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# Coal Combustion Products Management toward a Circular Economy—A Case Study of the Coal Power Plant Sector in Poland

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**Abstract:** Coal combustion products can be considered as commercial products or waste depending on the quality of the coal, the combustion process, and the country's legislation. The circular economy can create incentives for the implementation of new business models in large power plants in cooperation with coal mines and users of coal combustion products. This is particularly important in Poland, where coal still remains the main source of energy, employing over 80,000 workers. The objective of this study was to assess the readiness for change toward a circular economy and to identify challenges, barriers, and plans at seven large power plants. To do this, a final questionnaire was developed after checking environmental reporting, a CATI survey, and brainstorming between circular economy leaders from science, industry, and non-governmental organizations. The results indicate that even if the great economic and environmental potential of coal combustion products management are understood, all requirements connected with CO<sub>2</sub> and air pollution have higher priorities. Policy shifts away from coal do not promote cooperation, but the higher acceptance of products from waste and more transparent data shows a large potential for changes toward a circular economy.

**Keywords:** circular economy; coal power plant; coal combustion products; industrial waste

## 1. Introduction

The production volumes of coal combustion products (CCPs) are directly correlated with coal combustion in thermal power stations. Their quality, however, depends on the mineral composition of the coal, combustion efficiency, type and fineness of the coal, time of storage of the minerals in the furnace/boiler, etc. [1]. They constitute major inputs in the manufacture of construction materials and geotechnical engineering applications. Some of them i.e., pulverized fly ash, are a valuable waste residue used in concrete production [2]. However, they can also pose serious threats to air, water, and soil; over the past two decades, research has been developing methods to combine both the quality of power generation, economic viability, environmental safety, quality, and the effective use of waste products [3].

The beneficial use of CCPs varies in different countries; for example, Australia reached 5.936 million tonnes or 47% of CCPs in 2018 [4]. To facilitate precision and consistency, the members of the World Wide Coal Combustion Products Network have worked together to harmonize terminology and promote CCPs as a coherent nomenclature. This terminology is more positive and is in line with the concept of industrial ecology and circular economy (CE) principles, which is an approach that aims to reuse one industry's byproducts as another industry's raw material [5].

It is estimated that approximately 750 million tonnes of coal ash are generated every year in the coal industry throughout the world. A significant volume of coal fly ash is produced by major industrial countries, where it is one of the largest single sources of industrial solid waste [6].

Utilization rates vary considerably between countries, with the highest effective utilization rate of 99.3% being reported in Japan, while Africa/Middle East (still) has the lowest rate of 10.6%. In Poland, approximately 20 million tonnes of CCPs were generated (Table 1), of which approximately 65% was utilized in 2016 and 35% was landfilled. CCPs can substitute natural aggregate, as they are mainly used for in cement industry, in construction of new permanent disposal facilities, mining applications, in structural fills, waste stabilization, gypsum panel production, and agricultural applications. These applications can reduce greenhouse gas emissions, thus increasing energy efficiency and minimize use of primary resources, which is in line with CE strategy.

Based on the example of CCPs, Park and Chertow [7] have proposed the resource potential indicator (RPI) to promote the importance of managing wastes as resources in a closed loop. This measures the intrinsic value that a material has for reuse taking into account the technological recycling availability, economic feasibility and environmental requirements for the US market.

**Table 1.** Amount of coal combustion products (CCPs) generated in Poland in 2016 in enterprises and energy groups [8].

Energy Group/Enterprise	Amount of CCPs [Tonne/Year]
CEZ Produkty Energetyczne	260,000
ECO S.A.	70,350
EDF Polska S.A.	1,465,800
ENEA	1,351,504
ENERGA	357,709
Fortum Power & Heat	37,000
GDF Suez	1,117,200
Grupa AZOTY	322,500
PAK	2,454,342
PGE GKiK	9,792,071
PGNiG Termika	700,002
Tauron Ciepło	238,399
Tauron Wytwarzanie	1,656,555
Veolia	473,686
TOTAL:	20,297,118

The strategies of enterprises from the coal power sector in Poland contain provisions that prove that these enterprises carry out activities fulfilling CE objectives, but they do not directly refer to the CE aspects, as most data are available in corporate social responsibility (CSR) reports.

However, the current way of presenting this information does not allow for the comparison of data. In the context of CCPs, there are also no provisions proving the tendency (required by the CE) to carry out activities aimed at eliminating the generation of waste, hence only part of it is managed. Moreover, there is neither sufficient transparency in the statistics nor clear rules concerning waste, byproducts, secondary material, etc. [9]. Therefore, the management of CCPs is not the most important goal for either Polish companies or Polish energy policy. They first have to meet air quality standards and try to reduce GHG emissions. As Hopkins and Purnell (2019) indicate, the politics of GHG allocation may hide a lack of progress towards a CE [10].

