Potential of industrial symbiosis towards circular economy – a case of Poland

Muhammad Faizan Abbas

Bialystok University of Technology, Faculty of Engineering Management

e-mail: Muhammad.faizan.abbas.IS-4687@student.pb.edu.pl

Zaheer Abbas

Bialystok University of Technology, Faculty of Engineering Management

e-mail: zaheer.abbas.is-4681@student.pb.edu.pl

Joanna Godlewska

Bialystok University of Technology, Faculty of Engineering Management

e-mail: j.godlewska@pb.edu.pl

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Abstract

The aim of this study is to investigate the role of industrial symbiosis in fostering a circular economy in Poland, with a particular emphasis on the contributions of various sectors to material circularity. Industrial symbiosis, which involves using waste or by-products from one industry as inputs for another, is identified as a key mechanism for achieving resource efficiency and sustainability. This research conducts a thorough analysis of statistical data from the past decade to pinpoint key sectors crucial for enhancing material circularity, with the mining sector emerging as a critical focus due to its significant environmental impact and resource recovery potential.

The study's findings underscore the substantial benefits of shifting from a traditional linear economy to a circular economic model. By adopting industrial symbiosis practices, industries can markedly reduce their material footprint, lower environmental impacts, and create new economic opportunities. The research highlights the importance of policy frameworks and incentives to encourage the adoption of circular practices. It also addresses the challenges and opportunities of implementing industrial symbiosis, such as the need for technological advancements, industry collaboration, and supportive regulatory environments.

In conclusion, this study offers valuable insights into the implementation of industrial symbiosis as a strategy for advancing the circular economy in Poland. The results indicate that such practices not only support sustainable development goals but also enhance the overall resilience of the economy. This research contributes to a broader understanding of how industrial symbiosis can be effectively leveraged to achieve sustainability and resource efficiency at a national level.

Key words

industrial symbiosis, circular economy, material footprint, sustainable development

Introduction

As the global population continues to surge and economies expand, the demand for raw materials escalates, exerting immense pressure on natural resources and ecosystems. This will cause us to fulfil demand of current necessities with prior consideration of environmental impacts. The world is in the midst of a triple planetary crisis of climate change, biodiversity loss and pollution and waste. The global economy is consuming ever more natural resources, while the world is not on track to meet the Sustainable Development Goals. The scientific community has never been more aligned or more resolute on the need for urgent global transformation towards the sustainable use of resources [https://www.resourcepanel.org/global-material-flows-database, 20.06.2024].

The goal of the research is to identify the potential implementing a circular economy (CE) through industrial symbiosis (IS). This paper particularly targets Poland's statistic and shed light to sector which prioritized the most contribution towards circularity. The research also provides insight into why there will be a need to focus on marked sector. To get results, some recommendations are also expected to be taken out.

Urgent action is needed to ensure that current material needs do not lead to over-extraction of resources and further degradation of the environment. Policies must be embraced to improve resource efficiency, reduce waste and mainstream sustainability practices across all sectors of the economy. Material footprint refers to the total amount of raw materials extracted to meet final consumption demands [The Sustainable.., 2024, p. 33]. It is one indication of the pressures placed on the environment to support economic growth and to satisfy the material needs of people. The Global Material Flows Database provides data to help governments, policy researchers and interested stakeholders understand and trace the linkages between economic growth and raw material usage. Such information is basic for the development of effectively targeted sustainable consumption and production strategies. It also builds a strong quantitative basis upon which the success or failure of those strategies in lowering resources use can subsequently be assessed [https://www.resourcepanel.org/global-material-flows-database, 20.06.2024].

1. Literature review

Moving away from the linear "take-make-use-dispose" model and transitioning to a regenerative growth model is essential to keep resource consumption within planetary boundaries. In a circular economy, the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized [https://environment.ec.europa.eu/topics/circular-economy_en, 10.05.2024]. The implementation of the circular economy (CE) concept means that more and more attention is paid to the use of the raw material and energy potential inherent in the waste generated by the industry, as well as taking actions at the source to reduce its formation [Pan et al., 2015, p. 413]. The circular economy will help us decouple economic growth from resource use, protecting Europe's natural resources while boosting sustainable growth. It will help the European Union to strive to reduce its consumption footprint and double its circular material use rate in the coming decade.

