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Recognizing the economic and environmental potential of mining disposal sites and industrial landfills using SWOT analysis

Introduction

The heaps, dumps, and industrial landfills present in the spatial landscape are related to the centuries-long activities of the mining and related industries, including, e.g., metallurgy or power generation. Both the way in which these sites were constructed and the approach to their use evolved with technical and technological developments and increased environmental awareness. The first references to the secondary raw material potential of waste date back to the 16th century, when the processing of waste from calamine ore mining began, obtaining raw lead and slag from molten waste rock (Majorczyk 1985). However, the

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recovery of waste on an industrial scale did not begin until the 1990s. It was also during this period that environmental aspects, including issues related to rational waste management and environmental stewardship, started to become more important. Consequently, sites where waste from mining, processing, and industrial activities had accumulated began to be seen not only as a source of secondary raw materials, but also as places with great cultural, natural, tourist, or recreational potential.

Innovative solutions to recover secondary raw materials from mining waste have resulted in the demolition of many sites to use accumulated materials. Others have been reclaimed and managed to varying degrees or have been subjected to natural plant succession and blended into the landscape. The potential of many of these sites is still unrecognized – they may represent a valuable source of raw materials or possess unique natural values. This paper attempts to assess the environmental and economic (secondary raw material) importance of mining and industrial waste sites using a SWOT analysis supported by a TOWS analysis. This technique proves to be a universal tool in the first stage of strategic analysis and is often used to optimize decisions in various fields, including waste and environmental components management (Kot-Niewiadomska and Gałaś 2011; Szałata and Zwoździak 2011; Góralczyk and Żbikowska 2012; Marot and Harfst 2012; Neagua et al. 2015; Taufik et al. 2021; Šoštarić et al. 2022).

1. SWOT analysis – a strategic analysis tool

SWOT analysis (an acronym for Strengths, Weaknesses, Opportunities and Threats) is one of the basic methods of strategic analysis used to study an organization and its environment (Learned et al. 1965; Woźniak and Sołtysik 2024). Although the basic principles of SWOT analysis were developed in the 1950s and 1960s, due to its simplicity, it is still widely used, including in other functional areas such as environmental management (Szałata and Zwoździak 2011). The essence of SWOT analysis is strategic reasoning based on collected and sorted data and systematisation of knowledge. The result of the SWOT analysis is the basis for selecting an action option to be implemented and/or executed (Nowicki 2015; Miszewska and Niedostatkiewicz 2020).

The principle of strategic reasoning is to select the factors that should be key for a given group of sites and that should be disjoint. Otherwise, the results obtained may lead to an obscuring of the effects of the analysis, which may result in the possibility of adapting to the implementation of a scenario that does not reflect reality. The layout of the analysis (identifying strengths, weaknesses, opportunities, and threats) allows, based on the designated factors, to observe the conditions that may constitute obstacles to the implementation of the project and to identify those that may overcome or minimize them. It should also be noted that the factors analyzed are variable over time, which makes this analysis a complex process (Miszewska and Niedostatkiewicz 2020). This variability is influenced by both external (e.g., legal, economic, or technical) and internal (e.g., social) conditions. SWOT analysis can be applied both for a single project as well as for a group of projects or undertakings (Nowicki 2015), and for a place, product, project, or undertaking (Ingaldi 2017).

The SWOT analysis is complemented by an inverse TOWS analysis (an acronym for Threats, Opportunities, Weaknesses, and Strengths) (Figure 1). It collates the external factors potentially affecting the project and systematizes their importance according to their interaction with the project's strengths and weaknesses. This approach allows for a broader identification of the most relevant factors in the analysis process (Czerniejewski and Heller 2022). Both SWOT and TOWS analyses are one-way analyses. The former illustrates unidirectional relationships "from inside to outside" and the latter "from outside to inside". Combining these analyses allows two-way relationships to be made at the same time (Miszewska and Niedostatkiewicz 2020).

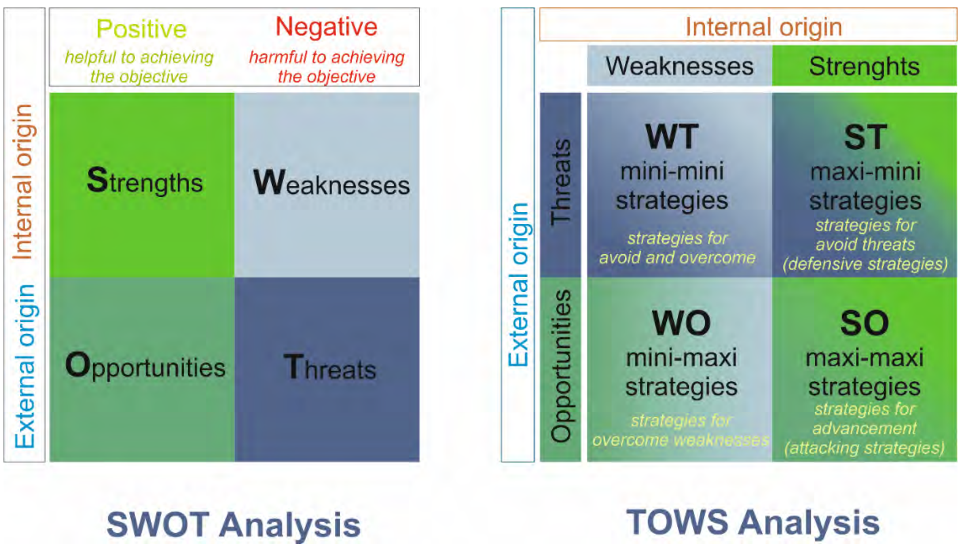

Fig. 1. SWOT/TOWS analysis diagram

Rys. 1. Schemat analizy SWOT/ TOWS

The SWOT/TOWS analysis provides information on the directions of key actions, which in the final phase determine the type of strategy for the analyzed project. There are four possible strategic options, viz: an aggressive strategy: maxi-maxi (which uses a synergy of strengths and identified opportunities), a conservative strategy: maxi-mini (in which strengths must outweigh threats), a competitive strategy: mini-maxi (in which weaknesses outweigh strengths but with clearly identified favorable external conditions), and a defensive strategy: mini-mini (characterized by a lack of strengths and any opportunities that can overcome threats) (Nowicki 2015; Ingaldi 2017; Gostkowska-Dźwig et al. 2023).

