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Original Research

Cost Rationalization of Maintaining Post-Industrial Regions

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Abstract

Maintenance of the dewatering regions of liquidated mines has a yearly cost exceeding $50 million. The results of research and forecasts conducted allow us to state that, in the dewatering plants operating in the Upper-Silesian Coal Basin, there are possibilities of reducing the general costs by 17% in the perspective up to the year 2030. However, this requires introducing the following changes and modifications: transforming some parts of stationary pumps into deep-well ones while taking into consideration the hydro-ecological restrictions; shortening the longwalls in the stationary pumps; and directing some of the pumped water to the operational mines that neighbor the longwalls of the liquidated mines. The changes presented should mostly be used in order to rationalize the costs of dewatering while maintaining the currently existing package of ecological and social benefits. These benefits are: the minimization of water hazards in the neighboring operating hard coal mines, and the protection of work places in the existing dewatering plants.

Keywords: costs rationalization, hard coal mines dewatering, post-industrial regions

Introduction

In many economies in the world the traditional branches of industry such as mining or metallurgy are finding themselves in a stage of decline: they are either being liquidated [1] or will be liquidated in the near future [2]. Along with their shrinking or liquidation, a problem of maintaining and possibly revitalizing the post-industrial areas arises [3]. In such cases it usually turns out that these industries are a burden to state budgets not only during their operation but also when they shut down, stopping economic activity [4]. This is an especially urgent problem in the case of the hard coal mining industry, in which the production is conducted underground, often under urban areas [5].

The commonly known effect of abandoning the unprotected pits is mining damage, i.e., deformation of the surface and the objects on it [6]. A less-known but equally burdensome effect of mining exploitation is the constant allocation of water in the abandoned tunnels [7]. Therefore, a need for dewatering of the liquidated hard coal mines arises [8], which forms an additional burden for the state budget in Poland and for those countries in which the hard coal mining industries are subsidized by the state.

The problem of mine liquidation and revitalization of post-industrial regions is always present in areas of mineral sources exploitation [9]. Liquidation of the mines, both underground and open-cast, brings about a problem regarding how to restore the devastated regions, or at least keep them in a regular state [10]. Along with this problem is the issue of covering the costs of these actions [11]. Land restoration is an issue not regulated by law; therefore, very often after exploitation ceases, the natural environment in the region of “nobody’s” mine is damaged without anyone to take the blame [12].

Such an example may be an iron mine in Saltburn Gill in Great Britain, which was liquidated in the year 2000. Uncontrolled water flow containing a great amount of iron was spreading to a national park, a relic of post-ice age forest.

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As metal mines in Great Britain were excluded from the jurisdiction of the Coal Authority and Mine Waste Directive, none of the owners were found responsible. No one was obliged to cover the cost of securing the area from water hazards, either. Finally, in 2005 the dewatering program of Saltburn Gill was expanded using financial support from the Environmental Agency. The cost of the program's implementation was estimated at 7.4 million pounds. However, thanks to this program, it was possible to avoid devastation of the natural environment priced in the perspective of 25 years at 10.4 million pounds. And what is most important is that it was possible to achieve ecological and social benefits on a wide scale, which would be hard to evaluate financially but would certainly add to the program's overall value [13].

Great Britain, where for many years there was a functioning hard coal mining industry, also is a great example of efficiently conducted dewatering of liquidated mines. In terms of mining industry liquidation, 55 successful programs were completed concerning the securing and dewatering of hard coal mines. The costs were borne by the Coal Agency, and the programs were compliant with strict legal regulations so that the problem of dewatering would not be disregarded.