The circular economy will:

- enable a healthier planet and reduce pollution,
- reduce pressure on natural resources such as water and land use,
- reduce emissions to help the EU become the first climate-neutral continent,
- create new business opportunities and local quality jobs,
- enable more resilient value chains [https://environment.ec.europa.eu/topics/circular-economy_en, 10.05.2024].

When put your head together with companies related to the circular economy and industrial symbiosis, the practical problem is to know when and how much material is available or supplied for production. It is challenging when you use by-products from another industrial actor, you just cannot order the exact amount of material. No one produces by-products purposefully; it is a waste from production and naturally, everybody aims to minimize the amount of waste. In addition, the changes in production volume will change the amount of by-product.

Previous research shows that there is lack of information to find a suitable partner as well as the availability of waste and by-products. There is a gap in the knowledge of long-term industrial symbiosis at the point of view of data and information sharing in the value chain [Järvenpää et al., 2022, p. 34].

This paper seeks understanding what are the most highlighted area of interest that needs to be done on priority basis for implementation of circular economy through industrial symbiosis which Poland's has potential to improve more. The research question is: which economic sector have more potential to contributes most to circular economy implementation in Poland? This paper belongs to research that explores root cause for why there is need to focus on industrial symbiosis and which sector contributes the most using different material flows statistics of Poland. This will create a pathway for further and deep research analysis in the area particularly how and which factors affect the most and what are the barriers?

Industrial Symbiosis engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of the required inputs, value-added destinations for non-product outputs, and improved business and technical processes'. This broad definition shows that in practice it covers not only physical exchange of materials, energy, water, and/or by-products, or waste for re-use, recycling, etc. but also innovative organisational and management solutions in the entire value chain [Chertow, 2007, p. 12], [Lombardi and Laybourn, 2012, p. 29]. Industrial symbiosis is a practical implementation of the circular economy. By facilitating the exchange of materials, energy, water, and by-products between companies, industrial symbiosis contributes to creating closed-loop systems, reducing the need for virgin materials, and minimizing waste. This collaboration aligns with the principles of the circular economy by promoting resource efficiency, sustainability, and economic resilience [Chertow, 2007, p. 12].

Kalundborg Symbiosis in Denmark is one of the most well-documented and successful examples of industrial symbiosis. This model has been operational since the 1970s and involves several companies like: Asnaes Power Station, Statoil Refinery, Novo Nordisk (pharmaceutical company), Gyproc (plasterboard manufacturer), and Kalundborg Municipality, that exchange and improved usage of energy, water, and materials to gain economic profit and reduce environmental impacts [https://www.symbiosis.dk/en/ 18.06.2024].

Poland ranks as the top extractors in the EU for many minerals, fossil fuels and ores and over one-quarter of all waste generated is currently landfilled. The economy is also characterized by its high levels of emissions, owing to its heavy coal use. The country's carbon footprint a consumption-based measure sits under its territorial emissions by 4%, showcasing that Poland is less reliant than its neighbours on consuming materials and generating emissions abroad. This provides the country with more control, but also responsibility, to transition away from an extraction-based economy with high domestic emissions [The Circularity…, 2022, p. 22]. On the governmental level, the basis of the circular economy concept is the assumption that all elements of the production chain, products, materials and raw materials, remain in circulation for as long as possible. Waste generation should be reduced to a minimum. The transition to a circular economy model requires taking appropriate actions at all stages of the product life cycle, starting from obtaining raw materials, through design, production, consumption, waste collection and their management. Implementation of the circular economy concept is not possible without organizational, process and product innovations. Although it seems complicated in theory, in practice it is already happening. What we have been doing so far under the banner of green economy or sustainable development is precisely "closing the loop". It is the use of solar energy, biodegradable dishes, reducing packaging, using reusable bags, recovering secondary raw materials - this is what circular economy is all about.