2. Origins of mine and industrial waste heaps, dumps, and landfills

The initial stages of mining development in Europe, dating back to the 12th century, were associated with open-pit and shaft mining. These methods were used to mine shallow subsurface deposits up to the depth of the aquifer, due to the lack of techniques for dewatering of pits (Majorczyk 1985; Ratajczak 1998; Czmuchowski 2013; Dulias 2013; Dworak and Tobiasz-Lis 2016). In the vicinity of such excavated sites, low post-mining mounds with flat top surfaces were formed, in later periods in the form of humps and embankments or separate heaps with steep slopes reaching heights of 2 m to 6 m (Ratajczak 1998), mounds and dikes forming clusters (Dulias 2013), or dumps and mounds (Zimnoch 1978). The latter forms usually reached heights of several meters and diameters ranging from a few to several tens of meters (Kaptur 2014).

The development of mining techniques and technologies, which began at the turn of the 18th and 19th centuries and was intensified in the post-war period, contributed to a change in the way deposits were exploited, from surface to deep mining. It also resulted in the automation of deposit access processes and the introduction of new waste placement technologies. This led to the formation of large-scale heaps and dumps of different heights and shapes, on which waste was deposited in a non-selective manner (Jaros 1975; Wrona 1975; Chudek et al. 1978; Majorczyk 1985; Ratajczak 1998; Meuser 2013; Wójcik 2018). In addition to heaps and dumps, wastes from mining activities were also deposited in settling ponds (e.g., mud settlers and tailings ponds). These were hollow forms of various shapes, e.g., oval or rectangular basins, and varied in depth, from a few to several meters (Jarzębski ed. 1994).

The mining waste consisted mainly of overburden and different lithological types of rock, depending on the extracted mineral and the mining technique and processing technology used. They were mostly collected in a non-selective manner. In the heaps after mining and processing of iron ore in the Częstochowa region, the waste consisted of dogger clays, sand and sandstones of the Kościelisko layers, as well as waste containing siderites and crude siftings (waste generated in the process of ore enrichment containing fragments of ore mixed with clays (Ratajczak 1998). Heaps and dumps after hard coal exploitation and processing were characterized by a significant share of Carboniferous silt shales, coal shales, claystones, sandstones with coal and iron sulphides (pyrite) of various granulations (Morawski 1968; Chudek et al. 1978). On the other hand, sites left after mining and processing of non-ferrous ores were represented, in the case of mining and processing of copper ores, by copper-bearing shales, carbonate rocks (limestones and dolomites), marls, clay rocks and sandstones (Kotarska 2012), and in the case of zinc and lead ores – mainly dolomites and limestones and, in minority, clays, sands and gravels. Gypsum, sphalerite (zinc blende), smithsonite (zinc spar), markasite (white iron pyrite), hematite (haematite), and goethite have also been found (Girczys and Sobik-Szołtysek 2002).

Industrial activities involving the processing of extracted minerals (e.g., power generation, metallurgy) were also inextricably linked to the mining sector. The waste generated in these processes was accumulated in industrial landfills of different volumes and in the form of heaps with different bases and heights (Majorczyk 1985; Kaptur 2014; Dworak and Tobiasz-Lis 2016). They were also deposited in settling ponds, as well as in ground and concrete tanks. The industrial wastes accumulated on the heaps were mainly metallurgical slags from the metallurgical processes of ferrous and non-ferrous metals and mixtures of ashes and slags from the energy industry, as well as chemical wastes. Their chemical characteristics depended on the quality of the input raw material (including additives) and the technological process used. The waste collected in concrete tanks and settling ponds was mainly hazardous waste. These included post-neutralization and plating waste generated in the metal industry or waste from the chemical industry (Jarzębski ed. 1994). They contained a significant load of hazardous and toxic substances for the environment.

3. Inventory of mining and processing waste deposition sites

In 2012, 368 closed and abandoned mine waste heaps and dumps with negative environmental impacts were inventoried in Poland. A list of disposal sites has been prepared on the basis of a document elaborated by PGI-NRI in 2010: "The methodology of an inventory of closed extractive waste facilities and desolated extractive waste facilities, which have a negative impact on the environment". However, it should be noted that the inventory did not include reclaimed sites and industrial landfills (including those from the metallurgical and energy industries), as well as heaps and dumps from the exploitation of rock resources due to their insignificant environmental impact (Kostrz-Sikora et al. 2013). A further inventory carried out between 2017 and 2020 covered 1,382 sites, including historic post-mining sites, industrial landfills, heaps and dumps including sites after rock raw materials exploitation (Baza Hałdy PIG-PIB 2024).

According to Statistics Poland (Environment 2023), industrial landfills and mining waste heaps and dumps at the end of 2022 covered an area of 4,362 ha, and settling ponds 3,641 ha. In these sites, 1,828.9 million Mg of waste were deposited, including more than 850 million Mg of waste from the mining industry, more than 82.7 million Mg of waste from the metallurgical industry, and 323.4 million Mg of waste from the energy industry. Mining and processing waste from hard coal mining accounted for 52% of the total waste accumulated, and waste from non-ferrous metal ore mining and processing accounted for 38% (Environment 2023). There is no aggregated data on the number of sites.

