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Circular Economy Models in Sustainability Reports of the Polish Electric Power Industry

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Abstract: The purpose of this article is the identification of circular economy implementation models characteristic of the Polish electric power industry based on the scope and degree of progress of activities included in companies' sustainability reports. A comprehensive four-level model was used in the study, and it was completed through an assessment of the progress of CE projects implemented in the companies. The scope and level of progress of activities undertaken in the companies of the analysed industry are relatively similar, which makes it possible to determine the model of CE implementation in the electric power industry. Companies are engaged in 2 of the 13 defined areas, energy efficiency and environmental improvements, and, on average, in 4 further ones (industrial waste recycling, dematerialisation, renewables, and industrial symbiosis), which means that they focus mainly on activities of level I and partially level II. Activities at levels III and IV are currently omitted or not advanced.

Keywords: circular economy (CE); electric power industry; sustainability reporting

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1. Introduction

Climate change and sustainability challenges have become key issues for the electric power industry in recent years. According to the Intergovernmental Panel on Climate Change (IPCC), the energy industry is responsible for about 73% of global greenhouse gas emissions [1]. This information is also confirmed by the report of Our World in Data, a non-profit organisation based in Great Britain. Looking at CO_2 emissions alone, Poland is 19th in the ranking of the largest emitters in the world and 4th in Europe, behind Russia, Germany, and Italy [2].

According to the World Energy Balances Highlights [3], about 64% of the world's energy industry is based on traditional sources of fossil fuels, such as coal, natural gas, and oil, which are non-renewable. Coal resources are estimated to be sufficient for about 100 years, and natural gas and oil resources for about 50 years. Technological advances, varying forecasts concerning global development, and increases in energy consumption, as well as discoveries of new sources of fossil fuels, make it difficult to reliably determine the size of the world's deposits. However, differences in estimates of resources cannot change the fact that they will inevitably run out in the next few decades. Moreover, combustion of these fuels has a huge impact on the emission indicators. At the same time, the electric power industry has potential for the development of renewable energy technologies that can contribute to reducing the negative impact on the climate and creating new jobs. The expectations concerning undertaking and reporting on circular economy (CE) activities, which lead to a transformation of current business models, are formulated especially by stakeholders who influence the electric power industry. Research by Ciechan-Kujawa et al. [4] revealed that environmental activists and employees are primarily interested in the level of investment to improve circularity and information regarding the company's impact on the environment, whereas shareholders and customers expect information on eco-innovation and eco-design, as well as engagement in industrial ecology. Nevertheless, the scope of CE activity reporting has not been regulated. Directive 2014/95/EU of the European Parliament and of the Council [5] only defined the scope of sustainable development reporting. Only the Corporate Sustainability Reporting Directive (CSRD), which entered into force in 2023, gives the possibility of harmonising standards for reporting information in terms of the CE, among others, and increasing the comparability of reported data. Reporting must follow specific, uniform standards, including the ESRS (European Sustainability Reporting Standards), developed by the European Financial Reporting Advisory Group (EFRAG), including the ESRS E5 resource use and circular economy standard [6].

The importance of the concept of the circular economy in the energy industry is often emphasised by scientists; nevertheless, it is difficult to find a comprehensive approach to assessing such activities of companies in the electric power industry in the current literature.

Previous analyses of reports on electric power industry companies show that they rarely mention initiatives related to the circular economy. Similar conclusions can be drawn from the analysis of 61 sustainability reports issued by EU energy companies in 2018–2020 conducted by Janik et al. [7]. On the other hand, Santos et al. [8] note that electric power industry companies prefer to disclose their greenhouse gas reduction efforts rather than CE strategies.

Therefore, this article aims to identify circular economy implementation models specific to the Polish power sector. As our study focuses primarily on practical solutions, policies, and systemic initiatives, the circular economy models discussed refer to conceptual frameworks rather than mathematical ones. Focusing on the unique challenges faced by organisations in this industry, we seek to understand how the scope and degree of advancement of actions undertaken by companies support their circular strategies. To this end, we utilise the companies' evidence in their sustainability reports. Ultimately, this study seeks to deliver insights that contribute to academic discourse and practical applications enabling the refinement of strategies currently implemented by companies in this sector and enhancing the scope and effectiveness of initiatives aimed at ecological environmental protection.

2. Literature Review

A review of studies indicates that both energy companies and researchers focus on selected areas of the CE rather than a holistic approach. Prevalent are assessments and proposals for activities in selected areas of CE, such as greenhouse gas (GHG) emissions, development of RES, or management of combustion by-products (CBPs).

The problem of high emissions in China due to the use of coal energy sources, for example, was addressed by Zeng et al. [9]. Their study confirmed that the implementation of a circular economy in coal power plants is necessary for environmental protection, and this is as an effective way to save energy and reduce emissions. Extensive studies of the problem of greenhouse gas emissions by the manufacturing and energy industry in the years 1990–2019 in the Nordic countries were presented by Alola et al. [10]. Liobikienė et al. [11] looked at the impact of different factors on greenhouse gas emissions and proposed an approach to simultaneously use the impact and correlations between energy efficiency, renewable energy development, and the fuel mix as moderators for shaping economic activity.

A review of the literature shows that authors agree on the positive impact of RES development on GHG reduction and the shift from a linear to a circular economy. This was confirmed by Kumar et al. [12], who analysed research from the last two decades of the 21st century, the latest developments in the field of green energy, adaptations, and the role of the circular economy in this context. A similar relationship between the circular economy and renewable energy was demonstrated by Olabi [13]. Empirical studies in this area were conducted by Brown [14], who analysed three cases—one in India and two in Brazil—that confirmed the effectiveness of cross-industry initiatives in the field of renewable energy and the resulting economic and social benefits. Similar results but from the perspective of the impact of RES projects on the business model of companies operating in Thailand were published by Niyommaneerat et al. [15]. Their findings were confirmed by Gallagher et al. [16], who indicated that renewable energy technologies are perceived positively as far as meeting future energy demand and reducing greenhouse gas emissions are concerned. However, it is necessary to optimise the mix of RES sources, as the components used to build RES sources are also exhaustible. The authors point to the sustainability of eco-design, which is another issue related to the CE.

