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THE MANAGEMENT OF POWER SUPPLY SECURITY OF MINE WATER PUMPING STATION

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Purpose: Growing global warming increases the threat of energy supply security in the form of the “blackout” phenomenon. Pumping stations pump out approximately 100 million m^3 of water annually (data from 2023). Discontinuation of mine water pumping would expose neighbouring mines and lower-lying areas to flooding.
Design/methodology/approach: For the designed database of functional scenarios of the mine water pumping station, the optimal variant was selected based on economic and ecological criteria as well as the energy security criterion.
Findings: The research analyzed five technically feasible variants of modernization of mine water pumping stations. Each variant is characterized by a different degree of security of energy supply and a different level of meeting energy demand.
Research limitations/implications: All variants of modernization of the pumping station provide for the production of electricity for own needs. All investment attractiveness factors should be taken into account while making investment decisions. It is up to the decision-maker to make the final multi-criteria decision so as to implement the selected variant.
Practical implications: One of the challenge is to ensure security of energy supplies in the event of a sudden energy shortage. Pumping stations have some retention, nevertheless a longer shutdown time could lead to environmental problems. Removing the damage would definitely require large financial expenditures and would take several years.
Social implications: The planned project of the energy supply security can have a positive impact on the local community and economy. The projects discussed will create new markets related to "green energy".
Originality/value: The aim of the article is to assess the investment relevance of safety projects for power supply to mine water pumping stations. The combination of the problems of drainage of liquidated mines, the use of renewable energy sources and energy storage to improve the security of power supply to pumping stations has not been the subject of scientific research so far.
Keywords: drainage of liquidated mines, energy storage, renewable sources of energy, hydrogen extraction, revitalization of post-mining installations.
Category of the paper: Research paper, conceptual paper, case study.

1. Introduction

Worsening global warming, more frequent wildfires, and other natural disasters are increasing threats to energy security known as "blackouts" (Tokarski et al., 2021). A blackout is a prolonged interruption in energy supply. Blackouts can occur in both winter and summer. In winter, blackouts can be caused by broken transmission grids, while in summer, they can be caused by grid overloads during a heat wave or prolonged droughts that cause power plants to shut down. The phenomenon of power shortages in the national grid will be possible in Poland as early as the middle of this decade during the processes of phasing out coal-based power generation. The largest blackout in Poland to date occurred in Szczecin in the winter of 2008. It was caused by strong winds and heavy snow that tore down power lines, leaving up to 500,000 people without electricity for three days. It is estimated that between 2025 and 2030 there could be several hours of blackouts per year, and after 2030 several hundred hours per year.

The European Union (EU) has adopted policies to achieve climate neutrality by 2050. One of the priorities is to shift from burning fossil fuels, including coal, to producing energy from renewable energy sources (RES). Poland is currently making several investments in renewable energy, and nuclear power plants. According to the current schedule, construction will begin in 2026, with the first of the three planned units coming online in 2033. Until these investments are completed, coal will be the main source of energy. Coal will generate almost 63% of all electricity in Poland in 2023 (about 105 TWh). The current situation of security of electricity supply is not bad, but Poland may soon run out of energy. The first blackouts could occur as early as 2025. Poland is also exposed to this risk due to its aging power grid. In Poland, the greater risk of power system inefficiency occurs in the summer, when significant amounts of energy are consumed by cooling systems. Major problems may arise when the liquidation of old coal-fired power plants begins. The threat of a blackout increased after Russia's aggression against Ukraine, when European countries, including Poland, decided to stop or reduce imports of energy resources from Russia.

In Poland, Spółka Restrukturyzacji Kopalń S.A. (SRK S.A. - Mines Restructuring Company) manages the assets of mines in liquidation (Bluszcz, Smoliło, 2012). One of the basic tasks of SRK S.A. is to protect the neighboring mines from water hazards and to take care of the environment. An important asset of SRK S.A. are mine water pumping stations, whose task is to pump, manage and discharge mine water (Michlowicz, Wojciechowski, 2021; Wysocka et al., 2019). The operation of pumping stations not only protects neighboring mines and lower-lying areas from flooding, but also protects near-surface aquifers from contamination (Biały et al., 2020; Bondaruk et al., 2015; Wysocka et al., 2019). The process of pumping mine water must continue even after mining has ceased. Pumping stations owned by SRK S.A. pump approximately 100 million m^3 of water annually (data for 2023). The pumping of this volume of water is associated with high electricity purchase costs (Bondaruk et al., 2015; Chmielewska et al., 2020). The main challenge for SRK S.A. is to purchase electricity, which is one of the largest components of the Company's operating costs, and to maintain security of energy supply (Maruszewska et al., 2023; Schoenmaker, Schramade, 2019). The energy consumption of the Company's branches in 2023 amounted to approximately 300 GWh. Most of the electricity consumed by SRK S.A. is used by pumping stations for dewatering abandoned mines. Blackout as an unforeseen long-term interruption of electricity supply will cause unexpected and unpredictable consequences (Fernández-Muñiz et al., 2020; Gajdzik et al., 2022). In a blackout situation, large industrial facilities such as SRK S.A. are the first to be cut off. Although SRK S.A.'s pumping stations have a certain level of retention, a prolonged outage could result in minor or major environmental problems (Kaczmarek, 2022; Kaczmarek et al., 2022).