In Poland, according to government documents, i.e., Polish Energy Policy to 2040 (2018) [11] and the Polish National Energy and Climate Plan for the years 2021–2030 published in 2019 [12], it was stated that the share of coal in electricity generation will be systematically reduced. In 2030, it will reach the level of 56–60%, and in 2040, the downward trend will be maintained. However, it was underlined that there is great potential for the better utilization of CCPs as building materials and for a reduction in the use of primary raw materials, which is in line with a CE. It is also estimated that the

renewable energy sources share in electricity production will increase to approximately 32% in 2030. These changes involve the most significant challenges for the current Polish energy sector relating to more stringent standards under the Industrial Emissions Directive (IED) [13] and the best available techniques (BAT) for the reduction of GHG and SO<sub>2</sub>, NO<sub>x</sub>, and dust emissions as well as the monitoring of hydrogen chloride, hydrogen fluoride, mercury, and ammonia. Enterprises have been allowed until 16 August 2021 to adapt to the new regulations, but the adaptation of installations to meet the stricter requirements involves the need for investment. Such solutions can have positive or negative impact on the quality of CCPs. Therefore, determining the impact of techniques focusing on reducing dust and gas emissions on the quality of CCPs, as well as possibilities of their further physicochemical processing according to end-user needs, is of extreme importance [14]. One of the good examples of this is the production of synthetic gypsum from flue gas desulphurization installations. Good quality of physical and chemical parameters of gypsum produced in the Bełchatów power plant was confirmed by laboratory tests. Therefore, about 60% of gypsum in Poland is used in different sectors, mainly for the construction market in the creation of various types of prefabricated products based on synthetic gypsum [15].

Several reviews focusing on technological issues relating to CCP utilization and application have already been published [16,17]. These analyze the economic and environmental constraints and benefits [18,19]. There is, however, a lack of publications focusing on surveys of energy companies on incentives and barriers that could have an impact on decisions on managing waste as a resource according to the CE concept. Moreover, there is lack of standards on how to measure micro-level circularity [20]. Therefore, the aim of this paper is to verify whether coal power plants were ready to implement CE models for CPP management. The research carried out in 2018 aimed to

1. identify the level of knowledge of CE principles in coal power sector companies,
2. determine areas that stimulate the implementation of a CE and allow one to specify activities for its further development,
3. identify the possibility of managing more CCPs in relation to the plans for implementing the CE roadmap in Poland adopted in September 2019,
4. introduce CE (NSS 7–Circular economy–water, fossil raw materials, waste) as a national smart specialization in Poland in January 2019 [21].

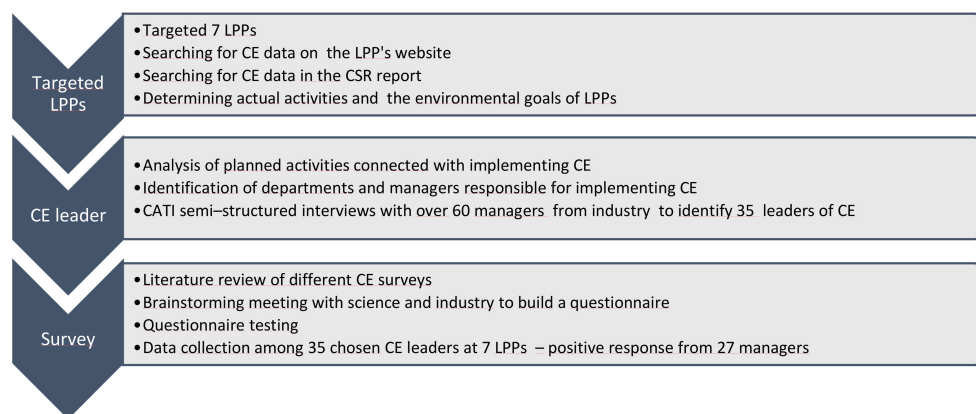
An analysis of good practice and research conducted (patents) relating to CCP management in Poland shows the existence of a large potential on the supply side, but long-term actions stimulating and legal solutions facilitating cooperation within the value chain are still lacking.

## 2. Materials and Methods

In order to investigate the role of CE in LPP (large power plant), we follow Gonenc and Scholten [22], who suggested that future studies should take into account corporate intentions and actions taken which are in line with such intentions. We focus on CE, but in 2018, there were no LPPs that had a CE strategy or any indicators focusing on CE. Therefore, we first chose the most important LPPs and then searched the official corporate web sites of LPPs concerning environmental aims and data presented in CSR reports. This allowed us to identify the activities focusing on closing material loops and waste minimization that are in line with environmental strategies. Second, we selected key activities that can reflect on LPP actions directed toward implementing a CE and identified the managers responsible for its application. We contacted them by email or phone to ask about the role of the CE and the scope and responsibilities in the companies. Third, we chose 35 managers from different departments at seven LPPs who were potential leaders of the CE. Fourth, based on a literature review of surveys of the CE and after brainstorming with CE leaders from science and industry, a survey questionnaire was constructed and sent to industry representatives (Figure 1).

The research was carried out on a group of the seven largest capital groups in the Polish energy sector (with coal-fired plants), for each of which the share in the volume of electricity introduced

into the grid amounted to more than 2% (73% in total)—PGE Polska Grupa Energetyczna S.A. (36%), Tauron Polska Energia S.A. (10%), Enea S.A. (9%), PAK S.A. (6%), EDF (8%), CEZ (2%), and PGNiG (2%) [5]. At the same time, these are the largest manufacturers of CPPs. The research was conducted with the participation of 27 managers who, due to the scope of their duties, had the knowledge necessary to carry out the research.



**Figure 1.** The circular economy (CE) implementation process.

The target group was selected from the above-mentioned companies after initially verifying the competences of the employees in departments such as Environmental Protection, Development and Quality Assurance, Development (Investments and Projects), R&D, Raw Materials and Waste, and Technological Processes. Telephone interviews (CATI) were then carried out over a period of five weeks (May–June 2018) using a questionnaire based on a five-step Likert scale (where 5 was equivalent to “strongly agree” and 1 was assigned to “strongly disagree”). The results of the research were aggregated before being presented, and the reliability of the survey was tested using the Cronbach alpha coefficient.

