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Green Transformation of Mining towards Energy Self-Sufficiency in a Circular Economy—A Case Study

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Abstract: This article presents the concept of green transformation of the coal mining sector. Pump stations that belong to Spółka Restrukturyzacji Kopalń S.A. (SRK S.A., Bytom, Poland) pump out approximately 100 million m^3 of mine water annually. These pump stations protect neighboring mines and lower-lying areas from flooding and protect subsurface aquifers from contamination. The largest cost component of maintaining a pumping station is the expenditure for purchasing electricity. Investment towards renewable energy sources will reduce the environmental footprint of pumping station operation by reducing greenhouse gas emissions. The concept of liquidation of an exemplary mining site in the context of a circular economy by proposing the development/revitalization of a coal mine site is presented. This concept involves the construction of a complex consisting of photovoltaic farms combined with efficient energy storage in the form of green hydrogen produced by water electrolysis. For this purpose, the potential of liquidated mining sites will be utilized, including the use of pumped mine wastewater. This article is conceptual. In order to reach the stated objective, a body of literature and legal regulations was analyzed, and an empirical study was conducted. Various scenarios for the operation of mine pumping stations have been proposed. The options presented provide full or nearly full energy self-sufficiency of the proposed pumping station operation concept. The effect of applying any option for upgrading the pumping station could result in the creation of jobs that are alternatives to mining jobs and a guarantee of efficient asset management.

Keywords: renewable energy sources; energy storage; post-mining land revitalization; circular economy

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1. Introduction

Due to the European Union's commitment to attaining climate neutrality, member countries are obligated to phase out the use of fossil fuels such as coal [1,2]. This transition presents a challenging and prolonged endeavor for the mining sector [3,4]. A significant amount of research has focused on the challenges associated with mine closure and the subsequent activities [5,6]. Liquidation activities in the mining sector in Poland, spread over many years, are a consequence of European Union policy, in particular the European Green Deal. This document is, in a nutshell, a roadmap for the EU transformation towards achieving climate neutrality by 2050 [7–9]. In order to achieve this goal, the EC has proposed a European Climate Law, which sets targets for greenhouse gas emissions, including a reduction of at least 55% by 2030 (relative to 1990) [10–12]. This is a very big challenge for Poland, where more than 80% of electricity is generated from fossil fuels (mainly hard coal and lignite). In practice, this means the search for new, alternative energy sources, withdrawal from fossil fuels, and the intensive development of renewable energy sources, including photovoltaic and wind farms. A special role in Poland's energy transition should be played by hydrogen, which is seen as a new, environmentally friendly energy carrier. Introducing hydrogen into the energy mix will afford Poland the opportunity to achieve energy independence, reduce greenhouse gas emissions, and make a meaningful contribution to the global fight against climate change. It is anticipated that the process of decarbonizing Poland's energy sector will be challenging and protracted, taking into account both economic and social factors. The utilization of coal gasification technologies in the Polish energy sector has the potential to effectively facilitate this process, especially when combined with carbon capture, utilization, and storage (CCUS). Gasification of coal has been a recognized technology for over a century, involving a thermochemical process that converts the fuel, in this case coal, into synthesis gas containing carbon monoxide and hydrogen [13–16]. Various scholarly papers have explored the co-gasification of lignite with biomass/biowaste or Solid Recovered Fuel [17–21].

Acquiring hydrogen through the electrolysis method outlined in this study necessitates a substantial quantity of both electricity and water. The electrolyzer's water consumption can reach approximately 22 dm^3/kg H2 due to technical constraints [1,2,7]. These challenges are exacerbated by a scarcity of potable water on a global scale, along with diminishing water resources and declining water quality, all of which require the exploration of alternative approaches to safeguard the reliable operation of water supply systems. To improve the flow of water and become independent from the public water system, it is essential to take steps to reduce reliance on traditional water sources. Utilizing groundwater and collecting rainwater are often overlooked methods of obtaining water [5,11].

The purpose of this article is to introduce the idea of managing the resources of a closed mine, specifically by upgrading the pumping station that removes water from the inactive underground tunnels. This is a significant issue due to the increasing number of coal mines being closed globally to support the shift towards green energy. The project fits in with the tasks of a closed-loop economy and is an opportunity for regional development, thanks to the introduction of new technologies, as well as modern economic solutions. The project outlined in this paper aims to generate new markets associated with contemporary transportation and sustainable energy sources. Furthermore, it presents an opportunity to rejuvenate areas once impacted by extensive mining activities [22–24]. To the best of the authors' understanding, there has been limited scientific research on the intersection of closed mine drainage and circular economies.

2. Materials and Methods

2.1. Selected Environmental Challenges Facing the Economy

In line with the European Green Deal and the EU Hydrogen Strategy, Poland's goal for hydrogen production is to provide the conditions for the start-up of hydrogen production facilities from low- and zero-emission sources. In order for hydrogen to contribute to climate neutrality, its use should take place on a much larger scale, and production should become fully zero-emission [25,26].

Approximately 96% of global hydrogen production comes from conventional fuels (the predominant technology is production by steam methane reforming). The most desirable hydrogen is the so-called green hydrogen, which is obtained by electrolysis using energy from renewable sources (energy produced by photovoltaic and wind farms). Energy from renewable sources can be used directly to power pumps or electrolyzers that produce green hydrogen, or it can be stored for further use for own needs [25,27,28].

CZOK SRK S.A. (Central Mine Dewatering Plant, branch of SRK S.A., Poland) pumps out approximately 100 million m^3 of water annually from the underground of liquidated mines. Much of the wastewater is discharged into local watercourses. The discontinuation of dewatering activities would result in the inundation of active mines and adjacent low-lying regions, along with the pollution of superficial groundwater reservoirs.

Pumping stations equipped with a Mining Water Treatment Station (MWTS) could act as strategic emergency intakes for emergency events, resulting in reduced water shortages, reduced discharge of contaminated water into watercourses, and reduced salt emissions to the environment [5,29]. Alternative ways of managing mine water can be to use its potential energy as a source of power for pumped storage power plants or its thermal potential in heat pumps [30,31].

In order to limit the impact of mines on the environment, it would be possible to adopt some of the mine shafts belonging to SRK S.A. for energy storage purposes [32–35]. One way of storing energy could be to obtain electricity using the shafts by flowing water from the surface reservoir into the shaft sump via a built-in hydrogenerator and pumping it to the surface during periods of peak energy production by renewable energy source (RES) installations.