The development of RES influences not only the reduction of greenhouse gas emissions, but also another area of CE—waste management. This was noticed by Zvirgzdins and Linkevics [17]. The authors assessed the development of renewable energy installations positively, but they point to the problem of waste management at the end of the device's lifecycle. This observation was developed by Khalid et al. [18], who concluded that today only 80–85% of wind turbine materials can be recycled. The authors argue that a 100% rate can be achieved if attention is paid to the recovery of all wind turbine materials and the adaptation of circular economy models.

In the field of waste management, CBPs are of particular importance in the literature. Many years of experience of electric power companies in this area have led to the creation of many scientific papers, which are helpful for waste management. The issue was addressed by Ghosh and Kumar [19], who presented several innovative concepts for the management of fly ash based on circular economy solutions. An in-depth analysis of the topic from the perspective of companies was performed by Bielecka and Kulczycka [20], who verified the willingness of seven power plants located in Poland to implement the CE strategy in the field of combustion by-products. A macroeconomic approach to CBPs was proposed by Rosiek [21], who estimated the economic, social, and environmental benefits of the introduction of a CE resulting from the management of CBPs. On the other hand, Santos et al. [8] examined the reports of 88 Portuguese companies and pointed to discrepancies between circular economy terminology and its presentation in the reports and the need for greater integration of circular-economy-oriented initiatives into electric power industry strategies. The character of the problem paired with the lack of a comprehensive approach to studying CE strategies in the electric power industry in the available literature indicate a gap in research. To fill it, focusing on the case of Poland, we formulated two research questions:

- RQ 1: What data concerning activities aimed at shifting from a linear to a circular economy are disclosed in sustainable development reports of Polish electric power industry companies?
- RQ 2: Are there similarities in the scope and level of progress of CE activities undertaken by Polish electric power industry companies?

3. Materials and Methods

In our research, we focused on a specific industry and country. We analysed sustainability reports of key representatives of the Polish electric power industry: PGE Polska Grupa Energetyczna, TAURON Polska Energia, ENEA, and ENERGA. We performed a qualitative assessment of the complexity of activities related to the implementation of a circular economy undertaken by these companies. Source materials come from official websites of the companies.

- "Integrated report of Polska Grupa Energetyczna SA and PGE Capital Group for 2022" [22].
- "Report on non-financial information of the TAURON Capital Group for 2022" [23].
- "ESG report of the ENEA Capital Group for 2022" [24].
- "ESG report of the ENERGA Group for 2022" [25].

The companies selected for the analysis are responsible for around 70% of electric power production and sales and around 93% of electric power distribution, as shown in Figure 1.

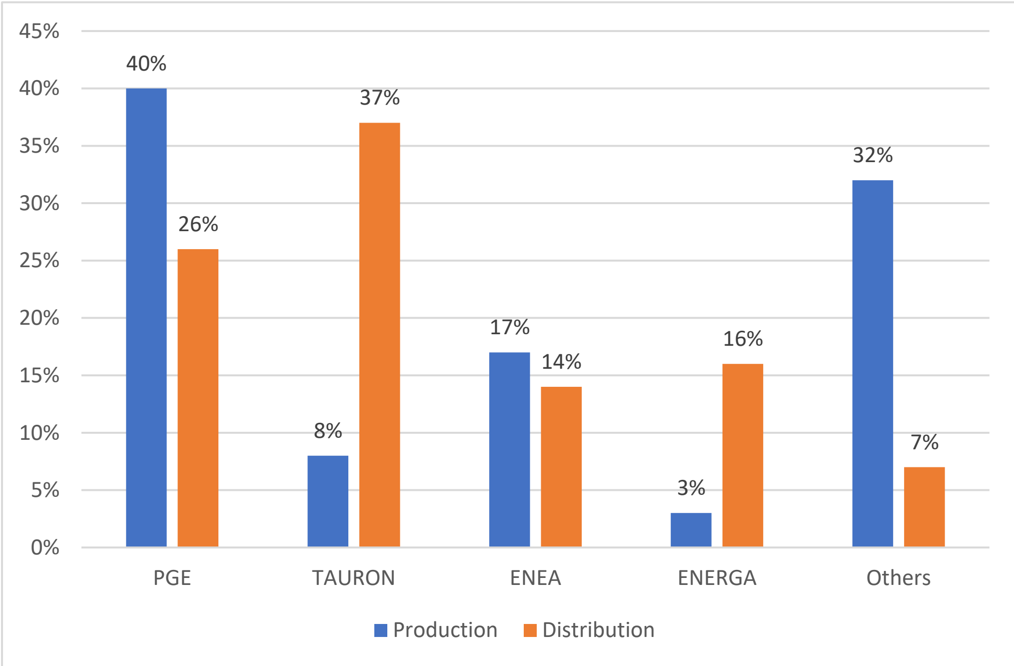

Figure 1. Participation of energy companies in the production and distribution of electric power in Poland. Source: author's work based on https://www.ure.gov.pl [26].

Market leaders form the "Other" group include PKN Orlen, ZE PAK S. A., and PGNiG Termika S. A., which has been a part of the PKN Orlen Group since November 2022, as well as ENERGA.