Aspects discussed in the survey were concerned with six topics as follows:

1. Perceived benefits relating to the potential implementation of CE;
2. Challenges related to the implementation of CE;
3. Hindrances to the implementation of CE;
4. What changes in company management are required in order to implement CE;
5. Reasons for implementing CE;
6. Prospects for implementing CE.

The detailed survey with questions is presented in Table 2. The questions (i.e., p 1\_1) were chosen based on literature, reports, and experts experience and advice.

**Table 2.** Summary presentation of the aspects assessed in the questionnaire.

Aspect 1	Environmental Benefits (Effects) Related to CE Implementation
p 1_1	increase in efficiency of resource use
p 1_2	extended product life cycle <sup>1</sup>
p 1_3	introducing more sustainable production
p 1_4	reduction of environmental footprint
p 1_5	establishing less energy-intensive relations with suppliers
p 1_6	establishing relations generating less environmental pressure with consumers
p 1_7	generating products instead of waste
p 1_8	improvement in environment quality
p 1_9	strengthening environmental management standards
p 1_10	increase in ecological activity
p 1_11	closing CCPs landfills
p 1_12	reduction of the environmental cost of production

Table 2. Cont.

Aspect 2	Risks/Challenges Related to Implementing CE
p 2_1	increased production costs
p 2_2	need for costly and risky investments
p 2_3	need to find a way to change the process's business model
p 2_4	risk of reduced competitiveness of a company
p 2_5	need to leave the "plant gates" <sup>2</sup>
Aspect 3	Barriers/Hindrances to Implementing CE
p 3_1	failing to implement a multi-product power engineering strategy
p 3_2	failing to promote CCPs as a fully-fledged waste product
p 3_3	lack of purchasers for raw materials recovered from waste
p 3_4	lack of indicators and guidelines for implementing and measuring CE
p 3_5	current CE-consistent activities are not appreciated and evaluated
Aspect 4	Requirements of CE with Regard to Company Management
p 4_1	environmental responsibility going beyond the plant gates
p 4_2	cooperation within clusters
p 4_3	construction of revenue generation logic based on identification of the value chain
p 4_4	internalisation of external environmental costs
p 4_5	evaluation of environmental policy as regards suppliers and consumers
p 4_6	creation of buyers-eco-consumers' market
p 4_7	implementation of a multi-product and waste-free strategy for power engineering
p 4_8	recognition of factors representing environmental costs in the expenditure structure
p 4_9	influencing the awareness and actions of other bodies
p 4_10	identification of the value chain to specify quantifiable environmental benefits
p 4_11	integration of environmental policy with development strategy
Aspect 5	Reasons for Implementing CE
p 5_1	awareness of the importance of environmental protection
p 5_2	possibility of waste management cost reductions
p 5_3	social benefits
p 5_4	possible reduction of the product's environmental footprint
p 5_5	economic benefits
Aspect 6	Assessment of the Feasibility of Implementing CE
p 6_1	within the next 10 years
p 6_2	within the next 20 years

<sup>1</sup> through activities that will be carried out aimed at eliminating the storage of CCPs as a result of solutions enabling their further use in the economy, so that the resources used will not lose their value and their useful life will be extended. <sup>2</sup> according to the "cradle to cradle" approach.

### Verification of the Research Tool

The test tool used in the research has been checked for reliability. For this purpose, an analysis of the results obtained was carried out using the Cronbach  $\alpha$  coefficient (Table 3). This is a coefficient for the total scale, whose items can be measured on any order scale. The Cronbach  $\alpha$  coefficient indicates what part of the variance of the total scale is the variance of the true value of that scale. A zero value means that individual scale items do not measure the true result but only generate a random error. As a result, there is no correlation between items of the total scale. In tests of the reliability of the measuring tools, the result should be within the range of 0.6–0.8.

A set of terms (in order from the highest to the lowest value of Cronbach's  $\alpha$  coefficient) for aspects 2, 3, and 1 obtained acceptable reliability. Aspect 6, which concerned predicting the possibility of implementing CE in a 10- or 20-year perspective, Cronbach's  $\alpha$  was 0.462, which can be explained by the fact that the respondents answered "strongly agree" for the 20-year period, whereas for the 10-year period, the vast majority only agreed. The set of aspects 4 and 5 did not receive acceptable reliability. In such a situation, factor analysis was used to indicate the number of factors (sub-aspects) that formed these aspects. Results of the analysis (selection of the optimal number of factors) were based on the screen test and the questions assigned to them were based on the varimax rotational strategy. Four factors were obtained for the set of aspect 4 and two factors for the set of aspect 5.

The values of Cronbach's  $\alpha$  coefficients for the subcategories obtained as a result of factor analysis are presented below.

**Table 3.** Internal consistency of the survey questionnaire.

Analyzed Scope of the Survey Questionnaire	Cronbach's $\alpha$ Coefficient
All survey questionnaire	0.837
Set of terms of aspect 1	0.641
Set of terms of aspect 2	0.727
Set of terms of aspect 3	0.677
Set of terms of aspect 4	0.322
Set of terms of aspect 5	0.193
Set of terms of aspect 6	0.462

As many as 11 terms of aspect 4 concerned the CE requirements for company management. Their diversity was so large that factor analysis, which was used to separate sub-aspects (factors), indicated three strong factors and one weaker one (the last one) (Table 4).