Poland's priorities within the circular economy include:

1. Innovation, strengthening cooperation between industry and the science sector, and as a result, implementing innovative solutions in the economy.
2. Creating a European market for secondary raw materials, where their flow would be easier.
3. Providing high-quality secondary raw materials that result from sustainable production and consumption.
4. Development of the services sector [Mapa…, 2019, p. 6].

Despite the development of waste technologies and increasing financial outlays on the implementation of environmentally friendly solutions, industrial waste is still a significant ballast that negatively affects the environment [Pan et al., 2015, p. 410]. In this context, the industrial waste generated must have an even composition and properties that significantly differentiate it from municipal waste. This largely allows for economically, ecologically, and socially effective planning its treatment methods.

In Poland, the priority sectors for implementing the circular economy include mining, processing (including the steel industry), energy, construction, the agri-food industry (bioeconomy) and plastics. Due to the hitherto low level of reuse of materials, parts, and waste, as well as the constantly growing demand for products and services of the abovementioned industry sectors, they are shown as key to the implementation of the postulates for sustainable development and a circular economy [Jąderko-Skubis et al., 2022, p. 4801]. Poland has all the conditions for the wider implementation of a closed-loop economy. At this moment, the following points related to the current state of the system are relevant:

- In Poland, domestic material consumption (DMC) and material footprint (MF) are approximately 660 million tonnes, and about 655 million tonnes respectively. On a per capita basis, both figures are higher than the EU average; according to the latest available data, both the annual DMC and MF per capita in Poland were approximately 18 tonnes each, while in the EU they did not exceed 15 tonnes per capita [https://raportsdg.stat.gov.pl/2022/en/Resource_consumption.html, 01.07.2024].
- Approximately 85% of Poland's energy mix in 2021 was derived from fossil fuels [Kardaś, 2023, p. 3].

Taking int account waste generated by industry sectors in Poland, following facts are crucial to be considered by implementing principles of circular economy:

- According to statistical data, as much as 45% of all waste is generated by coal mining (hard coal and brown coal) and metal ore mining. These are waste, a small part of which is recycled, which confirms the low effectiveness of Polish waste management.
- One of the more perspective groups of industrial waste is the by-products of combustion, of which about 35% is disposed in landfills. This represents a significant resource loss, given that this waste can be an important source of recovery of economically important minerals.
- The mining and quarrying industries are the largest waste-generating industries. Annually, they generate about 67 million tons of waste.
- The Polish construction market is the seventh largest in the EU and one of the fastest growing in Europe. Across the EU, the sector is responsible for using around half of all extracted raw materials. This is an important reference point in closing the waste cycle [Jąderko-Skubis et al., 2022, p. 4802].

2. Research methodology

This research employs a mixed-methods approach, combining quantitative and qualitative data collection and analysis to comprehensively understand waste management practices and the implementation of circular economy principles. The mixed-methods design ensures a holistic view, capturing both numerical data and contextual insights (Fig. 1).

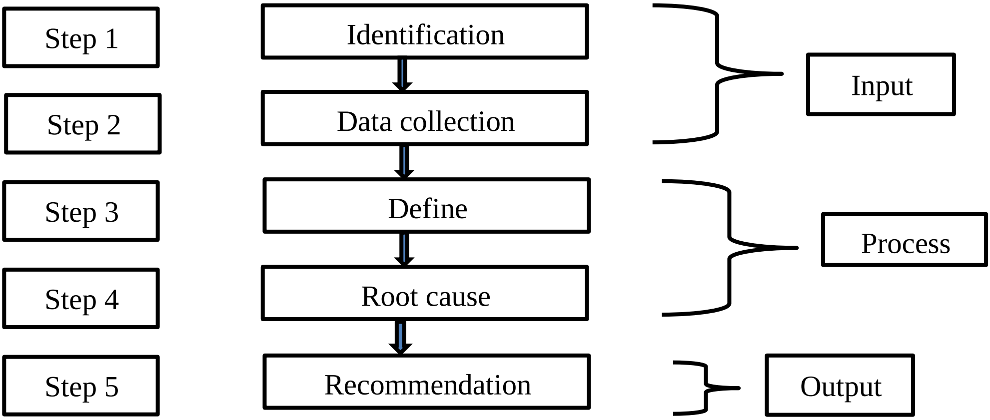

Fig. 1. Steps of research methodology

Source: own elaboration.