The purpose of the article is to evaluate the investment appropriateness of feasible projects for energy security and energy self-sufficiency of mine water pumping stations in the current economic conditions (Gawęda, Sajnóg, 2020; Gawęda, Złoty, 2023). To achieve this goal, several technically feasible projects for ensuring energy supply security and energy self-sufficiency in the situation of prolonged lack of power supply from the national grid are proposed for the district pumping station. The combination of the problems of dewatering abandoned mines with the application of RES and energy storage to improve the security of power supply to pumping stations has not yet been the subject of scientific research. The study evaluated the investment attractiveness of the proposed projects in terms of technical, economic, environmental, and social values (Bobruk, 2019). The results of the study proved that the available energy self-sufficiency projects are characterized by different investment attractiveness depending on the applied evaluation criterion, but those projects should be considered the most desirable in which the balance between investment expenditures and the projected assurance of security of electricity supply, energy, and social needs is the most favourable (Gawęda, 2021; 2022).

2. Materials and methods

SRK S.A., which carries out liquidation and post-liquidation activities at former coal mining sites, aims to maximize the reduction of negative environmental externalities resulting from its operational activities (Mhlongo, Amponsah-Dacosta, 2016; Mhlongo, 2023; Mucha et al., 2016; Salom, Kivinen, 2020). Spółka Restrukturyzacji Kopalń S.A. (SRK S.A.) intends to undertake investment activities to acquire alternative renewable energy sources, including photovoltaic farms with adapted energy storage and hydrogen. This is in line with the directions set by the European Commission. To this end, SRK S.A. is considering the possibility of building a number of photovoltaic farms on its sites, which would partially secure the Company's energy needs and to some extent protect the pumping stations from a sudden lack of power from the grid (Prakash, Prasad, 2022; Woszczyński et al., 2023). The term "blackout" is used to describe a sudden and severe failure of the power system that results in a lack of power from the national grid over a large area (Bazaluk et al., 2021; Doorga et al., 2022). Such an interruption in power supply may last only a few minutes, but usually a blackout is understood as a longer power outage of even several days (Fidalgo-Valverde et al., 2023; Kamiński et al., 2022). The main causes of blackouts are:

- extreme weather events (sudden downpours, gusty winds, or hot weather),
- overloading of the power grid,
- lack of energy resources on the market,
- armed conflict and terrorism.

To reduce the vulnerability of mine liquidation processes to unforeseen changes (Łabaj et al., 2020; Mercado et al., 2021; Rubio et al., 2019), SRK S.A. conducted energy efficiency audits of its liquidation and post-liquidation operations. The recommendations from the audits point to a number of projects, the implementation of which can significantly improve energy security and reduce the impact of mine restructuring on the local community. One of the recommendations is to reduce energy consumption and reduce the company's operating costs (Prusek, Turek, 2018; Shnorhokian, Mitri, 2022; Tokarski et al., 2021) through the construction of photovoltaic farms, on industrial land for production purposes. The "green" energy, produced on the post-mining land by means of photovoltaic panels, could significantly improve the safety of operations and significantly cover the energy needs of the company's branches. The economic impact of the investment would be a reduction in the need for a budget subsidy and the creation of new alternative jobs to mining for retrained miners. The environmental effect of the investments proposed in the audit would be a reduction of equivalent CO_2 emissions into the atmosphere (Wojtacha-Rychter et al., 2021; Doorga et al., 2022).

