).

### 2.2.2. The proposed action

The main elements of the proposals to amend EU waste legislation are:

- alignment of definitions,
- increase in the preparing for re-use and recycling target for municipal waste to 65% by 2030,
- increase in the preparing for reuse and recycling targets for packaging waste and the simplification of the set of targets,
- gradual limitation of the landfilling of municipal waste to 10% by 2030,
- greater harmonization and simplification of the legal framework on by-products and end-of-waste status,
- new measures to promote prevention, including food waste, and re-use,
- introduction of minimum operating conditions for *Extended Producer Responsibility*,

- introduction of an Early Warning System for monitoring compliance with the recycling targets,
- simplification and streamlining of reporting obligations,
- alignment to Articles 290 and 291 TFEU (2012) on delegated and implementing acts.
- The proposals will not have an impact on the European Union budget and are therefore not accompanied by the financial statement provided for under Article 31 of the Financial Regulation (EU; Euratom, 2012).
- The impact assessment led to the conclusion that an implementation of the CEC will bring the following benefits for the EU:
- administrative burden reduction in particular for small establishments or undertakings, simplification and better implementation including by keeping targets 'fit for purpose',
- job creation – more than 170,000 direct jobs could be created by 2035, most of them impossible to delocalize outside the EU,
- GHG emission reduction – more than 600 million tons of GHG could be avoided between 2015 and 2035,
- positive effects on the competitiveness of the EU waste management and recycling sectors as well as on the EU manufacturing sector (better extended producer responsibility schemes, reduced risks associated with raw material access),
- reinjection into the EU economy of secondary raw materials which, in turn, will reduce the dependency of the EU on raw materials imports.

## 2.3. Legal acts and regulations determining methods of the CEC implementation to the EU/Polish economy

### 2.3.1. EU economy

At the EU level, the European Commission (2015: 2) has included a description of the concept in its *Communication Closing the loop – An EU Action Plan for the Circular Economy*, which is part of the Circular Economy Package. Specifically, the *Circular Economy* is described as an economy 'where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized.' The transition to a more circular economy would make an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy. In this context, the *EU Action Plan* includes a series of measures aimed at addressing the full product cycle from production and consumption to waste management and the market for secondary raw materials.

The Commission has implemented the EU trade strategy for raw materials in line with the priorities set out in its 2008 and 2011 Communications on raw materials, promoting a sustainable supply of raw materials from non-EU countries. This is a three-pronged strategy which involves the following:

- securing agreement on international optimal trade disciplines and on export restrictions in bilateral and multilateral negotiations,
- effectively enforcing international rules and tackling restrictions, through dialogue, in the market access strategy, and through the World Trade Organization (WTO) dispute resolution process,
- raising non-EU countries' awareness of policies on trade in raw materials and developing best practice through bilateral dialogue and in international forums such as the *G8/G7, G20, OECD and the United Nations Conference on Trade and Development (UNCTAD)*. The European Commission regularly reports on progress in the implementation of the EU trade strategy for raw materials and participates in meetings and workshops involving Member States, industry associations and Non-Governmental Organizations.

*The European Resource Efficiency Platform (EREP)* was set up to provide high-level guidance on the transition to a more resource-efficient economy, stimulating growth and business opportunities. EREP issued recommendations in June 2013 and in March 2014. They include:

- moving towards a circular economy and promoting high-quality recycling,
- improving resource efficiency in business-to-business relations, in particular sustainable sourcing standards,
- putting a coherent, resource-efficient product policy framework in place.

Under the environmental theme of *the EU's Seventh Framework Programme for research and technological development (FP7)*, the Commission approved funding for 14 resource efficiency projects in October 2013. The projects involved over 140 partners from 19 European countries, research organizations and private companies. They tackled the challenges of recycling waste materials from manufactured products and the agricultural sector. The funds for the projects were EUR 40 million.

### 2.3.2. The Polish economy

Transition to the CE, where the value of products, materials and the raw materials are retained as long as possible while minimizing waste generation is an important element in

creating a low carbon, resource efficient, an innovative and competitive economy of Poland. Depletion of raw materials, increase in their prices and increasing dependence on suppliers from third countries poses a serious threat to further development and is an economic and environmental challenge. That is why it is necessary to take activities that will comprehensively deal with products and services from the raw material acquisition stage through design, production, consumption, and waste management. This last stage is key in the CEC. Waste - if need be - should be treated as secondary raw material. All activities preceding the incineration of waste in earlier stages are intended product life or service. At the same time, CEC aims to increase Polish innovativeness entrepreneurs and increase their competitiveness in relation to entities from other parts of Europe and the world (Roadmap, 2016).