We used text analysis to identify the activities leading to a shift from a linear to a circular economy disclosed by the companies in their sustainability reports (RQ 1) and to encode and classify them by type and level of progress. In the first area (classification of the scope of activities), we used the model of Aranda-Usón et al. [27], which is one of the few comprehensive concepts for assessing practices in the implementation of a circular economy at the micro level. Despite its limitations due to the fact that the research was conducted on the Spanish market, the model was developed by taking into account various industries; therefore, it is a universal reference point for our research. It should be emphasised that it is difficult to find attempts to design a universal and comprehensive model for assessing the circularity of organisations that takes into account the normative–empirical and qualitative–quantitative approach in the literature. This results from significant differences in researchers' views on the necessary level of unification (Lacy and Hayward [28]; Franco [29]; Lieder and Rashid [30]; Urbinati et al. [31]; Linder et al. [32], although the need for unification of the measurement and reporting systems of CE activities is not questioned.

Based on a multi-level survey for Spanish experts, Aranda-Usón et al. [27] classified various CE activities using thirteen categories and aggregated them at four levels (see Table 1). Verification of the activities by companies in different industries in the Spanish market using the above-mentioned model revealed that most of them successfully implement projects at level I considered to be basic, particularly in the areas of industrial waste recycling and energy efficiency. The activity of companies at levels II and III is much less intense, and it is this area that experts considered particularly important from the point of view of stakeholders. At levels II and III, most companies are active in the area of eco-innovation, and the fewest are active in the area of renewable energy. Level IV is relatively poorly researched, and it is most difficult to implement CE models at this level.

Table 1. Classification of CE-related activities.

Level	Name	CE Activities
I	Recycling and energy efficiency [REC]	1.1 Energy efficiency 1.2 Environmental improvements 1.3 Industrial waste recycling
II	Dematerialisation and secondary raw materials [DES]	2.1 Dematerialisation 2.2 Recyclability 2.3 Secondary raw materials 2.4 Renewables
III	Eco-innovation and eco-design [VALW]	3.1 Eco-innovation 3.2 Eco-design multifunction 3.3 Eco-design durability
IV	Industrial ecology and symbiosis [SIM]	4.1 Energy waste recovery 4.2 Internal recycling 4.3 Industrial symbiosis

Source: author's work based on Aranda-Usón et al. [27].

Using the described model, we identified not only the scope of activities undertaken by companies in the Polish electric power industry but also the level of their progress. In the latter case, we adopted criteria 0–3, which are described in Table 2.

Table 2. Criteria for assessing the progress of companies' activities at different CE levels.

Assessment	Assessment Criterion
0	Lack of data concerning activities in the company's reports, or they reported a lack of activity in the area.
1	The company provides information about the preparation of activities or starting a project in a given area, but no real activities have been performed yet or projects are at the initial stage of development (low rating of the company's activities).
2	The company provides information about the implementation of real projects in a given area (average rating of the company's activity).
3	The company provides information about the implementation of projects in a given area and the implementation of current activities, and it carries out further projects in a given area (high rating of the company's activities).

Finally, by analysing similarities and differences in the scope and level of progress of CE activities undertaken by companies of the Polish electric power industry (RQ 2), we identified dominant practices in the industry.

4. Results

The results of the analysis of CE activities undertaken by Polish electric power industry companies were classified according to four levels of circularity defined by Aranda-Usón A. et al. [27] (see Figure 2).

In general, out of 52 company activity assessments, the lowest rating (0) appeared 16 times and the highest (3) only 9 times. Rating 1 appeared in 11 cases, and rating 2 appeared in 16 cases. A review of encoded disclosures showed that activities at level I, which is the easiest to achieve, are the ones that are emphasised in the reports. Within the adopted research concept, at level I, recycling and energy efficiency, the latter was analysed. It included activities aimed at optimising energy use in order to reduce the amount of energy needed to provide products and services. It means maximising energy use efficiency, which contributes to minimising the consumption of raw materials and greenhouse gas emissions.