**Table 4.** Cronbach's  $\alpha$  coefficient results for factor analysis of aspect 4.

Additional Classification of Aspect 4 Terms:	Cronbach's $\alpha$ Coefficient
Set of terms for environmental costs and benefits: p 4_4, p 4_10, p 4_11	0.648
Set of terms concerning the external actions related to the implementation of a multi-product strategy: p 4_2, p 4_7, p 4_9	0.757
Set of terms for creating a purchaser market through the use of value: p 4_3, p 4_6	0.606
Set of terms concerning environmental costs generated in relation to suppliers and customers: p 4_1, p 4_5, p 4_8	0.397

The five terms of aspect 5 concerned the reasons for implementing a CE. The factor analysis, which was used to separate sub-aspects (factors), indicated that it was possible to divide them into two factors that could be associated with the external and internal reasons for implementing CE (Table 5).

**Table 5.** Results of the Cronbach  $\alpha$  coefficient for factor analysis of aspect 5.

Additional Classification of the Aspect 5 Terms:	Cronbach's $\alpha$ Coefficient
Set of terms concerning external causes: p 5_1, p 5_3, p 5_4	0.658
Set of terms for internal reasons: p 5_2, p 5_5	0.744

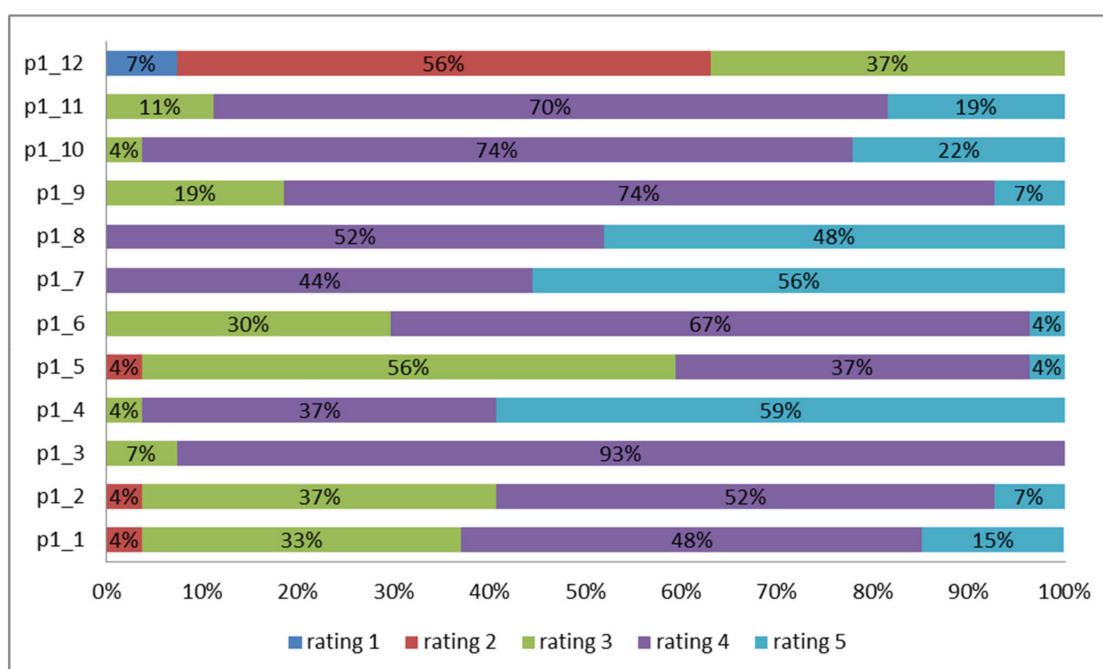
### 3. Results

The research undertaken has enabled

- the assessment of the attitude of coal power sector companies towards the CE concept;
- the identification of areas stimulating the implementation of CE, allowing one to determine actions for its further development;
- the use of questionnaire using a five-step Likert scale (where 5 was equivalent to "strongly agree" and 1 was assigned to "strongly disagree").

#### 3.1. Aspect 1

The set of terms under aspect 1 concerned the evaluation of the benefits/effects related to implementing CE in a coal power company (Figure 2).



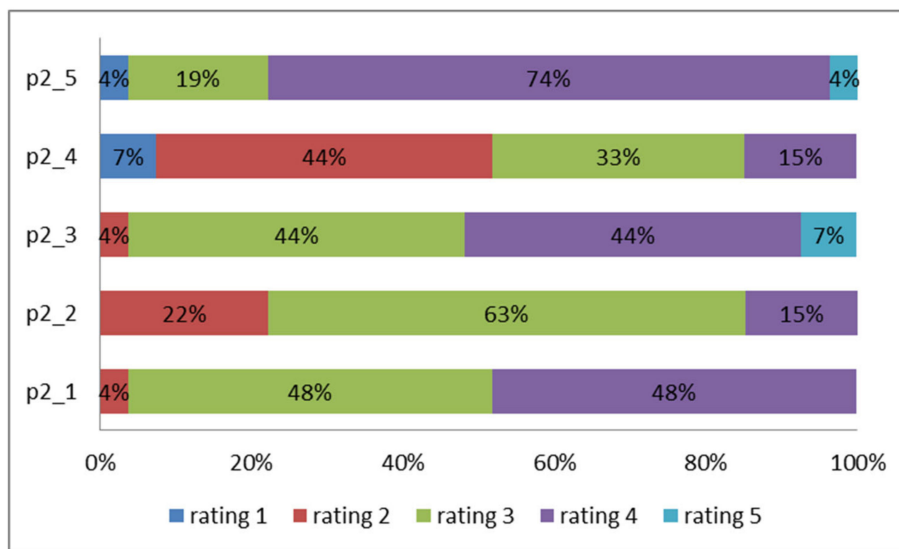
**Figure 2.** Assessment of the benefits (effects) resulting from implementing CE in coal power engineering.