An interesting analysis of costs and benefits that result from undertaking the revitalization of post-industrial regions also was conducted in the state of Ohio, where hard coal extraction has been conducted for 200 years. A cost-benefit analysis was made there based on revitalization influence on the increase of touristic attractiveness in the region [14]. Damages caused by mining exploitation were priced at $21 million in an area where 5 natural lakes exist [15]. The cost of revitalization, which was mostly sulfate reduction in the lake water, was estimated at $1.89 million and $4.92 million. Benefits, on the other hand, achieved due to the growth in touristic visits in the revitalized region used in NPV (Net Present Value) calculation, were estimated to be between $14.56 million (for 12 years) and $37.79 million (for 20 years) [16].

Taking into consideration the social, economic, and environmental importance of the dewatering problem, this article presents a proposal concerning cost rationalization of post-industrial region maintenance, based on the example of the Upper-Silesian Coal Basin.

Research Stages and Methods

Research Stages

The research process starts with conducting the literature study of the cost analysis in a public sector. Next, a case study of cost rationalization in an enterprise of mine dewatering located in the Upper-Silesian Coal Basin is presented. There are 15 regions of dewatering in the enterprise. Their main purpose is to minimize water hazards in liquidated hard coal mines. The research is conducted taking into consideration the research stages presented in Fig. 1, along with the research methods outlined below.

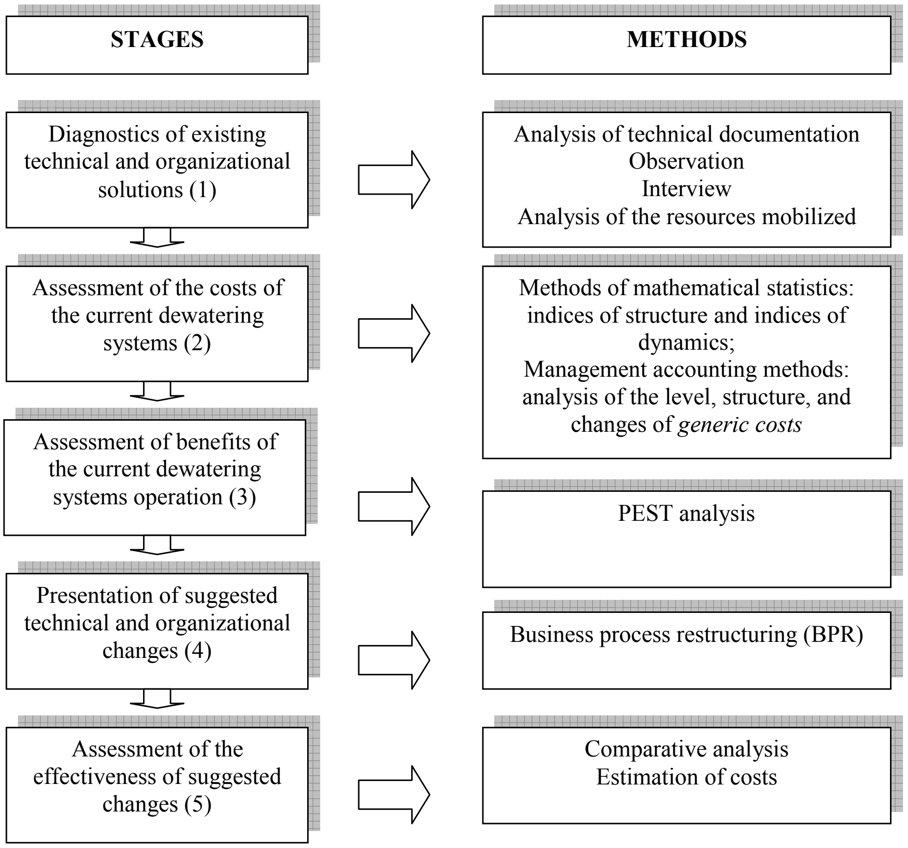

Fig. 1. The stages of the conducted research process and the research methods used.
Source: own work.