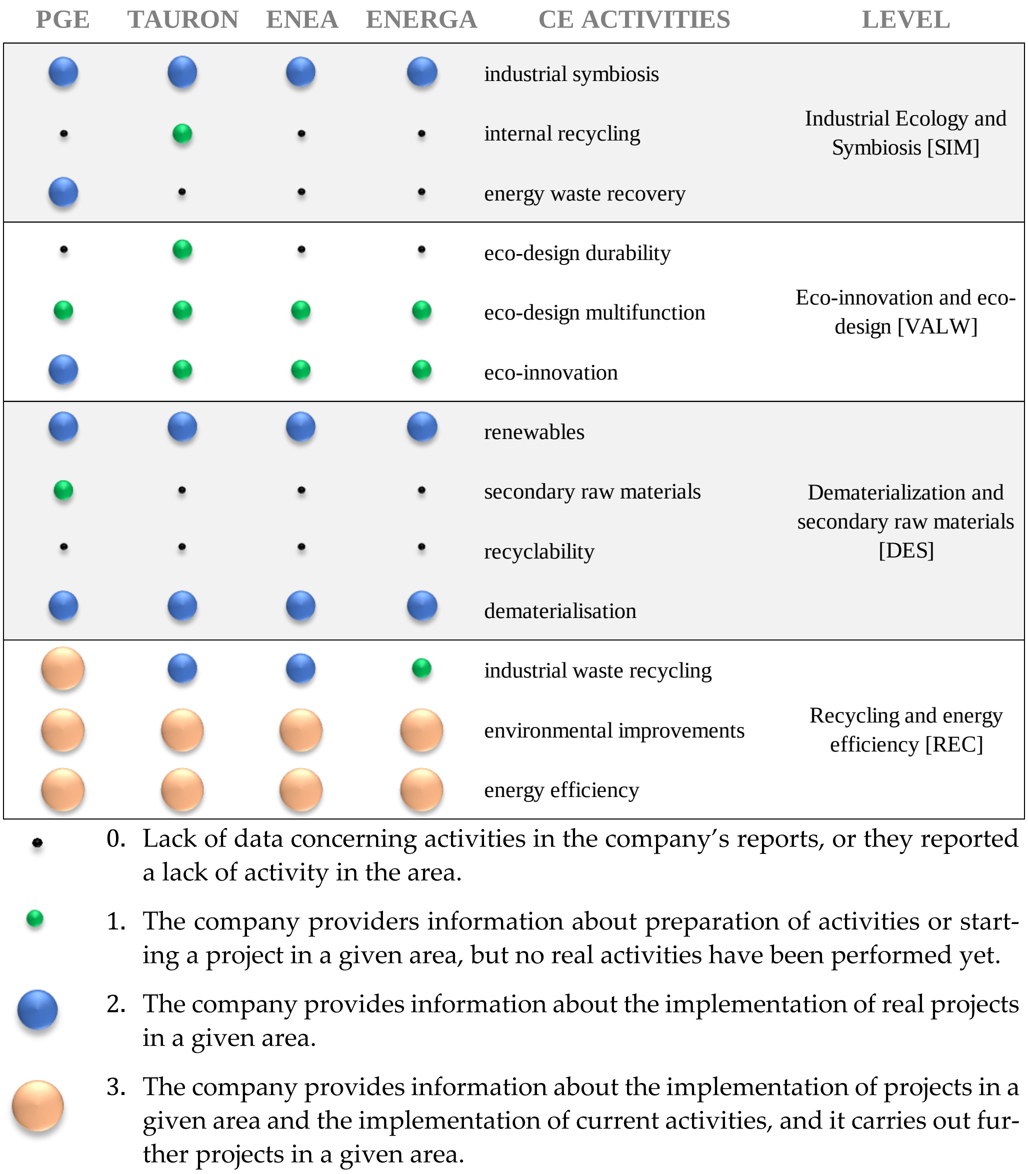

Figure 2. Areas of activities disclosed by companies of the Polish electric power industry in the field of the circular economy with the degree of their progress. Source: author's work based on reports of examined companies.

Based on the conducted research, it can be concluded that all companies include monitoring network loss indicators in the electric power and heat distribution industry in their reports. For many years, this has been a key indicator of improving energy efficiency [33]. A gradual conversion from passive to active energy networks, also known as the smart grid or the two-way grid, was of great importance for all analysed companies. Such solutions rely on the use of modern technologies and management systems to enable a bi-directional flow of energy between suppliers and customers.

Equally important for each company are plans to build new sources to replace existing ones. Apart from Tauron, which is completing the construction of a 910 MW coal-fired power station in Jaworzno, companies are moving away from the construction of coal sources in favour of gas furnaces. It should also be pointed out that companies find audits of their facilities and activities related to reducing energy consumption for their own needs important. This is consistent with the conclusions of Ma et al. [34], who note that buildings are among the major energy consumers and are responsible for about one-third of global energy usage and a similar share of energy-related CO_2 emissions.

The next element of the assessment at level I is environmental improvements, understood as activities aimed at minimising a negative impact of human activities on the environment and improving its condition. Increased environmental protection includes improvement of air and water quality, protection of biodiversity, reduction of greenhouse gas emissions, and minimisation of the amount of generated waste. The last element of the assessment at level I is activities in the field of the recovery of raw materials from industrial waste. The process of recycling industrial waste includes segregation of waste, its transport and processing, the recovery of raw materials, and the manufacturing of new products. In this area, the companies report primarily on the management of combustion by-products, which, according to the classification adopted in this study, belong to level IV, industrial symbiosis. As far as other waste is concerned, only PGE discloses meters and recycling plans. In addition to the management of CBPs, the companies report on significant investments in this area aimed at the modernisation of wastewater treatment systems and closing production water circuits.

Against the background of the analysed companies, PGE stands out in terms of the development of a circular economy concept, as in 2022 it launched a special circular economy segment, thanks to which waste generated as a result of electric power production is transformed into substances ready to be used in other branches of the economy. Also, ENEA declared that the new business lines will be related to the management of elements from used renewable energy installations and energy storage facilities.

Level II, dematerialisation and secondary raw materials, includes an analysis of activities aimed at reducing the consumption of raw materials and materials by optimising production processes, increasing productivity, and minimising resource waste. Secondary raw materials are materials recovered from waste and processed for reuse in the production of new products or materials. In short, they are raw materials derived from recycling, which, through recovery processes, can replace primary raw materials (those directly extracted from nature), including, for example, paper, cardboard, metals, plastic, and glass.

Dematerialisation is the pursuit of the production of goods and services with minimal consumption of raw materials.

Another area of focus at level II is recyclability. Highly recyclable products and materials are easier and more cost-effective to process and reuse in subsequent production cycles. The companies' reports lack information on the conscious use of materials that can be recycled more easily after use. A good example of potential initiatives in this area is paying attention to the material of the elements of energy infrastructure, as described by Khalid et al. [18].

Another area at level II includes activities of companies in the area defined as secondary raw materials, which are materials that are formed as a result of recycling or the recovery of raw materials from waste. Examples of secondary raw materials are those obtained from the recycling of metals, glass, paper, plastics, and other materials. They can be processed and used in subsequent production cycles, replacing used primary raw materials and reducing the consumption of natural resources.

The use of solar, wind, geothermal, hydropower, biogas, and natural renewable processes in electric power generation is part of the analysis of level II activities, referred to as renewables. The use of renewable energy sources allows for the replacement of fossil fuels and a reduction in the consumption of primary raw materials.

For each of the analysed companies, renewable energy sources constitute an important element of their development strategy. Companies consider them to be of great importance and prepare projects and even entire programs aimed at their development. Development projects concern mainly photovoltaics, but other projects can also be found in the company reports.