As regards the assessment of the benefits of implementing CE in the coal power industry, respondents assessed such effects as the increase in efficiency of the use of resources (p1\_1), extended product life cycle (p1\_2) and establishing relations generating less environmental pressure with consumers (p1\_6) in a similar way. In relation to these terms, more than 59% of the respondents answered in the affirmative, no more than 37% of the respondents expressed doubts, while the number of negative opinions did not exceed 4% of the answers obtained. More than 80% of the respondents assessed terms such as introducing more sustainable production (p1\_3), reduction of the environmental footprint (p1\_4), strengthening standards of environmental management (p1\_9), an increase in ecological activity (p1\_10) and closing CCP landfills (p1\_11). The above-mentioned terms did not obtain negative assessments. The unanimous affirmation (positive assessment) of all respondents was shown in relation to the term generation of products instead of waste (p1\_7) and improvement in environmental quality (p1\_8). The greatest reflection among the respondents was given to the assessment of the benefits associated with the possibility of establishing less energy-intensive relations with suppliers (p1\_5) expressed by 55% of the respondents. The remaining 40% of the respondents gave this term a positive assessment and only 4% a negative one. The statement that received the highest number of negative votes (63%) and no positive assessments was the one concerning benefit resulting from the possibility of reducing the environmental costs of production (p1\_12).

### 3.2. Aspect 2

The set of terms under aspect 2 concerned the assessment of the risks/challenges related to implementing CE in the coal power industry (Figure 3).

As regards the assessment of the risks/challenges associated with implementing CE in the coal power industry, more than 50% of the respondents negatively assessed the risk of reducing a company's competitiveness (p2\_4). Difficulty in making the assessment relating to the increase in production costs (p2\_1) was expressed by 48% of the respondents, and the need to implement costly and risky investments (p2\_2) was expressed by 63% of the respondents.



**Figure 3.** Assessment of the risks/challenges associated with implementing CE in the coal power industry.

The risk that may be posed by implementing CE in the form of an increase in production costs (p2\_1) received a greater number of affirmative (48%) than negative (4%) opinions. However, as far as the necessity to carry out investments (p2\_2) is concerned, the opposite situation occurred as it received more negative (22%) than positive (15%) opinions. More than half (52%) of the respondents see a challenge in the need to find a way to change the current business model of the process (p2\_3), but a large proportion of them (44%) had doubts in assessing this term. The vast majority (78%) of respondents see a risk/challenge in the necessity to go beyond the “plant gates” (p2\_5). In total, 18% of the respondents expressed doubts when making the assessment in relation to this term.

### 3.3. Aspect 3

The set of terms under aspect 3 concerned the assessment of the barriers/obstacles to the implementation of CE in the coal power industry (Figure 4).

In terms of barriers/obstacles that respondents see in the context of implementing CE, over 40% do not agree that raw materials recovered from waste do not find buyers (p3\_3). Moreover, in relation to this term, the highest number of opinions (56%) was given to the assessment “neither agree nor disagree.” About 50% of the respondents see problems with the lack of implementation of a multi-product strategy of power engineering (p3\_1) and the lack of promotion of CCPs as fully fledged products from waste (p3\_2). In relation to these two statements, an equally large number of respondents (over 44%) had difficulties in their assessment. More than 70% of respondents admitted that an obstacle to the implementation of CE is the lack of indicators and guidelines for implementing and measuring CE (p3\_4). Nearly 90% of the respondents indicated that an obstacle to implementing CE is the fact that the current CE-compliant activities are not appreciated and evaluated (p3\_5); moreover, this term was the only one that did not receive a negative assessment.



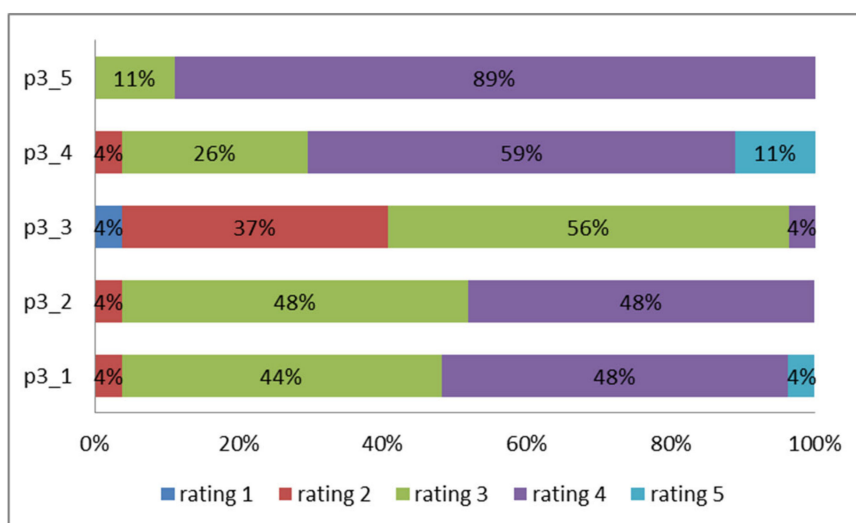


Figure 4. Assessment of barriers/ obstacles to the implementation of CE in the coal power industry.