Analysing the available information, it should be noted that, over the last 30 years, the area occupied by industrial and mining waste deposition has decreased by about 30% (3,170 ha compared to the 2022 area), including the area occupied by industrial landfills and mining waste heaps and dumps by 1,988 ha, and by settling ponds by 1,509 ha (Brodowska et al. 2003). The amount of waste deposited at these sites also decreased by about 9% in the analyzed period.

4. Economic (secondary raw material) and environmental potential of mine and industrial waste heaps, dumps and industrial landfills

4.1. Waste as a substitute for raw materials

Waste accumulated on heaps, dumps, and industrial landfills can be extracted and utilized in various industries (including construction, roads, mining, and agriculture), often as a substitute for raw materials. There is also the recovery of metallic and energetic raw materials from waste, and another interesting direction of their application is landscape architecture (Skarżyńska 1997; Lottermoser 2011; Wójcik 2012; Meuser 2013; Almeida et al. 2020; Lim and Alorro 2021; Fajfer and Kostrz-Sikora 2022; Rosario-Beltre et al. 2023; Abbadi and Mucsi 2024).

Examples of the use of heaps from hard coal mining for the production of shale aggregates included the exploitation of "Marcel" Coal Mine Heap, Świętochłowice Heap, Rybnik-Niewiadom Heap, "Gliwice" Coal Mine Heap, and Nowa Ruda (Przygórz) Coal Mine Heap. On the other hand, recovery of secondary raw material from heaps (coal) was carried out, e.g., at "Buków" Heap, "Dębieńsko" Coal Mine Heap. An example of the use of post-coal slurry accumulated in tailings ponds at hard coal mines is the production of coal pellets for use as a low-energy fuel at power plants and combined heat and power plants. Pellets were produced using slurry accumulated in old tailings ponds at the former Thorez mine in Wałbrzych, the "Piekary" Coal Mine, the "Knurów-Szczygłowice" Coal Mine, the "Brzeszcze" Coal Mine, the "Sobieski" Coal Mine, and the "Janina" Coal Mine, among others (Szlugaj 2020).

Waste accumulated on post-industrial heaps (e.g., the iron industry) is a good secondary raw material to produce aggregate, which can be used, e.g., in road construction. An example is the exploitation of the metallurgical waste dump in Pleszów in Kraków-Nowa Huta (Report… 2020), belonging to Arcelor Mittal Poland, and the Old Heap (PL – Stara Hałda) and New Heap (PL – Nowa Hałda) dumps in Ozimek, belonging to smelter Huta Mała Panew (Bożym 2018). Aggregate obtained from the processing of accumulated waste can be used for the construction of road embankments of different technical classes – for lower layers below the frost zone in dry or water-isolated areas (Zawisza and Gruchot 2017).

4.2. Environmental and natural values of mine and industrial waste heaps, dumps, and industrial landfills

Despite the development of new technologies and the increase in the recovery of waste accumulated on mine and industrial waste heaps, dumps, and landfills, not all sites have met the technical and/or economic conditions to make use of the waste deposited on them. Some of these sites were gradually subjected to a process of technical and biological reclamation (mainly in a forestry direction, but also in a recreational and sporting direction) or underwent natural plant succession and are now permanently integrated into the landscape.

Heaps, dumps, and hard coal mining waste disposal sites have most often been reclaimed in two directions: forest and forest-parking (Chudek et al. 1978; Rostański 2006; Řehounková et al. 2011; Wójcik 2018). Examples of reclamation towards forestry include dumps and heaps (or parts thereof) of CSGO Knurów, Smolnica III, Krotoszowice (Pietrzykowski et al. 2010), Heap of "Murcki" Coal Mine in Kostuchna, Heap of "Wałbrzych – Staszic" Coal Mine (Fajfer et al. 2022b), or the area after former tailing ponds of "Murcki" Coal Mine (Pełka-Gościniak 2015). One of the reclamation directions using recovery processes as a reclamation step is the shaping of landscape structures. These structures, once formed, are reclaimed in a forestry, sports, cultural, or recreational direction. Such a procedure was applied in the case of the dumps of "Krupiński" Coal Mine, "Pniówek" Coal Mine, and "Borynia-Zofiówka – Ruch Borynia" Coal Mine (Gruszka and Pruciak-Karasek 2011). The heaps after historical iron ore exploitation in the Częstochowa region were, in most cases, reclaimed as a result of spontaneous plant succession (they were mainly overgrown with trees). Only on a small number of heaps in the Konopiska area was the vegetation community rebuilt with the priority of vegetation of natural origin (Kluczyński 1982; Ratajczak 1998). Dumps and heaps after zinc metallurgy located in Ruda Śląska have been reclaimed in a recreational direction. On the heap at 1 Maja Street (in the Wirek neighbourhood), in addition to a green zone, educational and historical paths have been provided for residents, while on the heap at Niedurnego Street in (the Nowy Bytom neighbourhood) the degraded site has been returned to residents as an urban green area with park infrastructure (City Hall of Ruda Śląska 2024).