The use of RES depends on weather conditions, which poses many challenges (Krzemień et al., 2022; 2023a; Riesgo Fernández et al., 2020). On sunny days, the company's energy needs will be met by photovoltaic farms. During the period of electricity production at SRK S.A., it will be possible to use only part of the electricity generated. Thus, the remaining part of the generated energy will be a surplus that can be stored for use in periods of deficit. Energy storage through battery systems or shaft installations allows short-term storage (Chmiela, Smoliło, 2023; Chmiela et al., 2023). Efficient use of RES is only possible with the use of storage of surplus generated energy and its use in periods of shortage. Hydrogen is an environmentally friendly energy carrier suitable for storing surplus "green" energy generated by photovoltaic farms (Barszczowska 2023a; 2023b). This type of storage has been included in one of the options for energy security and energy self-sufficiency (Krzemień et al., 2023a; Villar et al., 2020). In a part of the proposed energy self-sufficiency projects, the storage of excess energy by hydrogen extraction was adopted, and battery storage was adopted only for buffering the generated energy or for the possible needs of stabilizing the operation of electrolyzers. Water electrolysis is considered the most promising and recommended technology for energy storage through hydrogen production (Smolinski, Howaniec, 2020; Wojtacha-Rychter et al., 2019). In the event of a blackout, it will be possible to use previously stored energy, and the energy security effect will increase the independence of pumping stations from external electricity supplies.

The selection of the size of the photovoltaic farms for variants 1 and 2 was based on the maximum area that does not generate the necessary surplus for feeding into the national grid, and for variants 3, 4 and 5 on the maximum available area of the former main plant of the abandoned mine. Revenues from the sale of hydrogen and oxygen and thermal energy will be used to purchase the missing part of electricity, which will reduce the need for a budget subsidy and reduce CO_2 emissions into the atmosphere (Wojtacha-Rychter et al., 2021). The calculations were performed for an exemplary district stationary pumping station located in a large city in the Silesian agglomeration. The pumping station pumps about 10 million m^3 of water per year. The pumping station is accompanied by a reclaimed post-mining area of about 23 hectares, suitable for the construction of a photovoltaic farm.

In terms of energy security and self-sufficiency, two groups of variants for the modernization of underground water pumping stations were designed (Smoliło, Chmiela 2021a; 2021b; 2021c), assuming the maximum use of the generated electricity. Due to legal restrictions preventing electricity trading, all variants were abandoned to apply for an electricity distribution license. A total of 5 decision alternatives were provided for evaluation, varying in the amount of required expenditures and in the degree of satisfaction of the security of electricity supply and the energy needs of the pumping station.

At the upgraded district pumping station, the photovoltaic panels and power consumers are located on the same property. The electricity consumers are infrastructure related to the pumping of mine water. The largest consumers are the pumping systems and the main ventilation systems. The options for upgrading the district pumping station were designed in two variations. In one group, the photovoltaic farm is small enough that all the "green" energy generated (i.e. energy from renewable sources) is consumed continuously by the pumping station - operation on a separate grid (variant 1). In the second case, the photovoltaic system produces more energy than the pumping station could consume continuously. In such a model of energy security and self-sufficiency, there is a surplus of usable energy after storage.

Option 2 involves the installation of a battery energy storage system. The size of the photovoltaic farm has been chosen so that the energy generated is partly consumed by the pumping station equipment at the time of generation and partly stored in the battery energy storage. On the same billing day, the stored energy is completely consumed by the pumping station equipment. In the study, the billing day is defined as the day from sunrise together with the immediately following night.

Variants 3, 4 and 5 use the entire available area of the former main plant of the abandoned mine for the development of photovoltaic panels. In order to avoid feeding excess electricity back into the national grid, these options also include infrastructure to store temporary excess electricity in the form of electrolytically harvested hydrogen. In Option 3, the stored hydrogen would be used to power cogeneration engines or hydrogen cells to generate electricity for the pumping station's own needs during periods of energy shortage. In variants 4 and 5, the hydrogen produced is to be sold wholesale to a local distributor (variant 4) or retail at the company's own vehicle filling station (variant 5). The sale of hydrogen is intended to be a form of virtual long-term storage of excess energy.

3. Results and discussion

3.1. Option 1 - photovoltaic farm

Option 1 is the simplest and cheapest example of an energy security project possible at the district pumping station under study. The project involves the construction of a 4.5 MWp photovoltaic farm with the necessary equipment and infrastructure at the existing district mine water pumping station. In order to buffer the power supply for the operation of the pumping station equipment with the energy generated by the photovoltaic farm, the additional development of a battery energy storage with a capacity of 2.5 MWh is envisaged. In the study, all expenses and costs were converted to the purchase of 1 GWh (for the unit purchase price of energy in the first quarter of 2024). The size of the farm and its power will be adapted to the energy needs of the pumping station equipment. The energy produced by the photovoltaic farm will not exceed the fluctuations in the pumping station's energy demand and will be completely consumed by the pumping station on a continuous basis, without even temporarily feeding energy back into the national grid.