At the end of 2015, the European Commission published (COM2015). It is a set of proposals for the coming years to be fulfilled in the European Union to contribute to the change in the economic model in this respect in force. It contains activities covering all stages of the life cycle, and moreover it focuses on several priority areas such as plastics, food waste, critical raw materials, demolition and construction waste and biomass and bioproducts. The message underlines the role of innovation for the CEC construction.

One of the conclusions of *the EU Ministers Meeting in the Environment Council* in June 2016 was to propose that the Member States - following the European Commission - develop their national programs implementing the CEC. It is necessary to make this new model of the economy have a comprehensive and coherent basis and be implemented at all levels - from the EU, through Member States to regions, provinces and municipalities. This document attempts to propose actions at the national level.

It is also important to have consistency in the implementation of the CEC with other areas. That is why, preparation of a road map of transformation towards a closed-loop economy for Poland is one of the strategic projects of the *Strategia* (2017). It includes an overall vision of the country's development. During the work on the Strategy project a number of challenges facing Poland were identified. Among them there should be the imbalance in the markets, as well as raw materials and price competition for their exporters threatening economic destabilization and decline in innovation, as well as threatening to weaken the dynamics of the world economy, and all the problems of the most important economic partners in Poland, including the development situation in the EU. A priori it can be stated that the CEC tries to face the above indicated challenges.

*The Roadmap* is intended to identify particular actions to increase resource efficiency and waste reduction. Including, however, a much broader scope of activities, it has to

comprehensively propose tools to move from a *Linear Economy to a Circular Economy*. Also, looking more broadly, it is supposed to be one of the main objectives of the Strategy for Responsible Development (2016) implementation, i.e. creation of conditions for increasing incomes of the inhabitants of Poland while increasing cohesion in social, economic and territorial dimensions.

Following the public consultation in 2015, a Polish Circular Economy non-paper (2015) was developed. It is a document identifying the main priorities for Poland which should be included in (COM2015), developed right at this time by the European Commission. According to this paper the key elements of building the CE in Poland are the following:

- innovativeness, strengthening cooperation between industry and the science sector, and in a consequence: implementing innovative solutions in the economy,
- creating a European market for secondary raw materials, which would facilitate their flow,
- ensure high quality secondary raw materials, resulting from sustainable production and consumption,
- development of the services sector.

The actions proposed in the *Road Map* (2016) should therefore contribute to the implementation of these four Polish priorities.

## 3. Importance of the Coal Combustion Products management for effectiveness of the CEC implementation to the Polish economy

### 3.1. Coal Combustion Products – definition, origin, types, possibilities and profits from using in the economy

*Coal Combustion Products* (CCPs) are anthropogenic mineral substances produced by combustion of hard coal and lignite in power boilers. According to a broader definition, CCPs are anthropogenic minerals produced by coal combustion in power companies: power plants, combined heat and power plants and heat plants. These minerals come from coal, but in the process of its combustion only their transformation is used. Recent trends suggest that further progress in resource efficiency is possible and it can bring major economic, environmental and social benefits. Turning waste into a resource is an essential part of increasing resource efficiency and closing the loop in the CE. There are four key areas of CCPs use: construction, road construction, energy and road maintenance. Increasing the use of CCPs can be achieved

by granting a legal status to waste products and convincing consumers and businesses to the following benefits of using them:

- decreasing production costs by substituting natural aggregate with waste aggregates (based on CCPs),
- reducing greenhouse gas emissions,
- increasing energy efficiency.