Reclaimed heaps can also play another important role in the spatial landscape. Some of them (e.g., the Orchid Heap (in Polish: Hałda Storczykowa) in the Ząbkowice poviat or the Bolesław Heap (in Polish: Hałda Bolesław) in the Olkusz poviat) are under legal protection (as an ecological utility) due to the presence of protected plant species on them (Fajfer et al. 2022b). "Hałda Popłuczkowa" (The Friedrich Mine Washing Tip) Cultural Park in Tarnowskie Góry was inscribed on the World Heritage List in 2017 (City Hall of Tarnowskie Góry 2024). Also in the Holy Cross region, anthropogenic landforms left over from historic ore and rock mining are part of the Holy Cross Geopark, which functions as a UNESCO Global Geopark (Poros et al. 2021). Heaps and dumps can also be part of another type of land use – as mining heritage sites. An example is a mine heap after iron ore mining in Nowa Wieś (Poczesna municipality, Częstochowa poviat), which is part of an established geological and natural history path belonging to the "Bractwo Kuźnic" Local Action Group (Fajer and Waga 2013). The heaps also have great cultural significance for some regions. On the initiative of the Czerwionka-Leszczyny municipality residents, three heaps were named (heap No. 1 – "Marianna", heap No. 2 – "Ciosek", heap No. 5 – "Dębieńsko"), reflecting mining traditions (these were the names of old mines operating in this area) (Rybnik Internet Service 2024a). In addition, these heaps were included in the landscape conservation zone under the local spatial development plan. Among other things, it established an order to preserve the shape and height of the heap's ground structures (Rybnik Internet Service 2024b). In Rydułtowy, on the other hand, a characteristic element of the landscape is the Charlotta Heap (named in 2007) (Ostręga and Cała 2020), which is included in the Monuments of Technology Route (Monuments of Technology 2024). The reclaimed sites are also used for art (painting, photography), filmmaking (e.g., K. Kutz "Salt of the Black Earth" (in Polish: „Sól ziemi czarnej")), and writing (Świtała-Trybek and Świtała-Mastalerz 2018).

The areas of reclaimed industrial landfills can be used for the construction of photovoltaic farms, examples of which include the quarters of the reclaimed furnace waste landfill of the Jaworzno III power plant in Mysłowice-Dziećkowice (TAURON Investments 2024), as well as the ash landfill in Marlowe (West Virginia, USA), closed in 2012 (Lewis 2022). An investment involving the construction of a photovoltaic farm on the site of the closed storage reservoir was also being carried out by the Chemical Plant "Siarkopol" Tarnobrzeg Sp. z o.o. (Resolution 2022).

The measures described above are also being taken in other European countries, including Germany and France. In the Ruhr area (Ruhrgebiet), which was one of the most industrialized regions in Germany, heaps have been reclaimed mainly for recreation, sports, and tourism, as well as left to natural plant succession. Some of them have been preserved as a legacy of the region's mining history (Kimic 2012; Kusińska 2018; Zequiry et al. 2024), while others are viewpoints and art promotion sites on the Route of Industrial Culture (Route "Industriekultur"). A recreational and scientific park with astronomical facilities (sundial and horisonarium) has been established on the largest heap in Hoheward. It is planned to expand further with other astronomical facilities (Chmielewska 2010). Interesting forms of development also occur on other heaps, e.g., on the Rheinelbe Conical Heap (Halde Rheinelbe in Geilsekirchen), a staircase was built to the very top, on the Beckerstrasse Heap (in Bottrop), a tetrapod-shaped viewing platform was built (Kimic 2012; Chmielewska 2018). The areas occupied by iron smelting have been reclaimed for services (a technology and service center) and for recreation (the construction of a water reservoir) (Chmielewska 2012).

One of the most industrialized regions of France, with mining, metallurgical, and textile industries, was the Région Nord-Pas-de-Calais. The remnants of this activity were degraded and devastated areas. The revitalization work undertaken in the 1990s focused on protecting the industrial heritage. A consequence of the work carried out was the recognition of 4 post-coal mines as memorial sites: Mine 9-9bis in Oignies, Mine 11/19 in Loos-en-Gohelle, Delloye Mine in Lewarde, now the Mining History Center, and Arenberg Mine in Wallers. In the following years, activities were carried out on the heaps and dumps located in the region, some of which have been included in the UNESCO World Heritage List (51 sites) due to landscape, historical, and natural reasons. The rest were demolished, and the accumulated waste was subjected to recovery or reclaimed processes and transferred or resold to municipalities (Nord-Pas de Calais Mining Basin 2012; Ostręga 2013; Policarpo and Souza 2024).

5. SWOT analysis as a tool for choosing the right management strategy for mining heaps, and dumps and industrial landfills

5.1. Assessment method

To make a preliminary assessment of the optimal direction for the management of mining waste dumps and industrial landfills, a SWOT-TOWS analysis was used for the study, which more comprehensively illustrates the occurring relationships between the analyzed factors. The analysis was performed separately, considering the economic (secondary raw material) aspects of waste management from heaps, dumps, and industrial landfills (including historical, closed, and reclaimed sites) (option I) and environmental aspects, including their scenic, cultural, and social values (option II).

First, the key factors for the two development directions were identified (keeping in mind their decoupling), which were classified and aggregated into sets characterizing strengths, weaknesses, opportunities, and threats, forming an interactive matrix. The number of identified factors was limited to 7, in accordance with the analysis's assumptions, which indicate the number of most relevant factors in the range of 4–10, with a recommended range of 4–6 in each category. Then, all identified factors were given weights (Table 1 and 4). The next step involved conducting analyses to find the interactions occurring between the selected factors classified in each category, and the result was the identification of the most optimal policy option for each of the development directions under consideration.

5.2. Option I – economic (secondary raw material) aspects

In the option of proceeding focused on the exploitation and management of waste from heaps, dumps, and industrial landfills (including historical, closed and reclaimed sites), factors, including the advantages of this type of solution (strengths), barriers that constitute limitations (weaknesses), and potential opportunities to improve the existing situation (opportunities), were systematized and dangerous phenomena (threats) identified (Table 1).