Variant 1 of the pumping station upgrade will ensure security of energy supply only during sunshine hours. The pump station can only operate in primary mode. On sunny days during the sunshine hours, it will be possible to replace up to 99.9% of the pumping station's demand with "green" energy during this time, which is about 40% of the pumping station's daily electricity demand and about 18% of the pumping station's total energy demand (Table 1).

Table 1.
Parameters of the analyzed district pumping station after modernization in variant 1

Expenditures for modernization of pumping stations	**Employee costs per year**	**Payback time**
[Expenditures and costs per 1 GWh purchase] (for the unit purchase price of energy in the first quarter of 2024)		[years]
35.3	0.3	6.2
Energy security of pumping stations	Additional financial security for energy purchases	Securing the energy needs of the pumping station
18.25%	0.00%	18.25%

Source: own study.

The implementation of this option does not generate any additional revenue that could be used to cover additional electricity purchases. The "green energy" generated by the farm is equivalent to the CO_2 emissions into the atmosphere of approximately 5.000 Mg CO_2. For the unit purchase price of electricity and the unit employee cost in Q1 2024, the expected payback time is estimated at approximately 6 years. The option will provide 1 job for relocated SRK S.A. employees.

3.2. Option 2 - battery storage of surplus energy

Storage of electricity in batteries is only possible in the short term (preferably within the same billing day). For this reason, the decision model of Option 2 provides for the storage of excess electricity generated only for own operation of pumping station equipment during the non-sunny period of the solar day (Khomenko, Jelonek, 2023; Magdziarczyk et al., 2023). Option 2 involves the construction of a 9.13 MWp photovoltaic farm and a battery energy storage system with a capacity of approximately 52 MWh. On non-sunny days, the most energy-intensive pumping station equipment will be operated, if possible, during the period with the lowest electricity purchase price. On sunny days, there will be a shift and the most energy-intensive equipment will be operated during the time of electricity generation to maximize the continuous effect of the photovoltaic farm. The farm will be sized so that the excess electricity it generates, after being stored in battery energy storage, will be used on the same billing day to power the pumping station. The model foresees the generation of electricity only for the pumping station's own needs. There will be no need to supply energy to the outside in any form.

The decision model provides energy security only during sunny billing days and ensures the security of power supply to the equipment both day and night. The pump station can only operate in its primary mode. On sunny days, depending on the duration of the power outage, it will be possible to power the pumping station at 100% during sunny periods and up to approximately 99.9% of the pumping station's daily power requirements during non-sunny periods. The generated energy will supply the pumping station with approximately 36% of the annual demand (Table 2).

Table 2.
Parameters of the analyzed district pumping station after modernization in variant 2

Expenditures for modernization of pumping stations	**Employee costs per year**	**Payback time**
[Expenditures and costs per 1 GWh purchase] (for the unit purchase price of energy in the first quarter of 2024)		[years]
402.4	0.3	35.2
Energy security of pumping stations	Additional financial security for energy purchases	Securing the energy needs of the pumping station
35.59%	0.00%	35.59%

Source: own study.

Implementation of Option 2 will not provide additional revenues that would cover the purchase of the missing electricity from the national grid. However, the "green energy" generated by the farm will result in a reduction in equivalent CO_2 emissions to the atmosphere by about 10.300 Mg CO_2. For the unit purchase price of electricity, the unit purchase price of battery energy storage and the unit employee cost in Q1 2024, the expected payback time is estimated at about 35 years. Option 2 provides for a reduction of 1 job reduction.

3.3. Option 3 - storage in the form of hydrogen from the electrolysis process

Option 3 proposes not to sell electricity to the national grid and to store excess electricity produced by the photovoltaic farm in the form of hydrogen. In addition to the construction of the basic 16.95 MWp photovoltaic panel plant, the so-called farm, and the necessary equipment and infrastructure, additional equipment is required for water electrolysis, hydrogen storage and combustion. The auxiliary equipment consists of electrolyzers, hydrogen and oxygen compressors, cogeneration engines or hydrogen cells, oxygen and hydrogen storage tanks, and thermal energy storage. In order to buffer the power supply of the pumping station equipment operation with energy obtained from the photovoltaic farm, an additional 2.5 MWh battery energy storage development is provided. The process of water electrolysis is a process associated with the incidental production of thermal energy. During the sunny periods associated with the farm's electricity production and the conduct of the electrolysis process, the heat demand is minimal. However, during the periods without sunshine, there is a heat deficit. Therefore, it is planned to build an underground thermal energy storage to provide "own" heat during the remaining period.