One way to reduce the need to purchase electricity from the grid is to build photovoltaic or wind farms. Photovoltaic farms can be created on industrial land for manufacturing purposes. Plots of land allowing PV cells to operate at full capacity should preferably have a southern exposure and a regular form, allowing for ordered development. An additional requirement is good access for technical vehicles and proximity to the transformer station [36,37].

The energy generated by photovoltaic farms at full capacity would meet approximately 42% of the Company's energy needs. The usage of all the energy produced in the best weather conditions is usually not possible for technical reasons. It is necessary to use energy storage facilities to store the surplus and manage it in times of energy shortage. The available lithium-ion storage facilities are best suited for use on farms located in the immediate vicinity of pumping stations.

2.2. Research Problem

SRK S.A.'s activities are dedicated to the secure retrieval of coal from operational mines. Failure to extract water could lead to potential flooding in the region and subsequent flooding in lower-lying areas. One of the major expenses for SRK S.A.'s legal operations is the procurement of electricity. The use of non-renewable energy sources, including fossil fuels, at the Company's different sites led to a total consumption of over 297 GWh in 2023 [38–40].

The purpose of the article was to develop a database of model solutions for the pilot modernization of mine water pumping stations that align with the principles of a circular economy. By merging the concepts of safe coal mining for active mines and the general safety of post-mining areas with the principles of a circular economy in the liquidated mine area, previously overlooked benefits of mine water pumping processes were realized. An innovative approach to areas affected by post-mining and large quantities of mineralized mine water that pollute local waterways presented the potential to transform current waste into valuable raw materials or energy sources. The investment attractiveness of the proposed solutions for specific conditions was then assessed using the main site of a liquidated mine being converted into a district pumping station belonging to the SRK S.A. branch, CZOK, as a case study. Apart from satisfying the energy requirements of the pumping station with renewable energy, the project seeks to rejuvenate the infrastructure of the closed mine, preserve current employment opportunities, and generate additional ones [41–43].

2.3. Characteristics of the Analyzed Pumping Station

In 2015, SRK S.A. assumed control of a coal mine that had been placed in liquidation. Once the outdated facilities were liquidated, the mine was integrated into the structure of a CZOK as a district pumping station. The examined pumping station is situated in the heart of a large city within the Silesian Agglomeration [38,40,44]. A permanent dewatering system is in place at the pumping station, utilizing a network of around 9 km of tunnels modified for the pumping station. All water entering the pumping station is channeled into the abandoned mine workings. For ventilation purposes, two shafts have been retained at the pumping station to manage the task of pumping out the wastewater. Water from the main dewatering system is pumped to the surface in accordance with the water-legal permit held, and through 3 surface sedimentation tanks, it flows gravitationally through a collector to a nearby river. The operation of the pumping station required some of the post-mining buildings and structures to remain. The remaining facilities of the acquired mine have already been liquidated or their demolition is ongoing. The surface facilities left behind are surrounded by an area of approximately 33 ha. In 2023, the pumping station pumped out approximately 8 million m^3 of water. It is estimated that the pumping station, in order to carry out its operations, requires approximately 35 GWh of electricity, with an annual thermal power requirement of approximately 2 MW [45–47].

2.4. Project Assumptions

The modernization of the existing infrastructure of a liquidated mine adapted to a district pumping station combined with new technologies is intended to be a self-financing solution with a positive image and social perception [10,48].

The surface of the liquidated mine has a southern exposure and a regular form, allowing for an organized development of the panels, with good access for technical vehicles and easy access to medium- and high-voltage installations. The calculations and design assume the implementation of a plant producing energy only for the company's own needs. The proposed projects assume the construction of farms with a generating capacity of approximately 7.4 to 23 MWp, which will be able to produce approximately 6 to 20 GWh of "green", "clean" electricity per year [15,49]. The pumping station carries out dewatering continuously on all days of the year. It requires approximately 2.3 MW of electricity during peaks. On sunny days, the demand will be met by a built-in photovoltaic farm, but there will also be an overproduction of energy in most cases. When the photovoltaic system has to provide electricity at night or on non-sunny days, it is necessary to use a storage system for the energy generated during sunny days [36,49,50]. Therefore, there is a need for energy storage for non-sunny days. Storing energy in the generated hydrogen allows the generated surplus energy to be stored very efficiently in the long term and used at times of electricity demand. Water electrolysis is considered to be the most future-oriented and recommended technology for energy storage by hydrogen generation [51–53]. For these reasons, part of the project variations for the pumping station upgrade adopted the idea of storing excess energy by electrolytic hydrogen generation. The project assumes the installation of a small battery energy storage facility to stabilize the power supply and buffer the energy generated or for the possible stabilization of the electrolyzer operation.

3. Results

3.1. Adapted Variants of Energy Self-Sufficiency Models Associated with Mine Wastewater Pumping

When choosing the capacity of the photovoltaic farm, maximum use was made of the available surface area, including the surface area of available roofs and shelters over car parks [54–56]. The revenue generated from the sale of hydrogen and oxygen, as well as any planned income from thermal energy trading, will be used to purchase the electricity, thus reducing the need for a budget subsidy and reducing CO_2 [11,50].

Under the assumption of maximizing the use of generated electricity, two groups of options were designed to restructure the liquidated mine to energy self-sufficiency systems [29,30]. Some of the variants considered providing only energy independence. These variants assume only the construction of a photovoltaic panel installation, the so-called PV farm, with the necessary equipment and infrastructure for energy storage or transmission. Some of the variants assume, in addition to energy self-sufficiency, the treatment of pumped mine water. The additional equipment in these variants is a Mining Water Treatment Station. The revenue from the sale of treated water in these options will go towards the purchase of the "dirty" energy. In the end, 12 decision-making variants were proposed, differing in the amount of investment required and in the different degree to which the energy needs of the pumping station would be met, as well as 5 optional variants that could be used in conjunction with the basic variants. The project includes solutions that allow using part of the energy for own needs and sending the rest to another pumping station or storing it, but also, some of the variants produce only for own needs.