### 3.4. Aspect 4

The set of terms under aspect 4 concerned the assessment of CE requirements in relation to the management of a coal power plant (Figure 5).

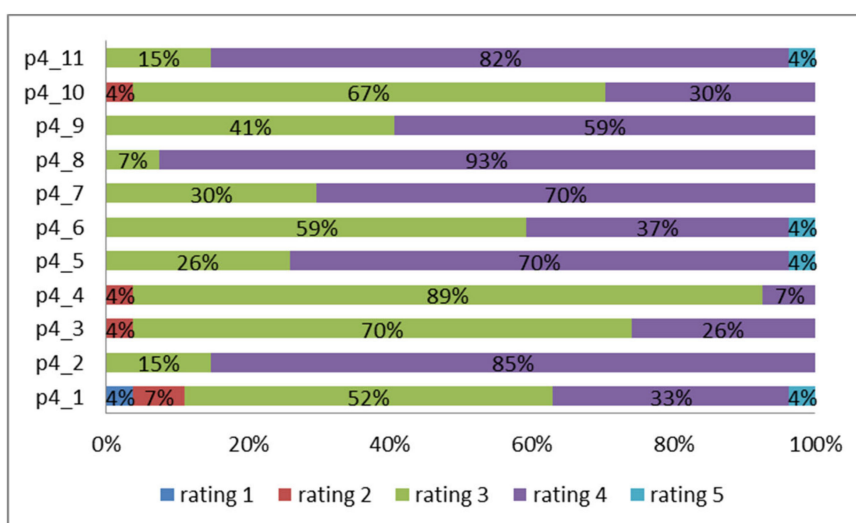


Figure 5. Assessment of the CE requirements in relation to the management of a coal power plant.

The analysis of the assessment of terms related to management activities indicated that more than 50% of the respondents had difficulty in assessing the need to go beyond the boundaries of the plant with responsibility for environmental protection (p4\_1) (52%), constructing an income generation logic based on the identification of the value chain (p4\_3) (70%), internalization of external environmental costs (p4\_4) (89%), creating a buyers–eco-consumers market (p4\_6) (59%), and identification of the value chain to specify quantifiable environmental benefits (p4\_10) (67%). The number of other responses expressed for these terms was always higher on the positive (affirmative) side.

None of the six terms described below received a negative assessment. These terms include cooperation within clusters (p4\_2) (85%), assessment of environmental policy in relation to suppliers and customers (p4\_5) (74%), implementation of a multi-product power engineering strategy (p4\_7) (70%), recognition of factors representing environmental costs in the expenditure structure (p4\_8) (93%), influencing the awareness and actions of other bodies (p4\_9) (59%), and integration of environmental

policy with a development strategy (p4\_11) (85%). The term about which most respondents (41%) were doubtful when expressing their opinion was influencing the awareness and actions of other bodies (p4\_9).

### 3.5. Aspect 5

The set of terms under aspect 5 concerned the assessment of the reasons for the coal power industry to implement CE (Figure 6).

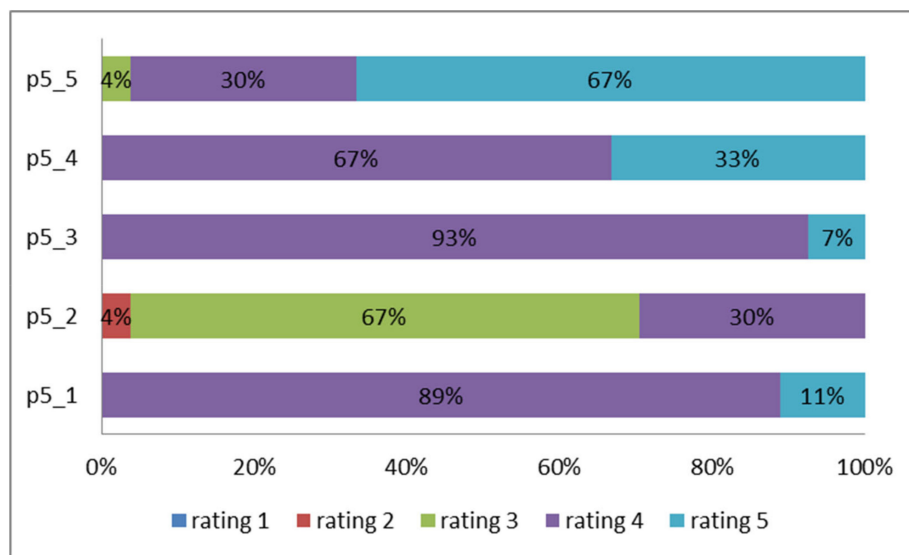


Figure 6. Assessment of reasons for the coal power industry to implement CE.

Respondents had an unequivocally positive assessment of four out of five reasons for implementing CE by coal power companies. These terms included awareness of the importance of environmental protection (p5\_1), social benefits (p5\_3), the possibility of reducing the product’s environmental footprint (p5\_4), and economic benefits (p5\_5) received 100% of affirmative responses. Only in relation to the term expressing the possibility of reducing costs related to waste management (p5\_2) were 4% of respondents doubtful in its assessment.