During periods of excess electricity production, excess energy will be stored in the form of hydrogen produced by electrolysis. The hydrogen produced, after being compressed to its nominal value, will be transferred to a tank where it will await periods of energy shortage at the pumping station. If there is no external power supply or if there is an energy shortage at the pumping station, the hydrogen will be directed to cogeneration engines or hydrogen cells, which will produce electricity for the pumping station's own use. The thermal energy produced is used for the station's own needs, and the surplus can be sold to the local operator's district heating network for a fee. The pumping station can operate in primary and emergency mode. In emergency situations, the hydrogen can be transported to another pump station to generate electricity and heat.

Electricity is purchased from a local supplier at the currently negotiated unit energy purchase price. The sale of the oxygen and thermal energy produced will provide additional financing for the purchase of energy from a local supplier. This will provide approximately 7.5% of the pumping station's energy needs (Table 3).

Table 3.
Parameters of the analyzed district pumping station after upgrading in variant 3 in the basic mode

Expenditures for modernization of pumping stations	**Employee costs per year**	**Payback time**
[Expenditures and costs per 1 GWh purchase] (for the unit purchase price of energy in the first quarter of 2024)		[years]
281.7	1.5	193.7
Energy security of pumping stations	Additional financial security for energy purchases	Securing the energy needs of the pumping station
50.26%	7.51%	57.77%

Source: own study.

In an emergency situation, in the emergency operation mode of the pumping station, the revenue from the sale of oxygen and thermal energy will allow the purchase of hydrogen on the market and additional coverage of the energy needs of the pumping station. Conversion of the entire financial surplus into hydrogen will allow additional generation of up to about 0.36% of the pumping station's energy needs. Due to the low efficiency of the electrolysis process and the hydrogen combustion process, it is estimated that about 68% of the generated surplus "green" energy will be usable. In this decision model, the security of power supply to the pumping station is ensured for all days of the year. In the basic operation mode, depending on the duration of the power failure, it will be possible to cover more than 50% of the annual demand of the pumping station with energy from the plant's own photovoltaic farm. The energy generated in the basic operation mode of the pumping station in Option 3, combined with the sale of oxygen and thermal energy, will reduce the purchase of electricity by about 58%. The "green energy" generated by the farm will result in a reduction of equivalent CO_2 emissions to the atmosphere by approximately 14.600 Mg CO_2. Under the economic conditions of Q1 2024, the expected payback period for Option 3 in the primary operation mode of the pumping station is estimated to be about 194 years. The emergency operation will further extend the payback period. Due to the fact that emergency operation will be incidental work, the extension of the payback period will not be significant. Option 3 provides for a reduction in employment at SRK S.A. by approximately 5 jobs.

3.4. Option 4 - with wholesale of hydrogen

Variant 4 is similar to Variant 3 and will have very similar equipment. In determining the operating model for Variant 4, the storage of hydrogen in tanks was abandoned for economic reasons in favor of virtual storage of hydrogen in the form of cash. This is to be realized through the wholesale sale of hydrogen to a local distributor. A smaller hydrogen storage facility will be built on the site of the pumping station, with a capacity to cover only a few days of the pumping station's own energy needs in the event of an external power shortage. The reduction in capital expenditure for upgrading the pumping station by constructing a smaller hydrogen storage facility will be partially offset by additional investment in the construction of a wholesale hydrogen distribution facility. The projected capital expenditures for Option 4 are slightly lower than those for Option 3 (Table 4). The decision model for variant 4 of the pumping station upgrade includes a basic pumping station operation mode and two emergency operation modes during periods of power failure, a "short" emergency mode and a "long" emergency mode.

Table 4.
Parameters of the analyzed district pumping station after upgrading in variant 4 in the basic mode

Expenditures for modernization of pumping stations	**Employee costs per year**	**Payback time**
[Expenditures and costs per 1 GWh purchase] (for the unit purchase price of energy in the first quarter of 2024)		[years]
276.9	1.2	11.6
Energy security of pumping stations	Additional financial security for energy purchases	Securing the energy needs of the pumping station
18.25%	56.96%	75.22%

Source: own study.

In the basic operation mode of the pumping station, the energy efficiency model assumed a mechanism for maximum consumption of the produced "green" energy for own needs and sale of the produced surplus "green" energy stored in the form of hydrogen to a local distributor at wholesale prices. Since the cost of hydrogen supply is difficult to determine at this stage of the design, it was assumed that hydrogen would be sold at 60% of the current retail price. To increase energy efficiency during the non-solar period, it is assumed that energy will be purchased from a local supplier with proceeds from the early sale of surplus "green" hydrogen and oxygen. Energy will be purchased from the local supplier at the currently negotiated energy purchase price.