The strength of the analysed development direction (option I) is the amount of waste accumulated in heaps, dumps, and industrial landfills, which could potentially be used as substitutes for natural raw materials. The growing demand for secondary raw materials observed over the years is conditioned by economic growth, including the development of new climate-neutral technologies, i.e., energy-efficient, minimizing the carbon footprint and increasing the recovery of raw materials (e.g., critical raw materials) from waste. The synergy of innovative technical solutions with well-functioning (according to BAT guidelines) waste treatment technologies strengthens the recovery of waste. On the other hand, increasing recovery of waste and substituting raw materials by recovered materials may reduce exploitation. This approach will have the advantage of protecting both raw materials

Table 1. Factors of analysis with weights assigned of economic aspects of waste management from historical, closed and reclaimed sites

Tabela 1. Czynniki analizy wraz z przypisanymi wagami dla ekonomicznych aspektów zagospodarowania odpadów z historycznych, nieczynnych i zrekultywowanych obiektów

Internal factors					
Code	Strengths	Weight	Code	Weaknesses	Weight
S1	High raw material potential of the sites due to the amount of accumulated waste	0.25	O1	Lack of a complete inventory of the sites and a raw material assessment of the waste accumulated on them	0.25
S2	Implemented technologies for the exploitation and processing of waste considering BAT guidelines	0.10	O2	Large variations in the quality of waste within the site	0.25
S3	Increasing demand for raw materials from various industries	0.15	O3	Past non-selective disposal of waste	0.20
S4	Possibility of substitution raw materials by secondary raw materials	0.20	O4	Unregulated legal status of historic inactive sites	0.10
S5	Reduction/limitation of raw materials exploitation	0.20	O5	Risk of non-viability of the project	0.20
S6	Obtaining funding for recovery processes	0.10			
External factors					
Code	Opportunities	Weight	Code	Threats	Weight
W1	Implementation of the circular economy concept	0.10	T1	Change in the economic condition climate	0.30
W2	Development of national strategy documents aimed at implementing the circular economy concept	0.15	T2	Complicated administrative procedures	0.15
W3	Possibility to recover waste accumulated in closed sites	0.35	T3	Changes in legislation	0.25
W4	Reducing the environmental impact of closed sites	0.15	T4	Lack of developed strategic documents	0.10
W5	Recovery of areas occupied by sites and the possibility of their reuse	0.25	T5	Lack of public consent to eliminate developed sites from the spatial landscape	0.20

Source: own elaboration based on Fajfer et al. 2022b.

deposits and the environment. Financial resources play a key role in the development of waste substitution. The forms of low-interest loans or subsidies available on the market for waste recovery investments are an incentive for future investors. Financial support for the implementation of the described projects (especially of supra-local importance) is provided by European funds (e.g., Infrastructure and Environment Operational Programme or Infrastructure, Climate and Environment Programme for 2021–2027). By participating in projects aimed at developing new waste recovery technologies, it is possible to finance or subsidise investments related to the waste substitution accumulated over the years on industrial sites.

The identified strengths are supported by the identified opportunities, that is, external factors. The biggest opportunity for the analysed option is the implementation of the circular economy (CE) model. The principle of this model is to leave manufactured products in circulation until they are completely exhausted of their useful functions, considering the minimization of waste generated in favor of implementing its recovery and recycling processes (Fajfer and Kostrz-Sikora 2022). This means that the waste accumulated on heaps, dumps or industrial landfills (both historical, closed and reclaimed) is intended to be a product (secondary raw material) for multiple use in the same or another technological process. In order to launch CE model, the European Union has implemented a number of action strategies, plans and directive packages. In Poland, support for action in this area is provided by the "Roadmap towards the Transition to the Circular Economy", developed and adopted in 2019. Among the initiatives planned for implementation and included in this document is the action "Analysis of the potential for opening up and using heaps of waste from processing and mining industries and analysis of the morphological composition of mining waste and the possibilities of its use in individual branches of Polish industry, as well as proposing legislative changes on this basis" (Resolution 2019). A number of recommendations and guidelines on the implementation of the CE concept and the possibility of using waste as a substitute for raw materials are also included in strategic documents at the national, voivodship (voivodship waste management plans) or local level (environmental protection programmes, local development strategies, etc.). Created possibility of recovering waste from the analysed sites, apart from application the CE concept, will also contribute to limiting their negative impact on the environment. The degree and extent of this impact depend on the type and chemical composition of the deposited material, the location of the waste storage site and the applied (or lack thereof) protection of the soil and water environment. Hence, the decommissioning of the sites through waste recovery and remediation of the occupied area will reduce their negative impact and create new spatial development opportunities.

The weak point of the analysed option is the lack of updated inventory and raw material assessment of waste accumulated on heaps, dumps and industrial landfills (including historical, closed and reclaimed ones). Raw material studies have been carried out on selected pilot sites (Girczys 2006; Pozzi and Nowińska 2010; Drenda et al. 2011; Kot-Niewiadomska and Gałaś 2011; Kugiel and Piekło 2012; Szlugaj 2020; Fajfer and Kostrz-Sikora 2022).