The research methodology consists of five main steps and their objectives are as follows:

1. The objective of problem identification is to understand the existing body of knowledge on waste management and circular economy practices. Also to identify gaps in current research and contextualize the study within the broader field. For this, conduct a systematic review of academic journals, industry reports, policy documents, and case studies. Also use databases such as Google Scholar, JSTOR, and Scopus for academic literature to identify sectors and area of interest. Gone through to review reports from environmental agencies, governmental bodies, and non-governmental organizations to successfully get suitable outcome for this phase of identification.
2. Quantitative data collection objective is to gather statistical data on waste generation and management across various sectors through secondary data from national statistical offices, environmental protection agencies, and industry reports. Main sources like: Polish Statistics and Eurostat were utilized to get data of total waste generated, waste types, recycling rates, landfill rates, sector-specific waste data.
3. Defining phase is essential for setting a clear and focused direction for this research. By thoroughly articulating the issue, researchers can ensure that their study is relevant, well-structured, and capable of producing meaningful insights and solutions with the help of citation. It sets the stage for the entire

research process by clearly articulating the issue that the research aims to address. Clearly defining the problem helps narrow the focus of the research, ensuring that the study is manageable and directed towards a specific issue. It also prevents the research from being too broad or too vague, which can lead to inconclusive or unfocused results. It will highlight the potential benefits of addressing the problem through the proposed research.

4. The objective of the root cause step is to delve deeper into the data to uncover the underlying factors or causes that contribute to the observed problem or issue. It aims to move beyond surface-level symptoms to identify the core issues that need to be addressed. The root cause phase provides the foundation for the subsequent development of effective strategies and interventions. By focusing on the underlying causes, researchers can propose solutions that are more likely to result in long-term, sustainable improvements. This is essential for identifying the true origins of a problem, enabling researchers to develop informed and impactful recommendations for addressing the issue at its core.
5. Recommendation is crucial for any article as it translates the findings and interpretations into actionable suggestions. It helps bridge the gap between research and practical application, providing with clear guidance on how to address the issues identified in the study. It provides clear, justified, and actionable steps for stakeholders to address the issues identified in the research, ensuring that the study has a tangible impact on policy, practice, and further research.

3. Research results

Poland's transition towards a circular economy hinge on significant improvements in waste management practices, especially in high-waste sectors like mining and manufacturing. By implementing targeted policies, fostering industry collaboration, and investing in innovative solutions, Poland can enhance its circularity and contribute to global sustainability goals. The research highlights the importance of focusing on these critical sectors to drive meaningful change and achieve a sustainable future.

The research focused on the implementation of circular economy (CE) through industrial symbiosis in Poland, aiming to identify sectors with the most significant contributions towards circularity. The data collected spans over the past decade, highlighting potential actions and recommendations for future policies.

Waste generated by main industry sectors in Poland in years 2004-2022 are presented on the Figure 2.