Some of the variants assume the storage of surplus energy in the form of "green" hydrogen obtained by electrolysis or the use of the generated energy on an ongoing basis exclusively for own purposes by feeding it into the national grid and receiving it at the same time at the Company's other pumping stations on a "virtual prosumer" basis [37,57]. Decision-making variants have also been proposed, where a small PV farm is installed at the pumping station to generate "green" electricity entirely consumed by the pumping station on an ongoing basis [54–56]. On the basis of the price survey carried out (June 2024), the amount of current outlays required for the upgrade of the pumping stations in the various options was determined. In the study, all expenditures are given as a multiple of the expenditures required for the implementation of variant 1, generating energy exclusively for own use.

3.2. Equipment and Principle of Operation of Variants 1 and 1S Generating Power Exclusively for Own Consumption

Variants 1 and 1S are the simplest examples of an energy self-sufficiency project possible to implement in the reality of Spółka Restrukturyzacji Kopalń. S.A. The variants present the construction of a photovoltaic installation with the necessary equipment and infrastructure at the existing mine water pumping station. The size of the farm, and at the same time its power, is adapted to the amount of energy demand of the pumping station equipment. In these decision-making variants, the energy generated by the photovoltaic farm is not to exceed the fluctuations in the energy demand of the pumping station and is to be consumed entirely by the pumping station without even temporarily feeding energy back into the national grid. On non-sunny days, the operation of the pumping station's most energy-intensive equipment will be carried out during periods of the day with the lowest purchase price of electricity from the local supplier's grid [26,43]. The options ensure, on sunny days, that up to approximately 40% of the pumping station's daily electricity demand is covered by the "green" energy.

3.3. Equipment and Principle of Operation of Variants 2 and 2S Distributing Surplus Electricity on a So-Called Virtual Prosumer Basis

Variants 2 and 2S assume the implementation of an installation producing energy for own use, sending into the national grid any surplus energy to be immediately consumed at another pumping station on a so-called virtual prosumer basis. A provision is made for the construction of a photovoltaic panel installation, the so-called PV farm, together with the necessary equipment and infrastructure. The variants assume the maximum consumption of electricity during the generation period, so a change in the operating time of the most energy-intensive equipment to sunny periods with the production of the PV farm was made. Such a change ensures that up to approximately 40% of the electricity produced is used at the pumping station. The remaining surplus, i.e., about 60% of the generated energy, will be fed back into the grid of the local supplier and collected at the same time at another pumping station owned by the Company. Such a model requires payment to the local supplier of energy transmission costs that reduce the amount of energy available for collection at another point. It is estimated that approximately 93% of the surplus returned to the grid (at Q2 2024 prices) will be available for collection at another pumping station.

3.4. Equipment and Principle of Operation of Variants 3 and 3S Involving Hydrogen Retailing

Variants 3 and 3S assume not feeding electricity into the grid of the local distributor. These options assume the storage of excess electricity produced by the photovoltaic farm in the form of hydrogen. The hydrogen is to be sold in its entirety at the farm's own refueling station, with the resulting revenue being used to purchase energy to power the pumping station equipment during non-sunny periods. The sale of the hydrogen obtained will be a form of long-term storage of the surplus electricity generated. Furthermore, for the assembly of the fundamental photovoltaic panel installation, known as the PV farm, along with the essential equipment and infrastructure, an additional set of equipment for water electrolysis, hydrogen storage, and distribution is required, including a hydrogen refueling station in Variant 3. An extra investment in this version is the establishment of a Mining Water Treatment Station. During periods of surplus "green" electricity production, excess energy will be stored through electrolysis in the form of hydrogen. The resulting hydrogen, once compressed to its standard value, will be conveyed to a tank and sold continuously at refueling stations at prices comparable to retail prices. Profit on sales is estimated at 90% of the current retail price, considering the challenging aspect of determining the hydrogen distribution cost at this stage. In non-solar periods, energy will be purchased from a local supplier using the proceeds from earlier marketing of "green" hydrogen. The purchase of energy from the local supplier will be at the currently negotiated purchase price for "dirty" energy. Additionally, the sale of the oxygen produced will contribute to covering part of the cost of purchasing "dirty" energy for the pumping station during non-solar periods. The water electrolysis process incidentally generates thermal energy, which can be utilized for the pumping station's internal needs. As a result, an underground thermal energy storage facility is planned to supply "in-house" heat when the electrolyzer is not operational. At the electricity purchase price of Q2 2024, it is estimated that approximately 98% of the stored electricity could be effectively utilized, ensuring a circular economy component in operation.

3.5. Equipment and Principle of Operation of Variants 4 and 4S Involving Hydrogen Wholesale

In establishing the operating model for Variants 4 and 4S involving the wholesale of hydrogen, the construction of a refueling station was abandoned. A mechanism was adopted to maximize the consumption of the produced "green" energy for own purposes and to sell all the produced surplus "green" electricity stored in the form of hydrogen to a local distributor. Due to the cost of hydrogen supply, which is difficult to determine at this stage of the project, it has been assumed that hydrogen will be sold at 60% of the current retail price. During the non-solar period, there will be a purchase of "dirty" energy from the local supplier from the proceeds of the earlier sale of surplus "green" hydrogen and harvested oxygen, and energy purchases will be made at the current purchase price of "dirty" energy. It is estimated that this model of pumping station operation could, at the Q2 2024 electricity purchase price, ensure that 74% of the stored electricity could be used.

3.6. Equipment and Principle of Operation of Variants 5 and 5S Involving Hydrogen Combustion

Variants 5 and 5S involve the process of not feeding electricity into the national grid but rather storing any excess electricity generated by the photovoltaic farm as hydrogen. In times of energy shortage, the hydrogen will be utilized in cogeneration engines to produce energy for internal consumption. Variant 5 calls for the basic construction of the photovoltaic farm alongside the necessary equipment and infrastructure, as well as the acquisition of further equipment related to water electrolysis, hydrogen storage, and combustion. Variant 5S requires an additional investment in the establishment of the Mining Water Treatment Station. In times of electricity overproduction, any surplus energy will be stored as hydrogen through electrolysis. The resulting hydrogen, once compressed, will be transferred to a tank to await periods of energy shortage at the pumping station. During these times, the hydrogen will be burned in cogeneration engines to generate electricity for the pumping station's internal use. The thermal energy produced will also be utilized internally, with any surplus being channeled back into the local operator's district heating network for a fee. Any leftover hydrogen can be transported to another pumping station to provide electricity and heat.

During non-solar periods, the purchase of "dirty" energy from the local supplier will be made at the currently negotiated rate. The sale of the oxygen and thermal energy produced, and in the treated water in Variant 5S, will cover part of the cost of purchasing "dirty" energy. Due to the low efficiency of the electrolysis process and the combustion process in the CHP engines, it is estimated that approximately 68% of the generated surplus "green" energy will be ready for use.