The lack of this type of information impedes the implementation of the project and increases its costs. The non-homogeneity of the accumulated waste within the site and the non-selective way in which it is deposited is also a weak point. A potential obstacle to the implementation of the analysed option may be the problem of establishing the legal status in the case of sites that were created even in the 19^{th} century. Determination of the legal owner of the area on which the site is located may significantly delay the implementation of the project and, in the most negative scenario, even lead to its abandonment. However, the most serious risk for the considered course of action, involving waste recovery, is the lack of its economic viability. The cost-effectiveness of any investment project involves, primarily, the need to carry out an economic calculation, considering a comparison between the expenditures needed and the profits that the project will generate in the future. Capital expenditure includes all costs associated with the project that would have to be incurred from its commencement up to its completion. Profit, on the other hand, is the sum of the net profit and depreciation that the investor will have as a result of the intended project (Bień 2008). If no profit has been identified, the project will not be realised. The lack of implementation will constitute an economic and environmental loss in the rational management of raw materials and in the implementation of the circular economy model.

The catalogue of threats includes negative processes and phenomena involving challenges and risks that may limit or even block the implementation of the project. In the analysed option, a change in the economic conditions is one such factor, which in the worst-case scenario may block the project. Also negative are potential procedural changes in obtaining administrative decisions and permits for waste recovery, which may, for example, lengthen the procedure. Procedural changes result from changes in legal regulations. A consequence of the amendment of legal acts may be the updating or development of new strategic documents, which may contain new recommendations and guidelines for the management of sites where mining and industrial waste is deposited. A barrier to the considered direction of development is also the lack of public consent for the elimination from the spatial landscape of sites that already perform specific functions (e.g., tourist, economic, landscape, cultural or recreational/sporting). The problem of managing of the final waste after the recovery process should also be considered.

Based on the SWOT/TOWS analysis and the assigned weights, the sum of the interactions taking place and the sum of the products of the weights from the interactions taking place were calculated. The results obtained form the basis for identifying the correct scenario (from among the four identified in the SWOT/TOWS analysis). The results of the SWOT/TOWS analysis, in the form of sums of the interactions between the factors and sums of the products of the weights, are presented in Table 2, while the selection of the correct policy option is presented in Table 3.

From the results obtained, it was found that the S/O combination, i.e. strengths – opportunities, achieves the highest values. It corresponds to an aggressive strategy [maxi-maxi]. This means that the analysed course of action has an advantage of strengths and opportunities over weaknesses and threats. In other words, the course of action associated

Table 2. Summary of SWOT/TOWS analysis

Tabela 2. Zestawienie zbiorcze analizy SWOT/TOWS

Combination	SWOT		TOWS		SWOT/TOWS	
	sum of the interactions	sum of the products	sum of the interactions	sum of the products	sum of the interactions	sum of the products
S/O	29	5.95	48	9.10	77	15.05
S/T	32	6.20	24	4.65	56	10.85
W/O	26	5.55	23	4.80	49	10.35
W/T	25	4.90	12	2.55	37	7.45

Source: own calculations.

Table 3. Strategy matrix for the project

Tabela 3. Macierz strategii dla przedsięwzięcia

<table>
<tr><td></td><td></td><td colspan="2">External factors</td></tr>
<tr><td></td><td></td><td>Opportunities [O]</td><td>Threats [T]</td></tr>
<tr><td rowspan="2">Internal factors</td><td>Strengths [S]</td><td>Aggressive strategy
[maxi-maxi]
77/15.05</td><td>Conservative strategy
[maxi-mini]
56/10.85</td></tr>
<tr><td>Weaknesses [W]</td><td>Competitive strategy
[mini-maxi]
49/10.35</td><td>Defensive strategy
[mini-mini]
37/7.45</td></tr>
</table>

Source: own study.

with the economic use of waste has more advantages than disadvantages, and favorable circumstances in its external environment will offset the identified threats. The actions taken should therefore take advantage of the synergy of strengths and opportunities to increase the efficiency of the project.

The use of machine learning methods can also support this scenario. The wide applicability of various machine learning algorithms illustrates its multifaceted usefulness for solving a variety of analytical tasks. One such task is the possibility of assessing the raw material potential of waste accumulated on active and reclaimed industrial landfills and heaps and dumps of mining and processing waste. Studies carried out for selected groups of post-mining sites (Fajfer and Rolka 2023; Fajfer at al. 2024) show that this method can be useful for identifying sites that may be prospective for this direction of recovery.

5.3. Option II – environmental aspects

Heaps, dumps and industrial landfills are integrated into the landscape, increasingly fulfilling a variety of functions in it, and their presence is accepted by society. Therefore, it is highly desirable to increase the attractiveness of these sites by conducting reclamation processes in directions that favor their integration into the surroundings. As in the previous case, a SWOT/TOWS analysis was used to assess the feasibility of this direction (Table 4). Factors including the advantages of this type of solution (strengths) and the barriers constituting limitations (weaknesses) were systematized, as well as potential opportunities for improving the existing situation (opportunities) and dangerous phenomena (threats) were identified.

The strengths of the option analysed will be to enhance the landscape and tourism value of the region as a result of the development of the sites in a way that combines an interesting way, which is part of the spatial landscape, with the policy of the local authorities and the approval of the public. This will contribute to the elimination of negative phenomena occurring inside the sites (e.g., fire hazards in the case of coal mining sites), the levelling of unformed, steep and unstable slopes (with the possibility of rockfalls or landslides), and the elimination of untidy areas as a result of illegal waste deposition. These measures will have the advantage of reducing the negative environmental and social impact of these sites, increasing green spaces and enhancing community safety. This is an important element if such sites are located near city centres and public infrastructure (e.g., near schools, kindergartens, playgrounds or parks). Another strong point of this project will be its multifunctionality, i.e. the combination of different elements representing e.g., the history of the site, its functionality in the social zone as e.g., a recreational area and an educational factor for future generations. Its originality and the element of differentiation from other ways of developing such sites (e.g., the astronomical park built on the Hoheward heap in Germany) will also be important. The approval by the local community for the way of development is one of the most important factors and a strong point of this scenario.