A summary of RES capacities [MW] together with planned projects of individual companies is presented in Table 3.

Table 3. List of RES capacities [MWe].

Company	Photovoltaics		Onshore		Water Energy		Biogas		Offshore	
	Facilities	Projects	Facilities	Projects	Facilities	Projects	Facilities	Projects	Facilities	Projects
PGE	23.7	154.0	688.2		1638.4				0.0	
Tauron	14.0	82.7	417.0	141.1	133.0	2.0			0.0	1000.0
ENEA	6.0	115.0	71.6	0.0	58.8	0.0	3.8	0.0	0.0	
ENERGA	8.4	155.2	243.9	0.0	359.3	0.0	0.0	0.0	0.0	1300.0

Source: author's work based on the reports of the analysed companies.

Level III refers to the classification of eco-innovation, i.e., innovative technological solutions, processes, and business models that contribute to environmental protection and sustainable development. In the circular economy, they can cover many areas, such as renewable energy, energy efficiency, recycling, water consumption reduction, the use of environmentally friendly materials, as well as changes in business models.

The second area at this level is eco-design multifunction, which involves designing products or services that are environmentally friendly, durable, and easy to maintain while offering users many different features. In this analysis, cogeneration, polygeneration, and other facilities enabling wider application of a given investment have been included in the eco-design multifunction category. Polygeneration encompasses not only the production of electric power and heat but also gas fuels, steam, cold, hydrogen, and even chemical products. For example, in the process of polygeneration, solar energy can be used to simultaneously generate electric power, heat, and cold and to produce green hydrogen. In the Polish energy industry, the technique of cogeneration (simultaneous production of electric power and heat) is well-known, as all groups possess facilities of this type among their assets. Projects using new cogeneration sources or focused on modernising existing ones play an important role in the investment plans of each of the companies. In addition to the sources already in operation, the companies report on the construction of new cogeneration facilities.

The companies also provide information about further plans for the development of cogeneration in individual locations as part of the decarbonisation of heating. They are also considering construction of solar panel car charging stations along with energy storage facilities as a development direction, but such ideas are just starting to appear (Tauron, ENERGA).

The final area at level III is eco-design durability. Products designed with eco-design durability in mind are durable and easy to maintain, which contributes to their longer use and reduces the need for frequent replacement. This, in turn, reduces the number of natural resources used, energy consumption, and greenhouse gas emissions associated with the production of new products. It is difficult to find information on the relevance of this issue in companies' sustainability reports.

Level IV, industrial ecology and symbiosis, is the last group of activities related to the circular economy. Recovering energy from waste can be implemented in various ways, including thermal (e.g., incineration), chemical, or biological processes. Examples of energy recovery from waste include the incineration of municipal waste to generate electric power, the conversion of biogas from organic waste to energy, the use of heat generated during industrial production processes, and the recovery of heat from water and air. The categories of energy recovery from waste include the incineration of municipal waste to generate electric power, the incineration of waste (RDF), the processing of biogas from organic waste to energy, or the use of heat generated during industrial production processes.

Alternative fuels, such as RDF (Refuse-Derived Fuel), are fuels produced from waste that have been appropriately selected and processed. This process involves mechanically crushing waste into the appropriate fraction (granulation), which allows for obtaining fuel with a high energy value. RDF is an alternative fuel that is gaining popularity due to its environmental and economic benefits.

As biogas and biomass were included in this analysis as RES, this level mainly refers to thermal waste treatment installations. Among the analysed companies, only PGE has prepared such a project, an installation in Rzeszów, and it is just starting to build a second technological line.

Level IV also covers internal recycling, the process of recovering and reusing waste or surplus raw materials within a single organisation or company. It means that waste or surplus raw materials that are generated in one production process are reused in another production process within the same organisation or company. It is difficult to find information about conscious activities in this area in the reports of companies.

The final area of analysis at level IV is industrial symbiosis. It is based on cooperation between different industries and organisations to maximise the use of resources and minimise waste and greenhouse gas emissions. An example of industrial symbiosis is zero-emission methanol production described in Sankaran [35]. Industrial use of combustion by-products (CBPs), which are formed during the combustion of coal, i.e., ash, slag, and gypsum, may be considered an activity of the companies in this area. These products are successfully used in housing or road construction.

CBPs, which were traditionally treated as waste in industrial models, become valuable raw materials in the circular economy. Thanks to innovative processing technologies, these by-products can be effectively used in various industries, from construction to the chemical sector, contributing to sustainable development and the conservation of natural resources. Their role in the circular economy demonstrates how crucial it is to implement innovations that allow for the full utilisation of waste and by-products, creating new business opportunities and positively impacting the environment.

According Chrzanowski [36], among the many directions for increasing the rational management of the UPS, one can mention research and implementation in the scope of the following:

- Increasing the recovery of microspheres from fly ash from current production and from landfills;
- Increasing the production and use of activated ash;
- Starting the production and use of fractionated fly ash (qualified ash);
- Resuming the production of hydrophobized fly ash;
- The recovery of metal concentrates;
- Recognising the feasibility of and possibilities for producing nanoproducts from fly ash as active components of binders and concretes and fillers for plastics.

5. Discussion

Based on the conducted research, it can be concluded that in their sustainability reports, the analysed electric power companies not only disclose information related to ESG but also describe CE activities. Each report provides a wide range of data on the importance of the circular economy in the companies' strategies. Looking for an answer to research question 1, we found that there were no long-term CE plans, measures for their implementation, or consistent criteria for disclosing individual areas, but it was still possible to identify both the scope and the level of progress of the activities implemented by the companies. Studies have shown that companies are taking action at level 1 mainly related to the modernisation of existing coal facilities in order to adapt them to increasingly strict requirements for CO_2, CO_2, sulfur oxides, and nitrogen emissions. Companies should be more involved in waste management (GRI 306-1, GRI 306-2, GRI 3-3). Against the background of other level I activities, disclosures in this area lead to the conclusion that either companies do not pay due attention to this aspect or there is a lack of guidance on reporting.