3.7. Equipment and Principle of Operation of Variants 6 and 6S Using Battery Storages

The storage of electricity in battery energy storage is designed for short periods. For this reason, the decision model for Variants 6 and 6S assumes the storage of surplus generated electricity only for the Company's own needs to cover the energy costs of operating equipment at the Company's other pumping stations. On non-sunny days, the operation of the most energy-intensive pumping station equipment, if possible, will be carried out at the time with the lowest electricity purchase price. On sunny days, a shift will take place, and the most energy-intensive equipment will be operated at times of electricity generation for maximum ongoing use of the effects of the photovoltaic farm. The surplus electricity generated by the farm, after being stored in battery energy storage facilities, is to be used to power other pumping stations still within the same billing day. As in Variants 2 and 2S, the stored surplus energy will be fed back into the national grid on the so-called "virtual prosumer" basis. The need to pay a distribution charge and the efficiency of the battery energy storage facilities means that, at Q2 2024 prices, up to approximately 90% of the stored surplus electricity will be recoverable. In option 6S, the income from the sale of treated water will cover part of the purchase costs of "dirty" energy.

4. Results

Table 1 shows the key parameters of the proposed options. The calculations were performed for the market realities of Q2 2024. The estimated expenditures for the revitalization of the main plant of a large mine into a district mine water pumping station, the expected savings in electricity purchase costs, the return on investment, the estimated satisfaction of the Company's energy needs, and the environmental effect of reduced CO_2 emissions are presented [53,58,59]. The decrease in carbon footprint from the upgraded pump station was determined by multiplying the quantity of non-renewable energy replaced with energy generated by the solar farm by the current emission factor of non-renewable electricity. In order to improve communication, the payback period was determined by dividing the projected cost of updating the pumping station by the anticipated savings from this update in the most straightforward manner possible. Similarly, for easier analysis, the amount of energy gained was given as a fraction of the Company's total annual energy needs. To protect confidential company information, the expenses and cost reductions were presented as a percentage of the mine's revitalization expenses in option 1, excluding the construction of the Mining Water Treatment Station.

The least extensive options (Variants 1, 2, 1S, and 2S) require the lowest expenditure. The expansion of the pumping station infrastructure obviously involves an increase in investment. This does not always go hand in hand with the efficiency of the project. As can be seen in Table 1, the alternative that ensures mine water treatment in each variant is admittedly more expensive, but within the variant, it always generates better financial results. The highest savings are generated by the variants providing for the storage of surplus generated energy in the form of electrolytic hydrogen (Variants 3, 3S, 4, and 4S) and Variants 2 and 2S working on the principles of the so-called virtual prosumer.

Among the variants assuming the storage of surplus generated energy in the form of electrolytic hydrogen are Variants 5 and 5S, yielding significantly lower financial results and providing significantly less satisfaction of the company's energy needs. These options provide for electricity and heat to be obtained during periods of shortage by burning the stored hydrogen in cogeneration engines [32,33,60]. These lower financial results are due to the efficiency of the CHP engines in question. However, these options have an important advantage. The process of burning hydrogen during periods of energy shortage is a process that is very independent of external factors and is least affected by external markets.

Table 1. Estimated parameters of revitalization options for the main plant of the liquidated mine.

Variants		Savings	Expenditure	Return on Investment	Independence of the Company	Reduction of CO_2	License
		[Multiple of Expenditure]		[Years]	[%]	[Mg CO_2/Year]	
1	Producing energy solely for own consumption	0.333	1.00	3.00	2.85%	6975	
1S		0.452	3.44	7.61	3.87%	9465	
2	Feeding back surplus electricity on a so-called virtual prosumer basis	1.212	3.96	3.27	10.37%	25,365	E
2S		1.334	6.40	4.80	10.53%	25,738	E
3	Covering retail sales of hydrogen	1.319	8.31	6.30	11.29%	10,274	H
3S		1.425	10.75	7.54	12.31%	10,882	H
4	Covering the wholesale of hydrogen	1.107	7.83	7.08	9.48%	10,882	H
4S		1.217	10.27	8.44	10.53%	10,882	H
5	Employing hydrogen combustion	0.765	8.38	10.96	6.56%	10,278	H
5S		0.896	10.82	12.07	7.67%	10,886	H
6	Using battery storage	0.912	29.69	32.54	10.76%	15,744	E
6S		1.017	31.22	30.72	11.80%	16,161	E
Result:		Best	Second	Third	E—license for electricity production H—hydrogen storage license		
Source: Author's own study.							

On a somewhat similar basis to Variants 2 and 2S, Variants 6 and 6S operate. As designed, Variants 6 and 6S are to store surplus generated electricity and return it to the grid during periods of energy shortage at the Company's other pumping stations. As in Variants 2 and 2S, the energy is to be immediately collected at another pumping station. The disadvantages of this operating concept are the high investment costs for the purchase of battery energy storage and the associated long payback time [61–63]. The advantages are the low losses of stored energy, the speed of response to power surges in the grid, and the potential possibility of earning money from so-called "grid compensation".

Variants 2, 2S, 6, and 6S require a license to produce electricity and depend on the grid capacity of the local electricity supplier. In this context, it appears that their implementation to the realities of a revitalized mine is unlikely. High power purchase prices in 2024 promote options that return surplus generated electricity to the national grid. The downward trend in the purchase price of electricity, observed throughout 2024 and projected for 2025, makes energy storage in the form of electrolytic hydrogen increasingly financially viable. Despite the fact that Variants 3, 3S, 4, 4S, 5, and 5S will require a license for storage and probably also for hydrogen generation, their use in the revitalization of mining sites seems very purposeful [8,9].

Of the variants analyzed, the most likely to be implemented is the variant with no energy surplus (Variants 1 and 1S). The advantages of such a project are low investment outlay, fast payback, and practical lack of implementation barriers [52,64,65]. The project requires virtually no approvals from external institutions [37,57]. The disadvantage is the small satisfaction of the Company's energy needs and lower savings compared to the other variants. A similar project is already underway at another pumping station owned by the Company.

The implementation of any of the proposed basic mine water pumping station upgrade options will result in significant savings for the Company in the purchase of electricity. All of the proposed options are self-financing projects, and their implementation will be positively received by the local community [61,66,67].