In the event of a power outage during full sunshine, the entire energy demand will be met by the operation of the photovoltaic system. Despite the emergency situation, the pumping station will operate in basic mode. If the power outage is prolonged or occurs during non-sunny periods, the pumping station will enter one of the emergency modes, depending on the duration of the outage. Initially, the pump station will enter a "short" emergency mode and the on-site stored hydrogen will be used to power the pump station from cogeneration engines or hydrogen cells. If all the stored hydrogen is used up and there is still no power supply, the pumping station will enter another "long" mode of operation. In this mode, the financial surplus from earlier oxygen and hydrogen sales is used to purchase hydrogen at retail prices from a local distributor. Conversion of the entire financial surplus to hydrogen will generate up to an additional 11% of the pumping station's energy needs.

It is estimated that the operation of the pumping station in baseload mode as an element of energy self-sufficiency of SRK S.A. would provide more than 18% of the annual demand of the pumping station with energy directly from the photovoltaic system and an additional 57% of the cost of the annual energy demand of the pumping station from the sale of oxygen and hydrogen (Table 4). In baseload mode, Option 4 provides financing for up to approximately

75% of the pumping station's annual electricity needs. The "green energy" generated by the plant will result in a reduction of equivalent CO_2 emissions to the atmosphere of approximately 5.000 Mg CO_2. Under the economic conditions of Q1 2024, the expected payback time for Option 4 in the pump station's primary mode of operation is estimated to be approximately 12 years. Operation in one of the emergency modes will further extend the payback period, but it should be assumed that operation of the pump station in emergency modes will be incidental. For this reason, a detailed economic analysis of operation in these modes was not carried out. Option 4 provides for 4 new non-mining jobs for SRK S.A. employees.

3.5. Option 5 - with retail sales of hydrogen

In Variant 5, all of the hydrogen produced is to be sold to the local community at the pump station's own fueling station at near-retail prices. In the baseline operation of the pumping station, the revenue from the sale of oxygen and hydrogen will be used to purchase energy to power the pumping station equipment during non-sunny periods (Howaniec et al., 2023; Wojtacha-Rychter et al., 2022). Selling the harvested hydrogen is a form of long-term storage for the excess electricity generated. Variant 5 requires, in addition to the construction of a basic photovoltaic panel plant with the necessary equipment and infrastructure, additional equipment related to water electrolysis, storage, combustion and distribution of hydrogen. The additional equipment consists of H35 or H70 standard hydrogen compressors (necessary for refueling hydrogen vehicles) and a hydrogen filling station.

In the basic mode of operation of the pumping station, during periods of overproduction of "green" electricity, the excess of this energy is stored by electrolysis in the form of hydrogen. The hydrogen produced, after being compressed to its nominal value, will be transferred to the tank, from where it will be sold at the filling station on an ongoing basis at prices close to retail prices. It is planned to leave a reserve of hydrogen to cover the electricity needs of the pumping station for several days.

Because distribution costs are difficult to determine at this stage of the design, it is assumed that the selling price of hydrogen will be 90% of the current retail price. During the non-solar period, energy will be purchased from a local supplier from the proceeds of the previous hydrogen and oxygen trading. The purchase of energy from the local supplier will be at the currently negotiated unit energy purchase price.

In case of a power outage, as in variants 3 and 4, during full sunshine, the entire energy demand will be covered by the operation of the photovoltaic system and there will be no change in the operation of the pumping station. Similarly to Variant 4, the prolongation of the power outage into a non-sunny period or the occurrence of a power outage during non-sunny periods will cause the pumping station to switch to one of the emergency operating modes. The emergency modes are the same as in Option 4. In Option 5, the financial surplus from the early sale of oxygen and hydrogen will be much greater, allowing more hydrogen to be purchased at retail prices from a local distributor than in Option 4. By converting the entire financial surplus to hydrogen, up to an additional 14% of the pumping station's energy needs can be generated. It is estimated that the basic mode of operation of the upgraded pumping station under Option 5 could finance up to approximately 95% of the pumping station's electricity needs at the unit purchase price of electricity from Q1 2024 (Table 5).

Table 5.
Parameters of the analyzed district pumping station after upgrading in variant 5 in the basic mode

Expenditures for modernization of pumping stations	**Employee costs per year**	**Payback time**
[Expenditures and costs per 1 GWh purchase] (for the unit purchase price of energy in the first quarter of 2024)		[years]
296.0	1.9	9.9
Energy security of pumping stations	Additional financial security for energy purchases	Securing the energy needs of the pumping station
18.25%	76.10%	94.37%

Source: own study.