The need to change the so-called energy mix and the war in Ukraine accelerated the process of building new sources of renewable energy, which translated into a greater presence of companies at level II. However, relatively little attention is paid to the use of recyclable materials and the need to use recyclable components. We also found that companies are well aware of the need for level III activities, but the degree of project progress in this area is relatively low. Most projects are at a preliminary stage, although it is a very attractive area of development for energy industry companies, which is also because of the possibility of providing additional services that extend the lifecycle of designs. Activities of the companies at level IV are reduced to the management of CBPs, which is due to the specifics of the industry. On the one hand, this activity can be classified as waste management, but, on the other hand, combustion by-products are an important element of the constant cooperation of energy companies with companies from other industries, such as road and housing construction or agriculture. According to Chrzanowski [36], in 2016, 21,494,685 Mg of CBPs was created in Poland, 28.3% of which was transferred to landfills. Ensuring appropriate quality parameters for CBPs requires close cooperation between the companies to optimally manage them and minimise CBP storage due to low quality, which is why this activity is included at this level.

The results of our study confirm that practices specific for a given industry can be identified among the activities of the companies (see Figure 3). Our analysis shows that it applied to 7 of the 13 analysed CE activity areas: 1.1, 1.2, 2.1, 2.2, 2.4, 3.2, and 4.2. It should be noted that the similarities concern both the scope and the level of progress of the activities undertaken by the companies.

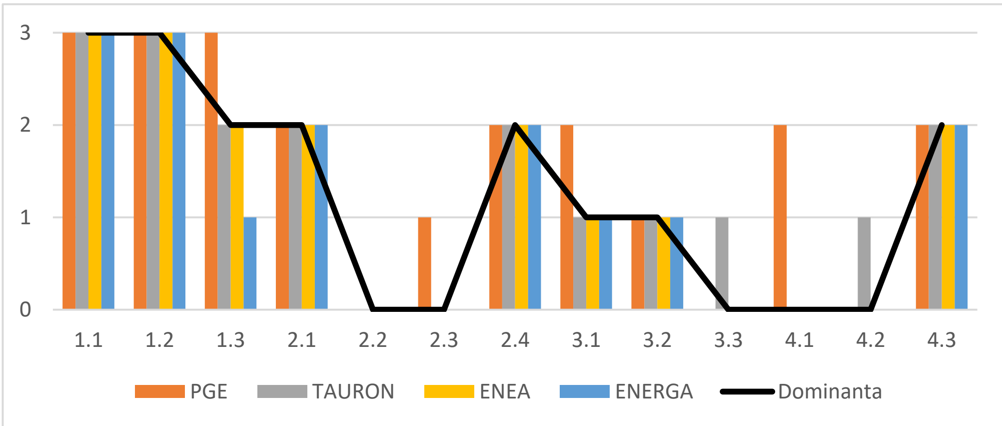

Figure 3. Dominant practices of Polish electric power industry companies within CE activities. Practice designations 1.1–4.3, as described in Table 1.

Searching for the dominant practices in the industry, we found that Polish electric power companies are strongly involved (dominant practice 3) in 2 of the 13 defined areas: energy efficiency (3.1) and environmental improvements (3.2). Research by Aranda-Usón et al. [27] indicated that nearly 80% of Spanish companies conduct activities in the area of improving energy efficiency, but their sample was not limited to energy companies. In the case of Polish electric power companies, it can be noted that this percentage is 100%. Intense activity in the area of energy efficiency can be noticed in the segment of electric power and heat distribution, and monitoring of network loss indicators has been an important element of the strategy of each of the companies engaged in this type of activity for many years. The development of smart grid and smart metering solutions will be crucial not only for improving energy efficiency [37] but, above all, for the further development of RES in Poland [38].

In the field of electric power generation, the construction of new power complexes with a much greater efficiency than the facilities that were built in the 1950s and 1960s contributes to improving energy efficiency. The system of white certificates based on the Energy

Efficiency Act is also important for improving the energy efficiency of companies. White certificates, regulated in the Act of 20 May 2016 [39], are certificates of energy efficiency issued for the obtained energy effect (energy savings) as a result of the implementation of a modernisation project. Activities in the field of energy efficiency have been taken by all actors operating on the electric power market for many years in accordance with Assumptions of Poland's [40] before the concept of the circular economy was created, and they resulted mainly from economic considerations. Continuation of these activities with the circular economy taken into account can bring new, interesting technical and organisational solutions.

A similar 100% of companies involved can also be observed in the area of improving environmental protection. Over the past few years, Polish energy companies have been forced to constantly modernise their assets in order to comply with EU directives and BAT. The system of penalties and the real risk of withdrawal of equipment motivated companies to engage in intense activity in this area. Practically all of the facilities owned by the companies have been adapted to the strict emission requirements or withdrawn and replaced with new low-emission ones. Total CO_2 emissions decreased by only 6% between 2015 and 2021, but this was largely due to the so-called Polish energy mix, i.e., a clear disproportion in the total number of installations in favour of coal facilities. Better results measured in percentages were achieved in the reduction of sulphur oxides (reduction by nearly 65%), nitrogen oxides (reduction by nearly 44%), and dust (reduction by 63.5%). Corporate sustainability reports are dominated by information on reducing emissions, which is consistent with the conclusions of Santos et al. [8].