The proposed options are elements of a circular economy. An important aspect of the assessment of the variants is their environmental effect in the form of reduced CO_2

emissions [2,59,68]. All options decrease the carbon emissions of water removal processes in mines that are no longer in operation. As expected, the major decline can be attributed to the variations that depend heavily on using the energy they generate for their own consumption (see Variants 2, 2S, 6, and 6S). At the current CO_2 charge, the implementation of each of the proposed variants will result in significant savings for the state Budget [45,60,69]. Each of the proposed options fits in with the Company's business objectives and the Just Transition program and brings us closer to achieving climate neutrality by 2050 [61,64,70].

Table 2 displays the planned assortment of options for upgrading mine water pumping stations and the scenarios in which these options will offer the greatest benefits. Table 2 is crucial in determining the best option based on current market conditions.

Table 2. Compilation of effective methods for utilizing water pumping facilities.

Evaluated Advantage of the Variant of Starting Water Pumping Stations	**Evaluated Variants (Y—YES)**											
	1	**1S**	**2**	**2S**	**3**	**3S**	**4**	**4S**	**5**	**5S**	**6**	**6S**
The smallest expenditure	Y	Y										
The highest energy consumption costs			Y	Y	Y	Y		Y				
The shortest payback time	Y	Y	Y	Y	Y	Y	Y					
The greatest satisfaction of the Company's energy needs			Y	Y	Y	Y		Y			Y	Y
The highest auto-consumption of generated energy	Y	Y							Y	Y	Y	Y
The highest reduction of CO_2			Y	Y							Y	Y
Water purification		Y		Y		Y		Y		Y		Y
Heat dissipation into the heating network									Y	Y		
Expanding the production of consents and permits	Y	Y			Y	Y	Y	Y	Y	Y		
Operation independent of power supply									Y	Y	Y	Y
The shortest reaction time to the accumulated surplus electricity											Y	Y

For the proper functioning of the pilot solution of the circular economy project at the analyzed pumping station, it is estimated that it will be necessary to increase the workforce by about 4 employees in Variants 1 and 6 to about 14 in Variants 3 and 4. This is in line with the objectives of Just Transition and with the constitution, vision, and mission of Spółka Restrukturyzacji Kopalń S.A. [46,71,72].

5. Discussion

The main reason for SRK S.A.'s investment in renewable energy sources is to reduce the Company's operating costs and protect the environment in line with the circular economy model. In addition to covering the pumping station's energy needs with "green" energy, the project also provides for the revitalization of the liquidated mine's facilities, the retention of existing jobs, and the creation of new ones. The described innovative energy systems in the facilities of the liquidated mines are attractive both economically and in terms of image.

The pumping station analyzed is one of 19 pumping stations protecting active mines and the surface area from flooding. The largest component of the Company's costs is electricity purchase charges. The development and implementation of efficient ways of generating and storing energy is part of projects increasing the share of RES energy in Poland's energy mix [73].

Investment in upgrading the pumping station to a closed-loop economy and energy self-sufficiency model would create the opportunity to establish a research and development center. At such a center, it would be possible to test innovative "zero-emission" technology solutions in practice, which could be replicated at other locations [28,32,39]. The constraints are due to legal stipulations and the resulting financial difficulties. As it stands, SRK S.A.'s operations in mine closure and restructuring are set to conclude by the end of 2025, and it is uncertain who will assume ownership of the potentially upgraded pumping station. This has created impediments in securing the necessary funds for the intended investment.

As a result of the research, six variants for restructuring a liquidated mine towards the concept of a circular economy were designed. Each variant comes in two sub-variations, resulting in twelve decision-making situations [54–56]. In some of the variants, no treatment of pumped water is carried out, while the remaining variants involve investment in the construction of a Mining Water Treatment Station. The possible construction of a Mining Water Treatment Station is highly dependent on the ability of the local community to receive the treated water. The Company is conducting discussions in this regard. It is likely that the discussions will be successful, so the implementation of the variants equipped with Mining Water Treatment Stations seems possible [42,44]. Income generated from the sale of purified water will be allocated to acquiring the deficient portion of "dirty" electricity. The project assumes that the revenue from the disposal of any other medium (hydrogen, oxygen, electricity, or heat) will also be directed towards meeting the energy needs of the pumping station and will be treated as a form of storage for the excess energy generated.

The research revealed that maximizing the potential of the mine water pumping station, and possibly the entire decommissioned mine, will yield optimal results for modernization. It has been demonstrated that the collaboration of these efforts will produce positive outcomes for the company, the local environment, and residents. Embracing a fresh perspective on waste management could lead to the development of an economic model that is conducive to both the community and the environment. The pursuit of new resources and their integration into a circular economy system remains a pressing scientific, technical, ecological, and social challenge that warrants further exploration in this field.

Despite the attention of the local authorities, the possible opportunity to market the salt extracted from treating mine water has not been considered. Before carrying out such a transaction, it is essential to conduct an examination of the chemical composition of water treatment waste products [5,68] and to devise a cost-effective technique for extracting technical salt from this waste. The reduction of salt being discharged into nearby water bodies and ultimately into the major rivers of Poland will have wide-reaching consequences beyond just mining regions. It is imperative to address this issue, particularly when elevated water salinity leads to summer algal blooms in Polish rivers, causing extensive loss of aquatic life.

6. Conclusions

The aforementioned projected measures are intended to reduce the Company's operating costs in the future and to generate additional revenue that will successively reduce the subsidy received. The high cost of purchasing electricity and the significant initial investment required make energy storage in the form of electrolytic hydrogen less economically feasible compared to other options. However, with the steady decrease in electricity prices and the expected advancements in hydrogen technology, it is advisable to consider options involving the storage of excess electricity in hydrogen. In the long run, the implementation of the projects described will attract new investors and create jobs that are alternatives to those in mining. Participation in these activities will also stimulate the development of other economic sectors by bringing post-mining areas and facilities back to life. The planned energy self-sufficiency projects could have a substantial impact on the social and economic structure of mining regions like Upper Silesia. These projects are part of the Just Transition process and present an opportunity for regional development through the introduction of new technologies and modern technical and technological solutions, as well as economic opportunities. They will also create new markets related to modern transportation and sustainable energy. Energy self-sufficiency projects offer a chance to revitalize post-mining areas affected by intense mining. The listed projects align with the statutory duties of Spółka Restrukturyzacji Kopalń S.A., are economically justified, and are recommended for implementation. To ensure the success of these activities, collaboration with local administration and the development of a unified position will be necessary. The assessment of the proposed measures for upgrading mining water pumping plants was conducted with the objective of providing a comprehensive evaluation while considering various options. The resulting analysis serves as information to guide final decision-making.