There are many ways to develop CCPs in different industries. For example, in construction, fly ash and fluid ash are used for concrete mixtures, but they are also a basic raw material or slimming material in building ceramics. They can also serve as building binders or cement additives. CCPs are used in the mining industry for sealing works, liquidation of excavations, as well as for fire prevention by isolating fire fields. In road construction, they serve to stabilize road land, which allows a significant reduction in cost while achieving the same stabilization parameters that are achieved using pure lime or cement. They are an excellent material for embankment construction as well as being used for sealing areas. Waste from the power industry serves to neutralize acidic industrial effluents and to neutralize municipal waste water. They also play an important role in the reclamation of degraded or barren land, fertilizing fly ash improves their physical properties of calcium and magnesium fertilizers serve to de-acidify the soil (ashes from fluidized bed boilers). Other less popular applications are: production of plastics and paints, fillers, thickets, tar, metallurgical blacksmith. The requirements imposed by the economy of the 21$^{st}$ century have led to research into new uses for ash. For this purpose, the structure of the light metal compounds, the content of the magnetite components and the pozzolanic properties, i.e. the binding capacity in combination with the water with the calcium compounds, is examined.

By using anthropogenic materials we contribute to the implementation of priority strategies for secondary raw materials and the assumptions of the CE. Another positive impact on the environment is the reduction in the consumption of raw materials and the reduction of the surface area of combustion by-products. In addition, using CCPs reduces the demand for energy and reduces $CO_2$ emissions into the atmosphere. In the United Nations Climate Change Convention Tefra, developed by Ekotech - Asbestos Engineering, has shown that any ton of combustion by-product used in place of cement or lime will reduce greenhouse gas emissions by about 0.5 tons (Chrzanowski; Masłowski, 2014). This is a unique argument that the development of anthropogenic minerals has a positive impact on the environment. By increasing the scale of CCPs use in the economy, we also prevent environmental degradation

by reducing the area of mines and the landfill of power plants. One of the major economic benefits is the possibility of achieving savings associated with the extraction of natural minerals and the reduction of transport costs due to low volume loads of ashes. Another advantage to mention is the availability of material and its compressive strength, frost resistance and durability. The benefits of resource-conscious management make it possible not only to have a positive impact on the environment, but also on growth and economic development. Production waste is generated in the process of:

- generation of electricity and heat from power plants (in this case the waste may become Coal Combustion Products (CCPs)),
- coal extraction by the hard coal mining industry (in this case the wastes may become Obsolete Mining Products (OMP)).

Hard coal mines and power plants produce waste that is used, among others, in three areas that have been analyzed in more detail in this study:

- concrete production,
- road construction,
- winter road maintenance.

Waste includes primarily:

- Fly ash,
- Fluid ash,
- Furnace slags,
- Ash-slag mixes,
- Gypsum.

## 3.2. Determining the CCPs potential in Poland and possibilities of its effective using

Identifying CCPs potential is one of the key challenges for the Polish economy, especially in the context of pursuing the concept of closed loop economy, so strongly supported by the European Union. The data presented in Table 1 shows the volume of generated and used CCPs in the Polish economy in the years 2010-2014 in general terms and in detail (with separate types of CCPs). According to the data presented in this table, the amount of CCPs generated in the years 2010-2014 increased from 19,350 thousand tons in 2010 to 21,000 in 2014, while the amount of CCPs used in the analyzed period decreased from 12,546 to 12,094 thousnd tons (Chrzanowski; Masłowski, 2014).

**Table 1.** CCPs management in Poland in 2010-2014

| Characteristic | Year | | | | |
|---|---|---|---|---|---|
| | 2010 | 2011 | 2012 | 2013 | 2014 |
| **Generation of CCPs (total, thousand tons)** | **19350** | **21700** | **21400** | **20300** | **21000** |
| **Using of CCPs (total, thousand tons), including:** | **12546** | **15077** | **13447** | **12488** | **12094** |
| **Ratio (in %): Using of CCPs (total, thouasnd tons)/ Generation of CCPs (total, thousand tons)** | **0.648372** | **0.694793** | **0.628364** | **0.615172** | **0.575905** |
| Production of clinker | 1170 | 1357 | 1174 | 1078 | 1130 |
| Cement production | 1726 | 2067 | 1741 | 1519 | 1581 |
| Concrete and prefabrication | 1027 | 1268 | 1038 | 1014 | 1033 |
| Ceramics | 788 | 828 | 724 | 687 | 700 |
| Binders and plasters | 1702 | 1778 | 1700 | 1600 | 1650 |
| Coal mining | 1789 | 1947 | 2000 | 2100 | 2000 |
| Macrolevellings | 2600 | 2800 | 2500 | 2600 | 2400 |
| Road construction | 1716 | 2950 | 2500 | 1800 | 1500 |
| Other uses | 30 | 60 | 70 | 90 | 100 |
| For landfill disposal | 6804 | 6623 | 7953 | 7882 | 8906 |

Source: Chrzanowski, Masłowski, 2014: 4.