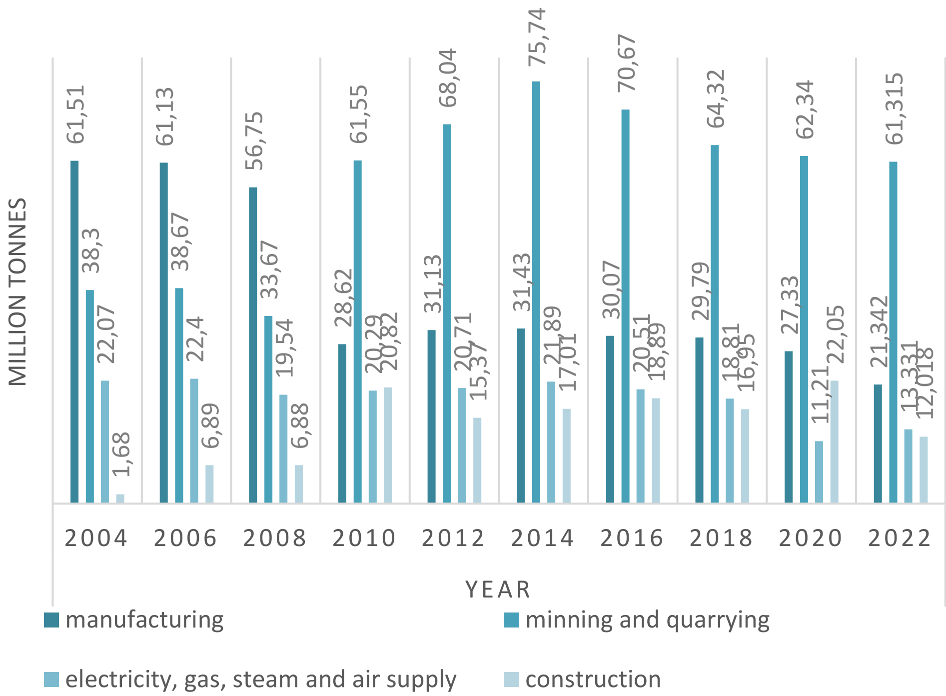

Fig. 2. Waste generated by sectors in Poland in years 2004-2022
Source: own elaboration on the basis of [https://stat.gov.pl/en/topics/environment-energy/environment/environment-2023,1,15.html, 10.05.2024].

Analysis of data presented on the Figure 2 provides a long-term perspective on waste generation across various sectors. Mining and quarrying are consistently the largest waste producers over the years, peaking in 2014 year with over 75 million tonnes. This trend underscores the need for targeted interventions to reduce waste in this sector. The problem is more important, because over 850 million tonnes of waste from mining were accumulated in landfilling.

Manufacturing demonstraits variability in waste generation, with a significant reduction after 2014 year. This suggests some progress in waste management practices but also highlights the need for sustained efforts. Manufacturing sector remains the second-largest contributor, generating over 21 million tonnes in 2022 year. This indicates significant potential for recycling and reusing materials within the sector.

Waste generation in electricity, gas, steam, and air supply sector remains relatively stable with minor fluctuations. Continuous improvement in energy efficiency and waste reduction is essential.

Generation of construction waste shows variability, with a notable reduction in recent years. In 2022 the sector generated over 12 million tonnes. This positive trend should be encouraged through more stringent regulations and incentives for recycling.

4. Discussion

Industrial symbiosis is an approach where waste or by-products from one industry are used as raw materials in another, promoting a circular economy. This practice has significant potential in the mining sector, where the management of waste materials is a major environmental challenge. Waste solids or slurries or by-products remaining after the treatment of minerals by separation processes contain the less valuable rock. The amount of waste generated varies quite significantly depending on the extraction operations and type of mining (underground, open pit). Where only a pure vein is mined almost no waste may be produced. In the case of coal, about 75% of the extracted material is coal and the other 25% is tailings. Gold ore contains only a few grams of gold (Au) per ton of mined material, e.g. a gold content of 5 g/t means that in order to extract a ton of gold about 200,000 tons of ore have to be mined which end up as tailings.

Depending on the type of mining waste or by-product, different technologies can be proposed for their management. Topsoil is usually stored on-site and used for ongoing reclamation in a nearby area or for revegetation once extraction has finished. Overburden and waste rock, depending on its size can be used as backfill in previously excavated areas or transported off-site and used in work on construction projects. There are many opportunities for its application, i.e. road, pavement, building construction, feedstock for cement and concrete, ceramic material, as a component of asphalt, but the one chosen depends on the quality of the waste, cost of reuse, long-term policy, stakeholder and citizen pressure, CSR policy, etc. However, in practice, due to it being the cheapest option most of the waste rock currently generated is deposited in piles near the mine site. Tailings usually occur in the form of a slurry consisting of 15–60% solids or as coarse tailings. Coarse and fine tailings can be used to backfill mines. Most mine tailings are deposited in on-site impoundments, called extractive waste facilities. But usually, they are used for reprocessing to reuse metal and minerals or the manufacturing of bricks, floor tiles, cement, etc. [Kulczycka et al., 2020, p. 78].