The "green energy" generated by the farm will result in a reduction of CO_2 equivalent emissions to the atmosphere of approximately 5.000 Mg CO_2. For the economic conditions of Q1 2024, the expected payback time for Option 5 in the primary mode of operation of the pump station is estimated at 10 years. Operation in one of the emergency modes will further extend the payback period, but due to the incidental nature of emergency operation, a detailed economic analysis of pump station operation in these modes has not been performed. Option 5 provides 6 new jobs for relocated SRK S.A. employees.

3.6. Analysis of the feasibility of the developed options for upgrading mine water pumping stations

The study analyzed selected variants of power supply security and energy self-sufficiency that can be applied to the analyzed mine water district pumping station. 5 technically feasible variants of energy self-sufficiency elements discussed above were presented for analysis. Each of the variants is characterized by a different level of initial investment, a different level of security of energy supply and a different level of satisfaction of the pumping station's demand for electricity (Tables 1, 2, 3, 4 and 5). On the basis of the conducted price survey (in December 2023), the amount of current expenditures necessary for the modernization of the pumping stations in the different variants was determined, and all expenditures and costs were converted into the purchase of 1 GWh (for the unit purchase price of energy in the first quarter of 2024).

From a financial point of view, the lowest expenditure and the shortest payback period would be the implementation of variant 1 (Tables 1, 2, 3, 4 and 5). The disadvantages of this variant are the relatively low guarantee of the independence of the pumping station from external supplies and the relatively low satisfaction of the energy needs of the pumping station. The pumping station is independent from the national grid only during sunny periods, when the photovoltaic system covers up to about 99.9% of the pumping station's energy needs.

The generated energy will only cover up to about 18% of the pumping station's annual energy needs. The technical system of variant 1 can only operate in basic mode, and the only way to protect the pumping station from long-term power failure is to adjust the operation of the most energy-intensive equipment to the time of electricity generation by the photovoltaic system.

Variant 2, with battery storage of excess energy generated for its own use, provides about 99.9% security of power supply to the pumping station on all solar days, which will provide about 35% of the annual energy needs of the pumping station. The operation model of the pumping station also includes only one basic operation mode. Adjusting the operating time of the most energy-intensive equipment to the time of electricity generation by the photovoltaic system can slightly extend the independence of the pumping station from external electricity supply. The disadvantages of this option are the high cost of project implementation - more than eleven times higher than in option 1 - and the long payback period of more than 35 years. For these reasons, the implementation of this option should be considered ineffective.

The variants with storage of the generated excess electricity in the form of hydrogen obtained by electrolysis (variants 3, 4 and 5) are characterized by a high implementation potential. The case of these variants is that the initial expenditure is more than eight times higher than that of variant 1. The advantage is the possibility of long-term storage of excess energy. The functional model of these variants protects the pumping station, to varying degrees, from a long-term lack of power from the national grid on all days of the year. However, there were doubts about variant 3, which provides for storing excess energy in the form of hydrogen obtained by electrolysis and burning it completely during periods of energy shortage. This variant protects the pumping station to the greatest extent from external power shortages. Thanks to such a technical and organizational arrangement of the pumping station's operation, up to about 50% of the pumping station's annual independence from external supplies is achieved. This variant can be operated in two modes: basic and emergency mode. Functionally, the basic mode of operation of variant 3 corresponds to the "short" emergency mode of variants 4 and 5, and the emergency mode corresponds to the "long" emergency mode of variants 4 and 5. This results in a very long payback time (almost 200 years), and although this variant should be considered the safest in the event of a "blackout", its implementation in this form is inefficient. The decision to implement it can only be based on concern for the highest possible level of protection of the system against external power failure.

For economic reasons, it has been proposed to implement variants 4 and 5, which are extensions of variant 3. In both variants, the excess electricity stored in the form of hydrogen is virtually stored by selling it wholesale (variant 4) or retail (variant 5). In variants 4 and 5, for technical reasons and to protect the pumping station from "blackouts", it is planned to store a volume of hydrogen in the pumping station's own storage tanks, so that the pumping station's equipment can be supplied with energy for several days by its own cogeneration engines or hydrogen cells. In this arrangement, however, it is questionable whether it makes sense to purchase these cogeneration engines or hydrogen cells, which, in the theoretical absence of a blackout, would be installed unnecessarily and never put into operation. However, for reasons of security of energy supply from the grid, it would be advisable to consider the purchase of a mobile version of these devices, which can be used in various locations.