As it is shown in Table 2, in the years 2015-2019, the overall CCPs production is expected to increase (from 21.11 to 23.44 million tons over the period under review), with a decrease in the total use (from 12,109 million tons 11.701 million tons in the same period). The drop in usage of CCPs will take place in the following types / areas of application: coal mining (from 2000 to 1807 million tons), macrolevellings (from 2400 to 1931 million tons), road construction (from 1500 to 1355 million tons).

On the other hand, with an increase in CCPs utilization, we should be dealing with the following developmental sectors: Production of clinker (from 1130 to 1176 million tons), cement production (from 1581 to 1637 million tons), concrete and prefabrication (from 1038 to 1102) million tons), ceramics (from 700 to 743 million tons), binders and plasters (from 1650 to 1700 million tons), landfill disposal (from 8996 to 11740 million tons) and other uses (from 110 to 250 million tons) (Chrzanowski; Masłowski, 2014).

**Table 2**. CCPs production and development forecast for the years 2015-2019

| Characteristic | Year | | | | |
|---|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 | 2019 |
| **Generation of CCPs (total, thousand tons)** | **21110** | **21210** | **22120** | **22450** | **23440** |
| **Using of CCPs (total, thousand tons), including:** | **12109** | **11935** | **11828** | **11792** | **11701** |
| **Ratio (in %): Using of CCP (total, thousand tons)/ Generation of CCP (total, thousand tons)** | **0.573614** | **0.562706** | **0.53472** | **0.525256** | **0.499189** |
| Production of clinker | 1130 | 1141 | 1153 | 1164 | 1176 |
| Cement production | 1581 | 1597 | 1589 | 1621 | 1637 |
| Concrete and prefabrication | 1038 | 1049 | 1070 | 1091 | 1102 |
| Ceramics | 700 | 707 | 721 | 736 | 743 |
| Binders and plasters | 1650 | 1667 | 1683 | 1700 | 1700 |
| Coal mining | 2000 | 1980 | 1921 | 1863 | 1807 |
| Macrolevellings | 2400 | 2160 | 2052 | 1990 | 1931 |
| Road construction | 1500 | 1485 | 1440 | 1397 | 1355 |
| Other uses | 110 | 150 | 200 | 230 | 250 |
| For landfill disposal | 8996 | 9275 | 10292 | 10659 | 11740 |

Source: Chrzanowski; Masłowski, 2014: 5.

Based on the analysis of the data in Tables 1 and 2, it can be said that since 2010 there has been a steady uptick in the number of CCPs generated (an increase from 19.35 in 2010 to 21.00 in 2014) Forecasts should persist until at least 2019, where the amount of CCPs produced should rise to 23.44 million tons. As far as the use of CCPs is concerned in total, it fell from 12546 to 12094 million tons in the period 2010-2014, and in the years 2015-2019, it can also be seen dropping from 12109 to 11701 million tons. Taking into account the percentage of use of CCPs/CCPs generation in the years 2010-2019, it shows a downward trend in usage of generated in the Polish economy of CCPs.

This is evidenced by the systematic decline in the value of this factor practically throughout the period considered from 0.648,372 in 2010 to 0.499,189 in 2019 (Chrzanowski; Masłowski, 2014).

Taking into account the current (in the period 2010-2014) and expected (in 2015-2019) the use of CCPs a clear upward trend can only be observed for landfill disposal (increase from

6804 in 2010 to 11740 million tons in 2019) and other uses (increase from 30 in 2010 to 250 million tons in 2019). It also highlights the fundamental reversal of trends in the coal mining sector, where 2010-2014 has seen an increase in the use of CCPs from 1789 million tons in 2010 to 2000 million tons in 2014 and the expected 2015-2019 It is down from 2000 million tons in 2015 to 1807 million tons in 2019 (Chrzanowski; Masłowski, 2014).

Increasing the use of CCPs in many of the above key sectors of the economy will be primarily the result of a change in waste management legislation and a change in the attitude towards the CCPs economy, by presenting the economic, environmental and social benefits of replacing natural aggregates with waste/CCPs.