It is worth to add, that in Poland, the recovery of secondary raw materials (both from production processes and from purchasing) applies, i.e. to steel scrap and waste, non-ferrous metals (copper, brass and bronze, aluminium, lead, zinc and tin). Extracting metals from waste materials is less energy-intensive than from primary sources [Smol et al., 2021, p. 2227].

In Poland, companies like PGE, GiEK are at the forefront of integrating industrial symbiosis practices, particularly with coal waste into new products and processes, demonstrating the feasibility and benefits of industrial symbiosis to foster circular economy. By adopting these practices, Poland not only mitigates the environmental impact of coal mining but also creates economic opportunities through the development of new industries and job creation. [Kulczycka et al., 2020, p. 80].

Conclusions

Industrial symbiosis offers a transformative approach to mining waste management in Poland. By fostering collaboration between industries, optimizing resource use, and mitigating environmental impacts, industrial symbiosis can significantly enhance the sustainability and efficiency of the mining sector. While challenges exist, the potential benefits in terms of economic gains, environmental protection, and regulatory compliance make industrial symbiosis a compelling strategy for Poland's mining waste management.

By integrating mining waste into the circular economy, materials can be recycled and reused within the production cycle, reducing the demand for virgin raw materials and promoting sustainability. Recycling and reusing materials from mining waste can lower production costs for mining companies by reducing the need for new raw material extraction. Developing technologies and businesses around mining waste recycling and management can create new economic opportunities and jobs. Demonstrating a commitment to responsible waste management can improve the relationship between mining companies and local communities, fostering trust and cooperation. Investing in R&D for mining waste management can lead to the development of more sustainable and efficient methods for handling waste, benefiting the entire industry.

ORCID iD

Joanna Godlewska: https://orcid.org/0000-0001-9538-7014

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Potencjał symbiozy przemysłowej w kierunku gospodarki o obiegu zamkniętym – przypadek Polski

Streszczenie

Celem artykułu jest zbadanie roli symbiozy przemysłowej w promowaniu gospodarki o obiegu zamkniętym w Polsce, ze szczególnym uwzględnieniem wkładu różnych sektorów w cyrkularność materiałową. Symbioza przemysłowa, polegająca na wykorzystywaniu odpadów lub produktów ubocznych z jednej branży jako surowców dla innej, jest uznawana za kluczowy mechanizm osiągania efektywności zasobowej i zrównoważonego rozwoju. Przeprowadzono szczegółową analizę danych statystycznych z ostatniej dekady, aby zidentyfikować kluczowe sektory istotne dla zwiększania cyrkularności materiałów, przy czym sektor górniczy wyłania się jako szczególnie ważny ze względu na jego znaczący wpływ na środowisko oraz potencjał w zakresie odzysku zasobów. Wyniki badania podkreślają znaczne korzyści wynikające z przejścia z tradycyjnej gospodarki liniowej na model gospodarki cyrkularnej. Poprzez przyjmowanie praktyk symbiozy przemysłowej, przemysły mogą wyraźnie zmniejszyć swoje zużycie materiałów, ograniczyć negatywne skutki środowiskowe i stworzyć nowe możliwości gospodarcze. Badanie zwraca uwagę na znaczenie ram politycznych i zachęt wspierających przyjmowanie praktyk cyrkularnych. Wskazuje również na wyzwania i możliwości związane z wdrażaniem symbiozy przemysłowej, takie jak potrzeba postępu technologicznego, współpracy przemysłowej oraz sprzyjających regulacji prawnych.

Słowa kluczowe

symbioza przemysłowa, gospodarka o obiegu zamkniętym, ślad materiałowy, zrównoważony rozwój