The greatest opportunity for the environmental option is the potential for economic growth in the regions as a result of improved attractiveness and increased visitor numbers. If this is the case, the construction or expansion of hotel and catering infrastructure and service facilities will be needed, which should contribute to raising the standard of living of local residents. These opportunities are enhanced by integrated measures in several areas that will contribute to the improvement of the region’s environment and increase not only economic but also environmental potential. A holistic approach to reclamation, taking into account not only the area of the site itself but also its interaction with the surrounding region, should ensure the developmental integrity of the area by eliminating weaknesses and minimizing threats.

Table 4. Factors of analysis with assigned weights for environmental aspects of site development

Tabela 4. Czynniki analizy wraz z przypisanymi wagami środowiskowych aspektów zagospodarowania obiektów

Internal factors					
Code	Strengths	Weight	Code	Weaknesses	Weight
S1	Enhancing the landscape and tourist value of the region	0.15	O1	Lack of possibility of functional use of the site	0.20
S2	Reducing negative impacts on the environment and human health	0.15	O2	Social conflicts when choosing the right direction for reclamation	0.25
S3	Minimization of devastated and degraded areas	0.10	O3	Long time needed to achieve environmental and social results	0.20
S4	Public acceptance of the preservation of such forms in the surrounding landscape	0.25	O4	Limited investment resources for the task	0.20
S5	Multifunctional use of reclaimed land	0.15	O5	Unregulated legal status of the site	0.15
S6	Increasing green areas in the region	0.10			
S7	Improving community safety	0.15			
External factors					
Code	Opportunities	Weight	Code	Threats	Weight
W1	Integration of natural, cultural and landscape assets	0.30	T1	Lack of local community consent to carry out works that interfere with the environment	0.20
W2	Improving the quality of the environment	0.20	T2	Social and economic barriers preventing the achievement of an environmental outcome	0.25
W3	Increasing importance for tourism	0.15	T3	Use of sites in an unregulated manner that threatens the environment and the community (including illegal dumping, landslides of accumulated material)	0.15
W4	Economic growth of the region	0.25	T4	Financial instability of project investors	0.25
W5	Promoting tourist and landscape assets using web tools	0.10	T5	Legal and administrative barriers to reclamation	0.15

Source: own study.

Despite the preponderance of strengths and opportunities, it should be noted that the analysis also indicates weaknesses and shortcomings due to the complexity of the intended project. The broad influence of various stakeholder groups (e.g., local community, administrative authorities, investors, local entrepreneurs, banks and funds) should be considered as a disadvantage. The lack of a regulated legal form of the sites may be a threat, which may contribute to the failure or delay of the project. A consequence of this may be the lack of consent of local communities to carry out works interfering with the environment due to lack of trust in the investor. This may result in the development of space in an unregulated manner, favoring the occurrence of various phenomena unfavorable to the environment and communities. Storage of residual waste generated after the recovery process can also be a negative factor. A significant range of activities, the success of which is influenced by institutions independent of the direct executors of individual actions, may also be a threat. This applies to all activities of a formal, legal, financial and management nature, such as e.g., administrative decisions and approvals, decisions on the allocation of funds.

Based on the SWOT/TOWS analysis and the assigned weights, the sum of the interactions taking place and the sum of the products of the weights from the interactions taking place were calculated. The results obtained form the basis for identifying the correct scenario (from among the four identified in the SWOT/TOWS analysis). The results of the SWOT/TOWS analysis, in the form of sums of the interactions between the factors and sums of the products of the weights, are presented in Table 5, while the selection of the correct policy option is presented in Table 6.

Based on the analyses carried out, the S/O combination, i.e. strengths – opportunities, again achieves the highest values. It corresponds to an aggressive strategy [maxi-maxi]. Therefore, the identified links between strengths and opportunities should be used to eliminate the disadvantages identified as weaknesses and threats. As a result of implementing this option, it can be expected that the region's landscape and tourism assets will increase affecting its economic growth and the safety of the local community.

Table 5. Summary of SWOT/TOWS analysis

Tabela 5. Zestawienie zbiorcze analizy SWOT/TOWS

Combination	SWOT		TOWS		SWOT/TOWS	
	sum of the interactions	sum of the products	sum of the interactions	sum of the products	sum of the interactions	sum of the products
S/O	52	9.95	48	9.0	100	18.95
S/T	26	4.30	50	8.7	76	13.0
W/O	46	9.45	20	4.7	66	14.15
W/T	32	6.40	36	7.2	68	13.60

Source: own calculations.

Table 6. Strategy matrix for the project

Tabela 6. Macierz strategii dla przedsięwzięcia

		External factors	
		Opportunities [O]	Threats [T]
Internal factors	Strengths [S]	Aggressive strategy [maxi-maxi] 100/18.95	Conservative strategy [maxi-mini] 76/13.00
	Weaknesses [W]	Competitive strategy [mini-maxi] 66/14.15	Defensive strategy [mini-mini] 68/13.60

Source: own study.

Conclusions

SWOT/TOWS analysis enables the simultaneous recognition of two-way relationships and supports the selection of the most optimal action scenario. Although typically used in organizational management as a universal tool to select an initial course of action, it can also be effective in other areas, including environment and waste management.

The use of SWOT/TOWS analysis in the process of preliminary assessment of 2 different courses of action, the first of which assumed economic (raw material) management of waste from heaps, dumps and industrial landfills, and the second of which envisaged sanctioning their environmental values, allowed the identification of strengths and weaknesses (representing internal factors) as well as opportunities and threats (describing external factors) of the analyzed options. The SWOT/TOWS analysis carried out allowed an aggressive strategy to emerge for further action, for both management scenarios.