### 3.2.1. Examples of CCP using in particular sectors of the Polish economy

*Concrete production:* fluid ash generated by power stations is used as a stabilizer of natural soils or ashes and ash-slag mixtures (conventional) or as a binder component. Fluid ash is primarily used by mines as a raw material for the so-called 'PKW aggregate', the main component of which is the coal slate. This aggregate is used in the construction of roads. Fluid ash is particularly important in road engineering, and it can be used to produce aggregates in the lower layers of the road. In the concrete production process, various types of aggregates are used, containing several components in the form of ash, cement, water and concrete additives. If we use ash (but in relatively small quantities, the larger cannot be due to technological standards), it can replace much more expensive cement (a ton of cement costs about 120 PLN, while a ton of ash - about 20 PLN). In this case, you can save about 7-11 PLN on the cubic meter of the produced concrete. This shows the cost analysis of one cubic meter of concrete produced below:

- **Option 1 (without ash)** - to produce one cubic meter of concrete (no ash admixture) you need:
  - 0.3 tons of cement at a price of about 240 PLN per ton, of the total value of 72.00 PLN,
  - 0.649 tons of sand at a price of about 50 PLN per ton, of the total value of 32.45 PLN,
  - 1.347 tons of gravel at a price of about 100 PLN per ton, of the total value of 134.70 PLN,
  - water worth - 0.15 PLN.

  The total cost of producing one cubic meter of concrete amounts to 239.15 PLN in this case.
- **Option 2 (with ash)** - to produce one cubic meter of concrete (with ash admixture) you need:

- 0.265 tons of cement at a price of about 240 PLN per ton, of the total value of 63.60 PLN,
- 0.624 tons of sand at a price of about 50 PLN per ton, for a total value of 31.22 PLN,
- 1.2969 tons of slag at a price of about 100 PLN per ton, with a total value of 129.69 PLN,
- 0.0874 tons of ash of the total value of 3.50 PLN per ton,
- water worth - 0.15 PLN.

The total cost of producing one cubic meter of concrete amounts to 228.16 PLN in this case.

The relatively low cost advantage of about 11.14 PLN is due to the fact that ash is a relatively cheap component of concrete, however, due to its physical and technical properties it can only be added to it in relatively small quantities.

*Road construction:* the specific gravity of fluidized ash is about 0.8 ton per cubic meter, which means that one cubic meter of ash costs 3.20 PLN (at a price of 4 PLN per ton) to 4.80 PLN (at the price of 6 PLN per ton). In turn, the specific gravity of natural aggregates (e.g. bedrock) is about 1.8 tons per cubic meter, while the price of this aggregate is 50 PLN per ton, i.e. about 90 PLN per cubic meter.

*Winter maintenance of roads:* calculation for one ton/one cubic meter of sprinkling material: artificial material is sand slag, while its natural substitutes are salt or sand. Salt costs about 250 PLN per ton, sand - about 8-10 PLN per ton, while slag sand at the power plant - about 3 PLN per ton (in winter). In practice, slag sand does not have a substitute, primarily because of its surface-damaging properties.

## 4. Conclusion

According to the data, which were presented above, the perspectives for Poland in the scope of potential and possibilities of using CCPs are the following:

- an increase in the production of CCPs by 12% (average of + 2% annually),
- a decrease in the total consumption of about 2% (average annual -0.5%),
- increased consumption in clinker production and cement production by 4% (annual average + 1%),
- increased consumption in the production of concrete mixes and prefabricates by 7% (average 1 - 2% annually),
- an increase in the consumption in ceramics production by 6% (average per year 1-2%),