Methods

Diagnostic Methods

In the area of public finance, as well as in the social and ecological spheres, the maximizing of economic benefits is not a priority issue [17]. In these areas there are specific, individualized operational objectives to meet, such as meeting social needs or the protection of the natural environment [18]. However, the rationality of spending public funds obliges each decision-maker to act carefully and effectively [19]. The tool that is supporting the decision-making process in the areas mentioned is the economic cost analysis adjusted to public, social, and ecological needs. Thanks to the use of this tool, it is possible to indicate and then rationalize such costs and at the same time achieve the social and ecological objectives [20].

In the research conducted, the cost analysis is preceded by a short diagnosis of the existing technical-organizational solutions (1). Its result is the description of the essence of the dewatering problem as well as the dewatering methods used. Next is the unit and total dewatering cost analysis, calculated in the examined regions in the years 2006-10 (2) [21]. Its result is the identification of areas generating costs and an indication of directions for modification of the current technical-organizational solutions that allow cost reduction. In the research conducted, the priority is to maintain the current benefits of dewatering; therefore, the next research stage is their indication and a short outline of their characteristics (3), made using the PEST analysis (political – aconomic – social – technological). PEST is a method used in strategic management in order to determine the influence of particular macro-environment segments on the enterprise's functioning. On the basis of a multi-aspect diagnosis of the existing dewatering systems and BPR method (business process reengineering), this stage lists the technical–organizational modifications suggested in the functioning regions (4) [22, 23]. The research ends with a comparative analysis of cost level before and after the implementation of the proposed changes (5). A detailed methodology of cost forecasting after the implementation of modification is presented below.

Forecasting Methods

When creating the cost forecast for the perspective up to the year 2030, the following set of general assumptions was adopted:

1. The forecast is based on a generic cost account, which includes salaries as well as energy use, external services, materials use, amortization, and other generic costs.
2. The forecast uses individual (separate for each region) econometric regression models, built on the basis of historical analysis of generic costs in the particular regions in the period 2005-10.
3. The basic parameter shaping the unit cost of dewatering was considered to be the quantity of water pumped, which is forecasted individually for each region on the basis of historical quantity of water pumped in 2005-10.
4. The information used for planning the investment outlays was gathered in the working mines, as well as information about materials for the realized investments in the examined dewatering regions.
5. In order to estimate changes in cost as an effect of implementing the particular modifications, each region is analyzed separately in regard to the planned period of investment outlays return. Such changes are analyzed in the context of their influence on investments of a similar character realized previously in order to avoid underestimation or overestimation.

In the forecasts of total cost, the basic model characterizing this cost [24] takes into consideration a division into variable cost, the value of which depends on the quantity of pumped water, and fixed cost borne in the regions regardless of the quantity of the water drained [25]. The following are included in the variable cost: salaries, energy, and materials. The fixed cost included foreign services (repairs and maintenance), taxes and fees, and other generic costs [26]. Additionally, the model was supplemented with a variant concerning modifications of the existing systems by including the value of investment necessary for their implementation. The form of both variants is presented below:

$$K_C^0 = k_{zp} \times q_p + K_s \tag{1}$$

$$K_C^{BPR} = k_{zp}^{BPR} \times q_p^{BPR} + K_S^{BPR} + N_I \tag{2}$$

...where:

K_c^0 – total cost in the non-investment variant

K_c^{BPR} – total cost in the variant concerning the modification of the existing solutions

k_{zp} – coefficient characterizing the level of variable unit costs in a particular region

q_p – forecast of the quantity of drained water

K_S – value of fixed costs characterizing a particular region

N_I – value of investment necessary for conducting the modifications

The estimation of the coefficient of variable cost and the values of fixed cost in the non-investment variants is based on the historical monthly data from 2005-10. The structure of costs is maintained in that period. In the variant assuming the modifications of the dewatering systems, the coefficients of variation and fixed cost are calculated anew, taking into consideration the changes occurring in the particular types of costs (e.g., the reduction of employment influencing a change in salary).