Reporting on biodiversity activities (GRI) is a new development in the area of improving environmental protection (304-1, 304-2, 304-4). In principle, all Polish energy companies take action in this area in accordance with their locations, which certainly translates into improved environmental protection. Recultivation is another important activity of energy companies. It is especially relevant in the case of companies integrated with coal mining, where rehabilitation of mining fields is extremely important from the perspective of environmental protection. All companies have implemented environmental policies and related internal acts. Most of these activities, however, do not have clear goals and benchmarks set by the organisation, and reporting is limited to a description of performed activities. Nevertheless, the commitment of all companies to environmental protection activities should be assessed as high, although it is likely that its stimuli were mainly systems of penalties and obligations.

An average involvement of companies (dominant factor 2) can be observed in the areas of industrial waste recycling (1.3), dematerialisation (2.1), renewables (2.4), and industrial symbiosis (4.3). Waste management is an important issue for energy companies. We noticed a large discrepancy between the different forms of waste disposal in companies. Relevant goals are also missing. PGE declares as its only goal recycling 65% of its waste. The companies are also aware of the enormous importance of water and wastewater in their business activity and therefore undertake significant investments aimed at modernising wastewater treatment systems and closing the production water circuits. This activity is largely stimulated by regional environmental agencies. The area of industrial waste recycling needs to be systematised in terms of reporting and given more attention in the context of achieving circular economy objectives, although some companies undeniably introduce interesting initiatives.

Dematerialisation activities of the companies are based on the use of IT systems, such as work-flow and e-learning platforms. Companies strive to eliminate paper documentation inside of the organisation, but external documentation and customer habits or technical limitations remain a significant problem. Simplification of services and further development of customer contact channels seem to be key to progression in this area.

In the years 2005–2020, Poland witnessed a significant development of RES (Figure 4), and it should be noted that legal limitations have been effectively blocking the expansion of wind farms since 2016. Currently, it is mainly photovoltaics that is being developed.

Some offshore wind energy projects are underway, although they are still at the stage of preparatory work.

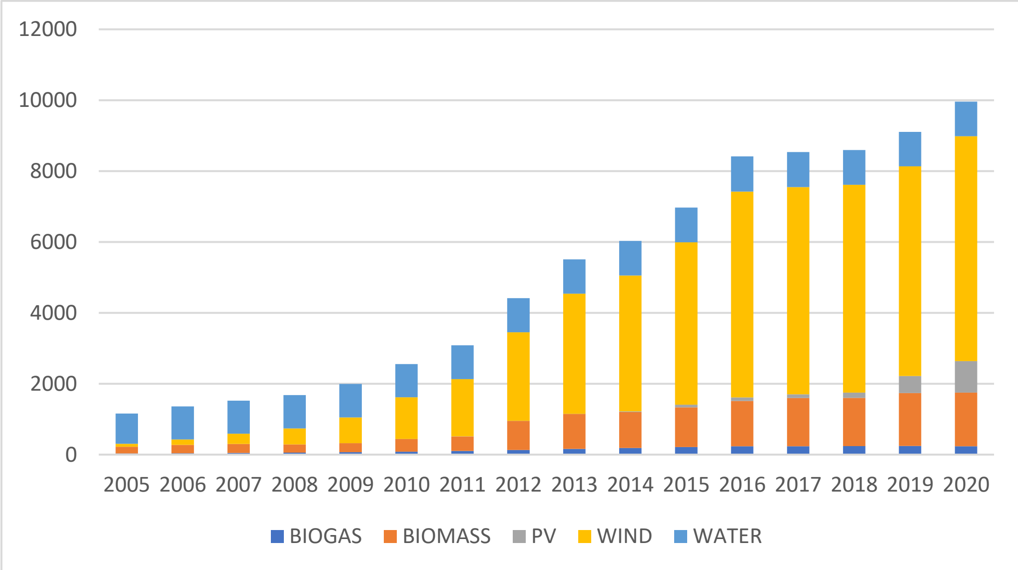

Figure 4. RES capacity in Poland in the years 2005–2020 [MW]. Source: author's work based on www.rynekelektryczny.pl/moc-zainstalowana-oze-w-polsce (accessed on 20 October 2023) [41].

Over the years 2005–2020, an approximately 8-fold increase in RES capacity was recorded. It should be noted that the initial stage in Poland included mainly hydropower facilities built several decades earlier. In 2022, photovoltaics experienced the most dynamic growth in Poland. According to the ESG report of PGE (2022) [42], at the end of December 2022, this technology had the largest capacity among renewable energy sources at 12.2 GW, and the vast majority of installations (8.8 GW) belonged to approx. 1.2 million prosumers. Thanks to the Act of 9 March (2023) [43] amending the Wind Farm Investment Act and certain other acts, as well as some liberalisation of existing regulations, the situation regarding the further development of onshore wind farms may improve slightly. A significant limitation to further activity in this area is current legal and network restrictions. An additional barrier to the development of RES is the relatively high cost of energy storage and difficulties in locating the related investment in the structure of charges for electric power. It should be noted that apart from PGE, the companies do not notice future problems connected with the end of products' lifecycles in their reports, which is consistent with the conclusions of Brown [14] and Zvirgzdins and Linkevics [17]. This is due to the relatively short period of use of such installations in Poland.

Taking initiatives in cooperation with other partners is not popular among energy companies. There is a large area for development in the form of the construction of energy clusters and dedicated generation facilities using local fuel (RDF, biogas). Examples of industrial symbiosis may include the use of waste as fertilizer for agriculture, the use of heat produced by one company to heat buildings nearby, or the use of residues from the production of one industry as raw materials for another industry. For the purpose of this analysis, industrial use of combustion by-products (CBP), which are formed during the combustion of coal, i.e., ash, slag, and gypsum, may be considered an activity of the companies in this area. These products are successfully used in housing or road construction. PGE also performs activities related to the use of production waste in agriculture. The use of combustion by-products in the power industry is well-developed in electric power companies, which does not mean that it is not necessary to look for new, innovative solutions proposed by, e.g., Ghosh and Kumar [19].