- increased consumption in the production of binders, plasters and insulating materials by about 3% (average annual 0.5 - 1%),
- a decrease in the consumption of the economy by about 10% (an annual average of -2%),
- a decrease in the consumption of macrolevellings and reclamation by 20% (annual average -4%),
- a decrease in road wear by 10% (average per year -2%),
- double consumption of CCP, e.g. biomass and processes of desulphurisation, in other areas of the economy, such as agriculture (average yearly + 25%),
- an increase in the amount of CCP to be managed by landfill by 30% (average yearly + 6%).
- further changes on the CCPs manufacturing side will constitute further modifications to the combustion and exhaust gas treatment technology,
- the implementation of further de-nitrification units will positively affect the quality of CCPs produced so far,
- CCPs produced in 2019 will come mainly from hard coal combustion,
- the share of brown coal CCPs will decrease, and will rise from the flue gas de-sulphurisation processes,
- the CCPs share of biomass burning will not increase, but new types of CCP will come from municipal waste incineration,
- the prospects for the CCP industry are good; with the demand up to the current level, the production of CCPs will increase to 23 ± 0.5 million tons per year,
- further consolidation of CCPs is anticipated, also due to the possible consolidation of generating units,
- it will be important to adopt appropriate strategies for the CCP industry as it will reduce the importance of the wholesale market and will increase the role of retail and distributed projects.

In the author's opinion, the directions of future research should be as follows:

- estimating the potential scale of generation, processing and utilization of different kinds of wastes: municipal, food, CCP, etc.,
- using analysis of the main components, factor analysis and DEA methods to estimate the effectiveness of the waste management,
- estimating the impact of policy stimulating implementation of the Circular Economy Concept (CEC) into the Polish Economy.

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## WYBRANE PROBLEMY IMPLEMENTACJI KONCEPCJI GOSPODARKI OBIEGU ZAMKNIĘTEGO (GOZ) W SEKTORZE UBOCZNYCH PRODUKTÓW SPALANIA (UPS) W POLSCE

Streszczenie

Gospodarka UE traci obecnie znaczną ilość potencjalnych wtórnych surowców, które są obecne w strumieniach odpadów. W 2013 r. Całkowite wytwarzanie odpadów w UE wyniosło około 2,5 mld ton, z czego 1,6 miliarda ton nie zostało ponownie wykorzystane lub poddane recyklingowi, a zatem uważa się je za stratę dla gospodarki europejskiej. Szacuje się, że dodatkowe 600 milionów ton można poddać recyklingowi lub ponownie wykorzystać. Każdego roku w Europie wytwarzane jest około 700 milionów minerałów antropogenicznych, w tym około 150 milionów ton produktów spalania węgla (UPS) w energetyce. W 28 państwach członkowskich Unii Europejskiej produkuje się ponad 100 milionów ton, z czego ponad 20 milionów ton w Polsce. Gospodarka w zamkniętych pętlach utrzymuje produkty, części i materiały w obiegu gospodarczym tak długo, jak to możliwe, wykorzystując jak najmniej zasobów. Koncepcja ta została zaprezentowana w dokumencie opublikowanym przez Komisję Europejską: *Circular Economy Package (CEP)*, który obejmuje również komunikat Komisji: Zamknięcie pętli - plan działania UE na rzecz gospodarki okrągłej. Ostatnie trendy sugerują, że dalsze postępy w zakresie

efektywnego gospodarowania zasobami są możliwe i mogą przynieść znaczne korzyści gospodarcze, środowiskowe i społeczne. Przenoszenie odpadów do zasobów stanowi zasadniczą część zwiększenia efektywności wykorzystania zasobów i zamykania pętli w okrągłej gospodarce. Istnieją cztery główne obszary zastosowań UPS: budownictwo, budowa dróg, energia i utrzymanie dróg. Zwiększenie wykorzystania UPS można osiągnąć poprzez nadanie statusu prawnego odpadom produktów i przekonywanie konsumentów i przedsiębiorstw do następujących korzyści związanych z ich używaniem: obniżenie kosztów produkcji poprzez zastąpienie naturalnego agregatu odpadami (na podstawie UPS), redukcja emisji gazów cieplarnianych, I zwiększenie efektywności energetycznej. W rezultacie UPS musi spełniać określone normy techniczne ustalone przez UE i wprowadzać do polskiej gospodarki. W opracowaniu podjęto próbę oszacowania, stosując analizę porównawczą, korzyści ekonomicznych, społecznych i środowiskowych wynikających z wdrożenia koncepcji gospodarki obiegu zamkniętego (GOZ) dla sektora UPS polskiej gospodarki.

**Słowa kluczowe**: implementacja koncepcji gospodarki obiegu zamkniętego (GOZ), uboczne produkty spalania (UPS), gospodarka UE i Polski.

**Kody JEL:** Q31, Q32, Q53.

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