### 3.6. Aspect 6

The set of terms under aspect 6 concerned the assessment of the prospect for implementing a CE in the coal power industry (Figure 7).

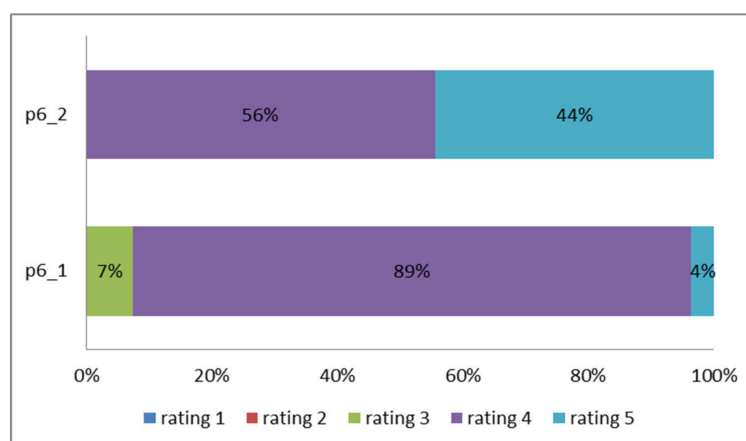


Figure 7. Assessment of the prospect of implementing a CE in the coal power industry.

Concerning the term relating to the possibility of implementing CE in the power industry within 10 or 20 years, the respondents agreed that, in their opinion, there is such a possibility.

#### 4. Discussion

The analysis of the assessments obtained from the respondents for aspect 1 shows that the vast majority of the respondents see the potential of environmental effects that can be achieved as a result of CE. This means that employees are aware of the potential that the implementation of this new trend may bring to the company. The reflection of the respondents shown in relation to the supply chain (benefits from establishing new relations with suppliers) may be caused by the fact that the power industry currently takes into account the quality aspect of the emerging CCPs in specifications for the purchase of raw materials (concerning the requirements for the calorific value of coal, content of ash and sulphur, etc.). Despite the positive assessments expressed in relation to most of the environmental effects generated by the implementation of CE, they do not refer to the initial stage, which is (immediately after the product design process) the stage of material procurement. The supply chain generated is of key importance and is translated into other processes and the environmental costs they create. The supply chain, through transferring the effects of the environmental impacts generated, influences the possibilities of CCP management, in relation to which the culmination of all effects generated in the preceding processes takes place. Therefore, in the opinion of the authors of this study, it can be assumed that in order to implement the CE model it is necessary to identify all links in the value chain and express them in the form of measurable indicators, which will allow the effects produced to be measured. On the other hand, the respondents fail to see that the benefits resulting from the reduction of environmental costs of production by eliminating the generation of waste may be related both to the underestimation of waste management costs (the costs of transport, storage and disposal of waste) and to the lack of internalization of external environmental costs. As a result, this may lead the respondents to believe that current relations do not require additional modifications unless they are additionally imposed by legal requirements.

The analysis of the assessments made for aspect 2 shows that they do not perceive CE as a threat related to disturbance of the position of enterprises on the market; this is due to the fact that they focus primarily on the process of energy generation. On the other hand, CCPs are perceived as a possible secondary product that may bring potential profits—but this is not the direction of the strategies currently being adopted. In the opinion of the respondents, the most important thing for enterprises is that the carrying out of a CE brings no increase in production costs. This aspect can be directly combined with the above described negative assessment expressed in relation to the benefits of implementing CE in the form of reducing environmental production costs through eliminating waste generation. This translates into further consequences, which are located in the concerns about the need to find a way to change the business model and the need to go beyond the plant gates related, for example, to the carrying out of a life cycle assessment. This may result from the lack of a consistent approach to environmental protection throughout the entire value chain generated by the company, which means that it is limited to analyses within the plant gates.

The answers obtained for aspect 3 prove that the respondents see the potential and the need to implement a multi-product power engineering strategy in the context of the possibilities that CCP management brings. However, at the same time, the potential for their sale is not utilized. The respondents also show that in their opinion activities carried out so far are CE compatible. However, the lack of guidelines for CE measurement is an obstacle in verifying this opinion.

As far as aspect 4 is concerned, the answers received confirm that requirements set by the CE, connected with the necessity to go beyond the plant gates and to analyze the impact of the activity throughout the whole life cycle determining the areas where the activities enabling the implementation of CE should be commenced. All activities where it is necessary to go beyond the plant gates and their measurement are a big barrier (e.g., introducing economic symbiosis), as are connecting with data availability and modelling.

The answers obtained for aspect 5 indicate that four out of the five reasons for implementing CE are important for coal power companies. It should be emphasized that generating economic profits was the only positively evaluated aspect for which the majority of respondents indicated the answer “I strongly agree.” The respondents’ doubts as to the possibility of reducing the costs of waste management may be explained by the fact that, at present, they are unable to direct their thinking towards the goal of eliminating the generation of waste in order to generate products/goods. This may be caused by focusing only on generating profits for the company from the leading activity, which is energy production (and focusing on current profits).

The answers obtained for aspect 6 indicate that the respondents envisage implementing CE in the next decade. This may be due to the decisions of the company that, through its declared environmental policy and the resulting pro-environmental attitude, will take actions related to implementing CE spontaneously. There is also an option that CE implementation will result from the need to adapt to anticipated changes in legislation.