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References

1. Changqing, L.; Jong-Beom, B. The promise of hydrogen production from alkaline anion exchange membrane electrolyzers. *Nano Energy* **2021**, *87*, 106162. [CrossRef]
2. Gajdzik, B.; Jaciow, M.; Wolniak, R.; Wolny, R.; Grebski, W.W. Assessment of Energy and Heat Consumption Trends and Forecasting in the Small Consumer Sector in Poland Based on Historical Data. *Resources* **2023**, *12*, 111. [CrossRef]
3. Kaczmarek, J. The Balance of Outlays and Effects of Restructuring Hard Coal Mining Companies in Terms of Energy Policy of Poland PEP 2040. *Energies* **2022**, *15*, 1853. [CrossRef]
4. Kaczmarek, J.; Kolegowicz, K.; Szymla, W. Restructuring of the Coal Mining Industry and the Challenges of Energy Transition in Poland (1990–2020). *Energies* **2022**, *15*, 3518. [CrossRef]
5. Bondaruk, J.; Janson, E.; Wysocka, M.; Chałupnik, S. Identification of hazards for water environment in the Upper Silesian Coal Basin caused by the discharge of salt mine water containing particularly harmful substances and radionuclides. *J. Sustain. Min.* **2015**, *14*, 179–187. [CrossRef]
6. Mhlongo, S.E. Evaluating the post-mining land uses of former mine sites for sustainable purposes in South Africa. *J. Sustain. Min.* **2023**, *2*, 3. [CrossRef]
7. Smoliński, A.; Howaniec, N. Hydrogen energy, electrolyzers and fuel cells–The future of modern energy sector. *Int. J. Hydrogen Energy* **2020**, *45*, 5607. [CrossRef]
8. Tokarski, S.; Magdziarczyk, M.; Smoliński, A. Risk management scenarios for investment program delays in the Polish power industry. *Energies* **2021**, *14*, 5210. [CrossRef]
9. Tokarski, S.; Magdziarczyk, M.; Smoliński, A. An Analysis of Risks and Challenges to the Polish Power Industry in the Year 2024. *Energies* **2024**, *17*, 1044. [CrossRef]
10. Manowska, A.; Bluszcz, A.; Chomiak-Orsa, I.; Wowra, R. Towards Energy Transformation: A Case Study of EU Countries. *Energies* **2024**, *17*, 1778. [CrossRef]
11. Manowska, A.; Nowrot, A. Solar Farms as the Only Power Source for the Entire Country. *Energies* **2022**, *15*, 5297. [CrossRef]
12. Wojtacha-Rychter, K.; Kucharski, P.; Smoliński, A. Conventional and alternative sources of thermal energy in the production of cement an impact on CO_2 emission. *Energies* **2021**, *15*, 4176. [CrossRef]
13. Ramos, A.; Monteiro, E.; Silva, V.; Rouboa, A. Co-gasification and recent developments on waste-to-energy conversion: A Review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 380–398. [CrossRef]
14. Howaniec, N.; Smoliński, A.; Cempa-Balewicz, M. Experimental study of nuclear high temperature reactor excess heat use in the coal and energy crops co-gasification process to hydrogen-rich gas. *Energy* **2015**, *84*, 455–461. [CrossRef]
15. Zhang, W.; Yuan, C.; Xu, J.; Yang, X. Beneficial synergetic effect on gas production during co-pyrolysis of sewage sludge and biomass in a vacuum reactor. *Bioresour. Technol.* **2015**, *183*, 255–258. [CrossRef] [PubMed]
16. Smoliński, A.; Stańczyk, K.; Howaniec, N. Steam gasification of selected energy crops in a fixed bed reactor. *Renew. Energy* **2010**, *35*, 397–404. [CrossRef]
17. Kokalj, F.; Arbiter, B.; Samec, N. Sewage sludge gasification as an alternative energy storage model. *Energy Convers. Manag.* **2017**, *149*, 738–747. [CrossRef]
18. Krawczyk, P.; Howaniec, N.; Smoliński, A. Economic efficiency analysis of substitute natural gas (SNG) production in steam gasification of coal with the utilization of HTR excess heat. *Energy* **2016**, *114*, 1207–1213. [CrossRef]
19. Skoglund, N.; Bäfver, L.; Fahlströmd, J.; Holmén, E.; Renström, C. Fuel design in co-combustion of demolition wood chips and municipal sewage sludge. *Fuel Process. Technol.* **2016**, *141*, 196–201. [CrossRef]
20. Lin, Y.; Liao, Y.; Yu, Z.; Fang, S.; Ma, X. The investigation of co-combustion of sewage sludge and oil shale using thermogravimetric analysis. *Thermochim. Acta* **2017**, *653*, 71–78. [CrossRef]