Other areas of activity in the reports of Polish electric power companies are poorly advanced (dominant factor 1) or even omitted (dominant factor 0). It is true that companies are eager to introduce eco-innovation initiatives, but they are often only at the research and development stage.

In the area of eco-design multifunction, apart from projects of new polygeneration facilities, the companies are considering the construction of photovoltaic car charging stations along with energy storage facilities as a development direction, but these projects are only beginning to appear in the companies' plans. The areas of eco-innovation and eco-design multifunction are certainly areas requiring intensive research and development activities of electric power companies. Some of the organisations may not describe their activities in the reports because of the protection of intellectual property at the initial stage of development and due to the fear of duplication of the project by other market participants. It should also be pointed out that eco-design durability is rarely a priority in investment decisions, which may result from objective difficulties in describing and subsequently enforcing such criteria in public tenders. In contrast to the conclusions of Aranda-Usón et al. [27], the level of progress of the Polish electric power industry at level III should therefore be assessed below ca 50%.

In the areas of recyclability and secondary raw materials, it is difficult to notice any activity of the companies (dominant factor 0). An idea for active involvement in recyclability could be a requirement of recyclability for the equipment suppliers, which means that equipment should be designed so that is easy to recycle after the end of its lifecycle. Companies also lack the concept of managing such waste, with the exception of the activities undertaken by PGE, which included the creation of the Research and Development Centre for CE. The companies' reports lack any information on the conscious use of secondary raw materials. These issues are not given enough attention, or there is a lack of awareness among the authors of the reports of their relevance from the perspective of the circular economy.

Other areas in which we observe a lack of companies' activity (dominant factor 0) are energy waste recovery and internal recycling at level IV. Activities in the field of thermal waste treatment in Poland are undertaken mainly with the use of EU grants in a partnership with local governments and, for example, equipment suppliers. In Poland, there are nine operating waste incineration plants, while, for instance, in France, there are 128 large thermal waste disposal plants. In Germany, there are 66 of them, and in Switzerland, which is a small country, there are 30. In total, there are over 400 municipal waste incineration plants in Europe, which account for nearly 25% of waste disposal. In Scandinavia, over 50% of waste is incinerated [44]. The analysed companies, with the exception of PGE, do not report running projects in this area, which is consistent with the small percentage of companies involved in this activity in Aranda-Usón et al.'s [27] study. It is also difficult to find information in company reports on conscious activities in the field of internal recycling.

The practices of the circular economy (CE) in Poland are shaped by the complex influence of political regulations from the EU as well as national development strategies and economic factors related to the profitability of circular technologies, access to raw materials and energy, and growing ecological awareness among consumers. Effective implementation of the circular economy requires both strong supporting policies and actions that motivate businesses to invest in sustainable technologies and resource management.

6. Conclusions

Sustainability reports are an important source of information for stakeholders. However, disclosure of the scope, status, and effects of CE activities was not regulated by law before the introduction of the CSRD directive. In the literature, there are no models for a comprehensive assessment of the activities of companies in this area. Both issues are relevant to the assessment of information published by companies regarding the implementation of CE strategies. Using the model proposed by Aranda-Usón et al. [27], we attempted to identify circular economy implementation models characteristic of the Polish electric power industry. Analysis of the reports showed that activities at level I, recycling and energy efficiency [REC], clearly stand out. At level II, dematerialisation and secondary raw materials [DES], the most intense activities include investments in RES, and at level IV, industrial ecology and symbiosis [SIM], the most intense activities are those related to the use of combustion by-products. A characteristic feature is poor representation of electric power companies at level III, although this area may be of interest to the industry in the context of the separation of coal facilities from the companies' assets. The conclusions presented here are slightly different from those of Aranda-Usón et al. [27]. In our opinion, the results are due to the specificity of the energy industry and the fact that activities at level I have been a priority of Polish companies for many years.

It can therefore be concluded that the Polish energy industry is aware of the challenges associated with the CE, but companies lack a comprehensive approach to building a CE strategy, setting goals, and measuring progress in this area.

Our study is not free from limitations. The sample is limited to Polish listed companies. The restrictions of the presented analysis also result from the adopted methodology. It is mainly based on information contained in the sustainability reports of companies. A lower rating of a company's activity in a given area may result from the lack of adequate information in these reports and not from a lack of actual activities of the company. Despite the awareness of the importance of the circular economy for electric power companies, reporting is based on the subjective approach of the reporters regarding the relevance of a particular activity. Some companies may consider a particular activity to be significant and report it, while others may consider it irrelevant. The companies possess varied assets, so it is difficult to compare the scale of the activities carried out in a given area from a financial perspective. For instance, PGE's expenses for the construction of new energy blocks will be incomparable with ENERGA's expenses. Therefore, we mainly focused on a qualitative assessment. It should be noted that the analysis was carried out without the participation of representatives of the companies, who could not refer to its results; the only source of data was the sustainability reports. However, the authors believe that these reports are a source of useful information for the companies' stakeholders, particularly with regard to areas with a strong socio-environmental impact, which include CE issues.

An interesting direction for future research would be to look at other European companies in this industry in the context of verifying the conclusions of this study. Overcoming the barriers to adopting a circular economy requires a coordinated effort on multiple fronts, including legislation, education, technological innovation, and changing social attitudes. Legislative and regulatory support and investment in technological innovation will be key for the entire sector. Changing business models from linear to circular seems to be a natural path for companies in this sector. The circular economy should be the main direction for shaping new business strategies for energy companies.

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