In contemporary Polish strategic document and policy, i.e., National Energy Policy until 2040, most changes focus on the reduction emissions of CO<sub>2</sub> and other air pollutant from burning coal and less on circularity and waste management. This is a global important priority, but despite the efforts of many countries in their policies and strategies to reduce energy production from fossil fuels, a significant share of the world’s energy supply, as well as the CO<sub>2</sub> emissions, is still generated from coal.

Global CO<sub>2</sub> emissions from fossil fuels combustion and processes further increased by 1.9% in 2018 compared to the previous year reaching a total of 37.9 Gt CO<sub>2</sub>. More detailed data about anthropogenic greenhouse gas emissions can be also found in Emissions Database for Global Atmospheric Research (EDGAR). Since 2015, the EU–28 share of global fossil CO<sub>2</sub> emissions has remained constant at 9.6% which is the equivalent of seven tonnes of CO<sub>2</sub>/cap/yr. The largest contributor in 2017 was Germany with a 22.4% share, followed by the United Kingdom (10.7%), Italy (10.2%), France (9.5%), and Poland (9%) [23]. Poland, however, noted a significant decrease (29%) in CO<sub>2</sub> emissions from the power industry in the years 1990–2017. In Poland, the emissions reached 8.3 tonnes of CO<sub>2</sub>/cap/yr in 2017, whereas in Germany, they reached 9.7 tonnes of CO<sub>2</sub>/cap/yr [24].

Wider and full utilization of CCPs in Poland can also have a beneficial impact on the reduction of energy use and CO<sub>2</sub> emissions in the industry. Beneficial use of CCPs as raw materials in manufacturing construction materials is well established both in literature [25] and the practice of many EU-15 countries as well as Japan, Korea, and China, where the utilization rate has reached over 70%. CCPs are mostly used for cement and concrete, road construction as well as for geotechnical and filling applications, including reclamation, as CCPs have established product standards or technical guidelines. There are, however, proposed solutions, such as

1. Extraction of aluminum content from coal fly ash [26] in Indian thermal power plants, which generate around 1 million tonnes with around 25–35% Al<sub>2</sub>O<sub>3</sub> and 50–60% SiO<sub>2</sub>. Al was extracted by sulphuric acid leaching with calcium sulphate as leach residue. At the conclusion of this process, the leachate is suitable for downstream operations to precipitate alumina.
2. Lithium recovery [27] from coal fly ash by a combination of an intensified acid leaching process and pre-desilication.
3. A method for the extraction from coal ash of iron, Al, and Ti (United States Patent 4567026) [28].
4. Research on the recovery of trace and rare metals from coal and the products of their traditional and thermal enrichment in Poland. Better value raw materials for the metallurgy industry are obtained through a careful selection of coals and the use of carefully selected methods of enriching metal concentrates. This also ensures a significant economic impact on the cost of production [29].
5. Furthermore, Hycnar and Tora [29] note research carried out in Poland that allows one to set up the technology for producing metal concentrates such as germanium and gallium oxide concentrate, iron oxides, aluminum oxide, and calcium oxide.

6. Analysis of the available technologies, the opportunities for their improvement, and the sources of financing in connection with the implementation of CE principles, as well as the results of research on assessing the implementation of CE in large energy concerns indicate that, along with the development of CE policy in Poland, there is a large potential for the full utilization of CCPs.

## 5. Conclusions

From the assessment of the respondents and legal changes in EU and new energy strategy Poland, it can be concluded that the implementation of CE requires unanimity in actions and ensuring their measurability, which can be achieved by the introduction of the circular business model and its indicators.

Based on the terms of all analyzed aspects, it can be concluded that

- The respondents do not understand the context of implementing CE in the value chain (aspect 1—benefits/effects of CE implementation);
- The solution to the problem of concerns about the need to find a way to change the business model toward CE by assessing the entire value chain, without limiting it to the so-called “plant gates.” Such changes can create the increase of production cost (aspect 2—risks/challenges related to CE implementation);
- The biggest obstacle to CE implementation is the lack of guidelines for CE implementation and measurement. Companies need indicators to be able to assess current activities that, in the opinion of respondents, are consistent with the CE (aspect 3—barriers related to CE implementation);
- CE requirements determine areas of necessary modifications to the current way the company is managed. In relation to these areas, it is advisable to propose measurement indicators so that companies can verify the implementation of CE and indicate actions for further modifications. Moreover, it can also be concluded that the respondents, although they show the need for indicators, are not prepared to measure them in the value chain (aspect 4—CE requirements in relation to the management of a company);
- Companies are willing to implement CE due to the economic, environmental, and social aspects. However, in order to capture the economic effects, it is necessary to present the environmental effects in the form of measurable indicators, showing the value that can be obtained when generating a product instead of waste (aspect 5—reasons for CE implementation);
- The respondents see the need to prepare for the changes that are expected in the current business model. The answer to this need is the necessity to develop a circular business model (together with indicators for its measurement), the implementation of which will enable the necessary changes to be made (aspect 6—prospects of implementing CE).

In relation to the results obtained, it can be concluded that the respondents see potential in the modification of the current method of company management in the context of the CCPs generated, but they lack precise guidelines on how to do it (areas of action and indicators), which determines the direction and need for further research in this area. Successful implementation of the circular economy rules in Poland creates conditions for the promotion of zero waste technologies. Polish companies could analyze in more detail and assess good practices from different countries and focus on closer cooperation with scientific institution. It additionally allows them to apply for financial support for such eco-friendly investments.

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