21. Li, H.; Chen, Z.; Huo, C.; Hu, M.; Guo, D.; Xiao, B. Effect of bioleaching on hydrogen-rich gas production by steam gasification of sewage sludge. *Energy Convers. Manag.* **2015**, *106*, 1212–1218. [CrossRef]
22. Badakhshan, N.; Shahriar, K.; Afraei, S.; Bakhtavar, E. Evaluating the impacts of the transition from open-pit to underground mining on sustainable development indexes. *J. Sustain. Min.* **2023**, *22*, 6. [CrossRef]
23. Krzemień, A.; Álvarez Fernández, J.J.; Riesgo Fernández, P.; Fidalgo Valverde, G.; Garcia-Cortes, S. Restoring Coal Mining-Affected Areas: The Missing Ecosystem Services. *Int. J. Environ. Res. Public Health* **2022**, *19*, 14200. [CrossRef]
24. Riesgo Fernández, P.; Rodríguez Granda, G.; Krzemień, A.; García Cortés, S.; Fidalgo Valverde, G. Subsidence versus natural landslides when dealing with property damage liabilities in underground coal mines. *Int. J. Rock Mech. Min. Sci.* **2020**, *126*, 104175. [CrossRef]
25. Chand, K.; Paladino, O. Recent developments of membranes and electrocatalysts for the hydrogen production by anion exchange membrane water electrolysers: A review. *Arab. J. Chem.* **2023**, *16*, 104451. [CrossRef]
26. Martín Narbaitz, R.; Chartrand, Z.G.; Sartaj, M.; Downey, J. Ammonia-Ca-K competitive ion-exchange on zeolites in mining wastewater treatment: Batch regeneration and column performance. *J. Sustain. Min.* **2020**, *19*, 1. [CrossRef]
27. Fernández-Muñiz, Z.; Pallero, J.L.G.; Fernández-Martínez, J.L. Anomaly shape inversion via model reduction and PSO. *Comput. Geosci.* **2020**, *140*, 104492. [CrossRef]
28. Gado, M.G.; Hassan, H. Potential of prospective plans in MENA countries for green hydrogen generation driven by solar and wind power sources. *Sol. Energy* **2023**, *263*, 111942. [CrossRef]
29. Gupta, J. Application of Green Management in Business Processes. *Natl. J. Leg. Res. Innov. Ideas* **2023**, *3*, 84–97.
30. Gupta, J. Role Of United Nations Environment Programme In Addressing the Issue of Climate Change. *Bharat Manthan Multidiscip. Res. J.* **2023**, *3*, 83–91.
31. Łabaj, P.; Wysocka, M.; Janson, E.; Deska, M. Application of the Unified Stream Assessment Method to Determine the Direction of Revitalization of Heavily Transformed Urban Rivers. *Water Resour.* **2020**, *47*, 521–529. [CrossRef]
32. Al-Orabi, A.M.; Osman, M.G.; Sedhom, B.E. Analysis of the economic and technological viability of producing green hydrogen with renewable energy sources in a variety of climates to reduce CO_2 emissions: A case study in Egypt. *Appl. Energy* **2023**, *338*, 120958. [CrossRef]
33. Barszczowska, B. Monitoring i kontrola procesu restrukturyzacji górnictwa węgla kamiennego w latach 2003–2023. In *Jak to z Tym Węglem Było, Jest i Będzie*; Galos, K., Barszczowska, B., Eds.; Wydawnictwo Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk: Kraków, Poland, 2023; pp. 31–43. Available online: https://se.min-pan.krakow.pl/pelne_teksty36/k36_monografia_ARP.pdf (accessed on 29 July 2024).
34. Krzemień, A.; Álvarez Fernández, J.J.; Riesgo Fernández, P.; Fidalgo Valverde, G.; Garcia-Cortes, S. Valuation of Ecosystem Services Based on EU Carbon Allowances—Optimal Recovery for a Coal Mining Area. *Int. J. Environ. Res. Public Health* **2023**, *20*, 381. [CrossRef] [PubMed]
35. Salom, A.T.; Kivinen, S. Closed and abandoned mines in Namibia: A critical review of environmental impacts and constraints to rehabilitation. *South Afr. Geogr. J.* **2020**, *102*, 389–405. [CrossRef]
36. Gajdzik, B.; Tobór-Osadnik, K.; Wolniak, R.; Grebski, W.W. European Climate Policy in the Context of the Problem of Methane Emissions from Coal Mines in Poland. *Energies* **2024**, *17*, 2396. [CrossRef]
37. Howaniec, N.; Zdeb, J.; Gogola, K.; Smoliński, A. Utilization of Carbon Dioxide and Fluidized Bed Fly Ash in Post-Industrial Land Remediation. *Materials* **2023**, *16*, 4572. [CrossRef]
38. Chmiela, A.; Wrona, P.; Magdziarczyk, M.; Liu, R.; Zhang, L.; Smolinski, A. Hydrogen Storage and Combustion for Blackout Protection of Mine Water Pumping Stations. *Energies* **2024**, *17*, 2357. [CrossRef]
39. Gado, M.G.; Nasser, M.; Hassan, H. Potential of solar and wind-based green hydrogen production frameworks in African countries. *Int. J. Hydrogen Energy* **2024**, *68*, 520–536. [CrossRef]
40. Magdziarczyk, M.; Chmiela, A.; Dychkovskyi, R.; Smoliński, A. The Cost Reduction Analysis of Green Hydrogen Production from Coal Mine Underground Water for Circular Economy. *Energies* **2024**, *17*, 2289. [CrossRef]
41. Amoah, N.; Stemn, E. Siting a centralised processing centre for artisanal and small-scale mining—A spatial multi-criteria approach. *J. Sustain. Min.* **2021**, *17*, 215–225. [CrossRef]
42. Barszczowska, B. Hydrogen valleys as opportunities for SME in Poland. In *Preserving, Evaluating And Developing the Mediterranean*; Institute of Social Sciences Ivo Pilar, VERN' University: Zagreb, Croatia, 2023; pp. 379–386.
43. Prakash Pandey, B.; Prasad Mishra, D. Improved Methodology for Monitoring the Impact of Mining Activities on Socio-Economic Conditions of Local Communities. *J. Sustain. Min.* **2022**, *21*, 65–79. [CrossRef]
44. Barszczowska, B. Nowy system wsparcia dla sektora górnictwa węgla kamiennego–istota i wyzwania związane z monitoringiem i kontrolą systemu dopłaty do redukcji zdolności produkcyjnych. *Zesz. Nauk. Inst. Gospod. Surowcami Miner. Energią Pol. Akad. Nauk.* **2024**, *1*, 93–102. [CrossRef]
45. Abramov, Y.; Basmanov, O.; Krivtsova, V.; Mikhayluk, A.; Makarov, Y. Determining the functioning efficiency of a fire safety subsystem when operating the hydrogen storage and supply system. *East.-Eur. J. Enterp. Technol.* **2024**, *2*, 75–84. [CrossRef]
46. Abramov, Y.; Kryvtsova, V.; Mikhailyuk, A. Justification of the characteristics of the fire-safe condition control system of the storage system and hydrogen supply. *Eng. Sci. Archit.* **2023**, *1*, 125–130. [CrossRef]
47. Moradi, R.; Groth, K.M. Hydrogen storage and delivery: Review of the state of the art technologies and risk and reliability analysis. *Int. J. Hydrogen Energy* **2019**, *44*, 12254–12269. [CrossRef]