Settlements in hydrogen trading, as a commercial product, may make it possible to purchase more energy than was originally stored. It is estimated that a lower unit purchase price for electricity would increase the amount of energy available for purchase from hydrogen sales revenues. For example, a very likely decrease in the price of electricity of only 7 percentage points compared to Q1 2024 would make it possible, under Option 5 with retail sales of hydrogen, to meet all of the pumping station's annual energy needs with energy generated by the photovoltaic system and energy purchased from revenues from the sale of oxygen and hydrogen on the gas market. The implementation of options 4 and 5 will also ensure the operation of the pumping station in the absence of an external power supply. The only difference is the amount of financial surplus generated (Table 4 and 5) that can be converted into the eventual purchase of hydrogen. With similar capital expenditures, a comparable payback period of 12 years is obtained for Variant 4 and 10 years for Variant 5. Economically, both options are recommended for implementation, although it is noted that Option 5 provides greater operational savings. Both variants fully protect the pumping station from a lack of power supply from the national grid during sunshine periods and, depending on the size of the hydrogen reserve in its storage facilities, will secure the operation of the pumping station during the remaining period.

Table 6 shows a comparison of the degree of protection of pumping stations against loss of external power. Variants 2 and 3 have the highest level of protection of pumping stations and the largest reduction of equivalent CO_2 emissions to the atmosphere. For financial reasons, their implementation seems inefficient, but considerations of security of supply or reduction of greenhouse gas emissions may lead to the decision to implement them.

Table 6.
Comparison of the degree of protection of pumping stations against loss of external power supply by the analyzed pumping station upgrade options

Protection period	Option 1	Option 2	Option 3	Option 4	Option 5
Sunshine period	99.9%	100%	100%	100%	100%
Non-sunny period of a sunny day	-	99.9%	100%	100%	100%
Non-sunny days	-	-	32.4%	11%	14%

Source: own study.

For image and social reasons, the creation of new jobs, variants 3 and 5 are promoted. The high labor costs, the low efficiency of the electrolysis process, and the subsequent hydrogen combustion process implement option 3 appear inefficient.

All analyzed options of pumping station modernization provide electricity generation only for own consumption and require only basic external permits. It can be assumed that their implementation will not be difficult from a legal point of view.

Making investment decisions primarily through the prism of the amount of initial expenditure required to implement the project is incorrect and indicates that the perspective on the project in question is too narrow. Other factors should also be considered in determining the attractiveness of an investment. It is up to the decision maker to make the final decision to adopt one of the implementation options presented.

4. Conclusions

The main reason for investing in RES and storing excess energy generated is to reduce the Company's operating costs and protect the environment.

- Reducing the financial expenditures for the purchase of electricity, one of the largest components of the Company's operating costs, would reduce SRK S.A.'s need for budget subsidies. In addition to meeting the energy needs of the pumping stations with "green" energy and environmental aspects, the projects undertaken by SRK S.A. are aimed at maintaining existing and possibly creating new alternative jobs in the mining industry. The modernization of existing pumping stations, combined with new technologies that also serve the local community, will be a form of self-financing technical solution with a positive social and image perception.
- The challenge for SRK S.A. in the current reality is to ensure the security of energy supply in a situation of sudden shortage in the national grid. SRK S.A.'s pumping stations have a certain retention capacity, but a prolonged shutdown could cause minor or major environmental problems. Blackout as an unforeseen, unexpected and prolonged lack of electricity supply from the national grid could cause a threat to public safety or other social, economic or technical consequences. The cessation of mine water pumping would expose the operations of neighboring mines and lower-lying areas to flooding or could cause contamination of near-surface aquifers. Remediation of the resulting damage would require significant financial resources and would likely take up to several years.
- In addition to the power security aspects, participation in the activities described above will promote the development of other economic sectors through the introduction of new technologies and the possibility of rehabilitating post-mining areas and facilities. The development of SRK S.A.'s assets and the use of post-industrial areas will be positively perceived by local governments and the local community in terms of image. In the long term, the implementation of the described investments will make it possible to attract new investors to the restructured and revitalized post-mining assets and enable the creation of alternative jobs to mining.

- The planned energy security and self-sufficiency projects can have a positive impact on the local community and the economy of the Upper Silesian mining region. The projects are part of the European Union's activities in the field of sustainable development, in particular the Fair Transition process. The projects under discussion will create new markets related to modern transport and "green energy". Energy security and self-sufficiency projects are an opportunity to revitalize post-mining areas degraded by intensive mining.

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