In the case of Option I related to the recovery of accumulated waste, the strategy identifies the use of strengths, which mainly include the increasing demand of various industries for raw materials, as well as the reduction/limitation of raw materials exploitation. The strengths are supported by opportunities expressed by factors relating to the recovery of land occupied by the sites and the possibility of their reuse, the implementation of the circular economy concept and the recovery of waste accumulated on closed sites. They offset the weaknesses and threats, which are the risk of lack of profitability of investments and changes in legislation.

In the case of Option II (focused on environmental aspects), the chosen strategy is based on using the strengths of enhancing the landscape and tourism values of the region and the multifunctional use of these areas in activities with public acceptance. Identified factors on the opportunity side in the form of integration of natural, cultural and landscape values together with improved environmental quality in the region reinforce the role of the project's strengths. The synergy of factors on the strengths and opportunities side reduces the impact of the weaknesses and threats, which are the social and economic barriers preventing the environmental effect from being achieved and the long time needed to achieve the environmental and social effect. As in the first case, this scenario can be realised.

The choice of a specific option for action (economic or environmental) will be a compromise between the investor, local authorities and the public. In any case it is necessary to take into account the physico-chemical and mineralogical characteristics of the accumulated waste. It is particularly important on the sites where, in the past, the simultaneous disposal of materials of different origins and characteristics was permitted. Therefore, the results should then be supported by direct analyses carried out in situ.

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RECOGNIZING THE ECONOMIC AND ENVIRONMENTAL POTENTIAL OF MINING DISPOSAL SITES AND INDUSTRIAL LANDFILLS USING SWOT ANALYSIS

Keywords

raw materials potential, heaps, dumps and industrial landfills,
mining and processing waste, SWOT/TOWS analysis

Abstract

In recent years, priority has been given in the areas of waste management and environmental protection to measures aimed at maximizing the utilization of raw materials and products and minimizing the amount of waste generated. Advanced technologies also allow for the recovery of secondary raw materials from waste, which, in the case of mining and industrial waste that has been deposited in the past on heaps, dumps, and industrial landfills, enables effective protection of the mineral deposits' resources and balanced management of them. The possibility of substituting raw materials with waste generated in the mining and processing sector is conditioned by economic factors, including above all the quantity and composition of the waste, as well as environmental factors, especially when disposal sites are incorporated into the landscape as valuable natural, cultural, or recreational objects. A SWOT/TOWS analysis can be one step in the decision-making process aimed at assessing their potential (economic and environmental). By systematizing information and considering the current state, this tool is used to analyze the strengths, weaknesses, opportunities, and threats of a planned project. This paper attempts to use SWOT/TOWS analysis as an instrument to help decide on a strategy for dealing with heaps, dumps, and industrial landfills and the waste accumulated on them. The use of SWOT/TOWS analysis in the process of preliminary assessment of two different courses of action allowed the identification of strengths and weaknesses (representing internal factors) as well as opportunities and threats (describing external factors) of the analyzed options. The SWOT/TOWS analysis carried out allowed an aggressive strategy to emerge for further action, for both management scenarios.

ROZPOZNANIE EKONOMICZNEGO I ŚRODOWISKOWEGO POTENCJAŁU SKŁADOWISK ODPADÓW WYDOBYWCZYCH I PRZEMYSŁOWYCH Z WYKORZYSTANIEM ANALIZY SWOT

S ł o w a k l u c z o w e

potencjał surowcowy odpadów, hałdy, zwałowiska i składowiska przemysłowe, odpady wydobywcze i przeróbcze, analiza SWOT/TOWS

S t r e s z c z e n i e

W ostatnich latach priorytetem w obszarach gospodarki i ochrony środowiska są działania ukierunkowane na maksymalne wykorzystanie surowców i produktów oraz minimalizację ilości powstających odpadów. Zaawansowane technologie umożliwiają także odzysk surowców z odpadów, co w przypadku odpadów wydobywczych i przemysłowych, które w przeszłości zostały zdeponowane na hałdach, zwałowiskach i składowiskach, pozwala na skuteczną ochronę zasobów złóż kopalin i zbilansowane gospodarowanie nimi. Możliwość substytucji surowców naturalnych odpadami wytworzonymi w sektorze wydobywczym i przeróbczym warunkowana jest czynnikami ekonomicznymi, w tym przede wszystkim ilością i składem odpadów, a także czynnikami środowiskowymi, zwłaszcza gdy hałdy, zwałowiska, składowiska są wkomponowane w krajobraz jako cenne obiekty przyrodnicze, kulturowe lub rekreacyjne. Jednym z etapów procesu decyzyjnego ukierunkowanego na ocenę ich potencjału (ekonomicznego i środowiskowego) może być analiza SWOT/TOWS. Narzędzie to, systematyzując informacje i uwzględniając stan aktualny, wykorzystywane jest do analizy mocnych i słabych stron oraz szans i zagrożeń związanych z planowanym przedsięwzięciem. W artykule podjęto próbę wykorzystania analizy SWOT/TOWS jako instrumentu wspomagającego decyzję o wyborze strategii postępowania w zakresie zagospodarowania hałd, zwałowisk i składowisk oraz nagromadzonych na nich odpadów. Wykorzystanie analizy SWOT/TOWS w procesie wstępnej oceny dwóch różnych kierunków działań pozwoliło na określenie mocnych i słabych stron (reprezentujących czynniki wewnętrzne) oraz szans i zagrożeń (opisujących czynniki zewnętrzne) analizowanych wariantów. Przeprowadzona analiza SWOT/TOWS pozwoliła na wyłonienie strategii agresywnej dla dalszych działań dla obu scenariuszy postępowania.