48. Cui, S.; Zhu, G.; He, L.; Wang, X.; Zhang, X. Analysis of the fire hazard and leakage explosion simulation of hydrogen fuel cell vehicles. *Therm. Sci. Eng. Prog.* **2023**, *41*, 101754. [CrossRef]
49. Nasser, M.; Hassan, H. Green hydrogen production mapping via large scale water electrolysis using hybrid solar, wind, and biomass energies systems: 4E evaluation. *Fuel* **2024**, *371*, 131929. [CrossRef]
50. Manowska, A.; Dylong, A.; Tkaczyk, B.; Manowski, J. Analysis and Monitoring of Maximum Solar Potential for Energy Production Optimization Using Photovoltaic Panels. *Energies* **2024**, *17*, 72. [CrossRef]
51. Seheda, M.S.; Beshta, O.S.; Gogolyuk, P.; Blyznak, F.; Yu, V.; Dychkovskyi, R.; Smoliński, A. Mathematical model for the management of the wave processes in three-winding transformers with consideration of the main magnetic flux in mining industry. *J. Sustain. Min.* **2024**, *23*, 20–39. [CrossRef]
52. Squadrito, G.; Maggio, G.; Nicita, A. The green hydrogen revolution. *Renew. Energy* **2023**, *216*, 119041. [CrossRef]
53. Taha, A.M.; Abdel-Wahab, E.I. Water used by soybean and maize intercropping patterns as affected by different soybean cultivars and plant population. *J. Soils Crops* **2024**, *34*, 29–39.
54. Álvarez, M.; Bodeman, C.; Cafferata Ferri, S.; Di Blasi Regner, M.; Fasce, C.; Morgaday, M.E.; Santos, S. *Modelización Matemática. Propuestas Para su Enseñanza*; Dunken: Buenos Aires, Argentina, 2024.
55. Calderón, I.; Di Blasi, M.; Capello, V.; Tomazzeli, G.; Balbi, M.; Cuello, N.; Ochoa Rodirguez, P.; Sacco, L.; Martínez, H.; Rozenhauz, J.; et al. *Buenas prácticas Desarrollo de la Competencia de Modelización Matemática*; edUTecNe–Editorial de la Universidad Tecnológica Nacional: Buenos Aires, Argentina, 2023.
56. Kashkarov, S.; Dadashzadeh, M.; Sivaraman, S.; Molkov, V. Quantitative Risk Assessment Methodology for Hydrogen Tank Rupture in a Tunnel Fire. *Hydrogen* **2022**, *3*, 512–530. [CrossRef]
57. Jae-Chan, K.; Junhyeong, K.; Jong Chel, P.; Sang Hyun, A.; Dong-Wan, K. Ru2P nanofibers for high-performance anion exchange membrane water electrolyzer. *Chem. Eng. J.* **2021**, *420*, 130491. [CrossRef]
58. Vladyko, O.; Maltsev, D.; Sala, D.; Cichoń, D.; Buketov, V.; Dychkovskyi, R. Simulation of leaching processes of polymetallic ores using the similarity theorem. *Rud.-Geološko-Naft. Zb.* **2022**, *37*, 169–180. [CrossRef]
59. Wrona, P. The influence of climate change on CO_2 and CH_4 concentration near closed shaft-numerical simulations. *Arch. Min. Sci.* **2017**, *62*, 639–652. [CrossRef]
60. Barszczowska, B. Polska Strategia Wodorowa. Rola dolin wodorowych. *Zesz. Nauk. Inst. Gospod. Surowcami Miner. Energią Pol. Akad. Nauk.* **2023**, *1*, 109–116. [CrossRef]
61. Gawęda, A. Sustainability Reporting: Case of European Stock Companies. *Eur. J. Sustain. Dev.* **2021**, *10*, 41–53. [CrossRef]
62. Gawęda, A.; Złoty, M. The impact of ESG ratings on the market performance of commodity stock sector before and during the COVID-19 pandemic. *Ekon. I Prawo. Econ. Law* **2023**, *22*, 531–553. [CrossRef]
63. Schoenmaker, D.; Schramade, W. *Principles of Sustainable Finance*; Oxford University Press: Oxford, London, 2019.
64. Gawęda, A. ESG Rating and Market Valuation of the Firm: Sector Approach. *Eur. J. Sustain. Dev.* **2022**, *11*, 91. [CrossRef]
65. Janicka, M.; Sajnóg, A. The ESG Reporting of EU Public Companies–Does the Company's Capitalisation Matter? *Sustainability* **2022**, *14*, 7. [CrossRef]
66. Gawęda, A.; Sajnóg, A. Cross-sectoral detection of the Return on Equity determinants based on the 7-factor DuPont model. *Stud. Prawno-Ekon.* **2020**, *114*, 217–234. [CrossRef]
67. Khomenko, D.; Jelonek, I. Study of a Low-Cost Method for Estimating Energy Fuel Resources in Anthropogenic Sediments. *Manag. Syst. Prod. Eng.* **2023**, *31*, 434–441. [CrossRef]
68. Gajdzik, B.; Wolniak, R.; Nagaj, R.; Grebski, W.; Romanyshyn, T. Barriers to Renewable Energy Source (RES) Installations as Determinants of Energy Consumption in EU Countries. *Energies* **2023**, *16*, 7364. [CrossRef]
69. Fidalgo-Valverde, G.; Menéndez-Díaz, A.; Krzemień, A.; Riesgo-Fernández, P.; Marqués Sierra, A.L. Environmental risk assessment in coal mining with methane degassing. In Proceedings of the 11th International Symposium on Occupational Health and Safety (SESAM), Bucharest, Romania, 18 October 2023. [CrossRef]
70. Doorga, J.R.S.; Hall, J.W.; Eyre, N. Geospatial multi-criteria analysis for identifying optimum wind and solar sites in Africa: Towards effective power sector decarbonization. *Renew. Sustain. Energy Rev.* **2022**, *158*, 112107. [CrossRef]
71. Skibski, M.; Barszczowska, B. Sektor górnictwa węgla kamiennego po 8 miesiącach 2023 roku. *Zesz. Nauk. Inst. Gospod. Surowcami Miner. Energią Pol. Akad. Nauk.* **2024**, *1*, 83–92. [CrossRef]
72. Villar, Y.; Menéndez, M.; Fernández, Z.; Bernardo, A. Sustainable earthworks: Optimization with the ICOM method. *Energy Rep.* **2020**, *6*, 404–419. [CrossRef]
73. Kamiński, P.; Niedbalski, Z.; Małkowski, P.; Bozic, D. Application of composite materials in underground mining industry–foreshaft closing platform. *Min. Mach.* **2022**, *40*, 19–31. [CrossRef]