Additionally, in both variants, taking into account the change of monetary value over time and the long-term horizon of the forecast, the value of particular costs is updated by including the coefficient of inflation (for salaries, materials, foreign services, other generic costs) in the forecasts for the years 2011-30. The coefficient of changes in electric energy prices up to the year 2030 assumed in the Polish Energy Policy (for electricity) is updated as well.

The quantity of drained water is forecasted based on the historical data from the particular regions in the years 2005-10. Three scenarios [27] of the forecast are considered:

I. the minimum scenario, in which the lowest quantity of the water drained annually from a given region is used
II. the average scenario, in which the average quantity of the water drained annually from a given region is used
III. the maximum scenario, in which the maximum quantity of the water drained annually from a given region is used

The basis for determining these variants is data from 2005-10.

As shown above, each of the 14 examined regions has an individual forecast of costs up to 2030 in three scenarios (minimum, maximum, and average). The regions in which the modifications of dewatering systems are designed have six forecast scenarios: three for the non-investment variant (as a reference point) and three for the variant with BPR. The sum of total costs in particular regions enable us to determine the total costs of dewatering for the liquidated mines in the Upper-Silesian Coal Basin in both variants. The difference between those variants determines the value of cost reduction achieved thanks to the planned technical and organizational changes.

In this study, in order to objectify the results and to maintain the clarity of the considerations, only the maximum scenario is presented. This scenario assumes the highest level of variable pumping cost in the regions. The reduction of cost determined by using this scenario is lower than in the average and minimum scenarios. It is determined using the following:

$$R_{KC} = \sum_{t=1}^{n} K_{Ct}^{0} - \sum_{t=1}^{n} K_{Ct}^{BPR}$$

...where:

R_{KC} – reduction of total dewatering costs in the Upper-Silesian Coal Basin
K_{Ct}^{0} – total cost in the non-investment variant
K_{Ct}^{BPR} – total cost in the variant concerning the modification of the existing solutions
t – particular regions of dewatering (t=1, 2, …, 14)

Results

Diagnosis of the Existing Technical-Organizational Solutions

The Essence of the Dewatering Problem

In the region of the Upper-Silesian Coal Basin in Poland, there are 4 functioning coal enterprises which currently consist of 27 hard coal mines. Their existence provides employment for over 85,000 workers, and extraction of hard coal guarantees energy independence for Poland [28].

In 1990-2005 a deep hard coal mining restructuring was conducted in Poland. Its basic results were employment decrease, improvement in effectiveness of extraction, and liquidation of unprofitable mines [29]. The liquidation actions concerned both organizational issues, one of which is the archiving of technical, measurement-geological, human resource, and payroll documentation. Another issue tackled by the liquidation was the settling of claims of the ex-workers of liquidated mines, as well as technical actions, including: liquidation of surface infrastructure objects, using the assets of liquidated mines, revitalization of post-mining areas, and repairing mining damage. Most of the aforementioned actions have been completed until now [30].

However, as a result of the extraction conducted in the past, the liquidated mines contain hundreds of kilometers of mining pits that are close to the working mines still extracting coal from longwalls. The junctions between the liquidated and functioning mines are direct, in the form of mining passages, post-extraction pits, and shafts. There are also indirect connections, such as thin coal layers, water-bearing faults, and permeable rocks.

The resistance of horizontal and vertical rock pillars is limited, and they start to break after the critical values are exceeded. The direct junctions enable two-way water flow between the pits of the neighboring mines. Consequently, they cause water infiltration among the rocks in the working mines and regions of the liquidated mines. The flow intensity depends on, among other factors, geological setup, hydrogeological parameters, hydrostatic pressure, and mining conditions of the exploitation conducted in the past. In the case of a significant water rise and accompanying increase of hydrostatic pressure, the direct junctions may cause a rise or rapid increase, in big quantities, of water flow into the empty spaces, like the pits of a neighboring mine [31].

In the pits of the liquidated mines, favorable conditions are appearing for the underground water gathering in tanks, which may be about several million cubic meters in capacity. Each of the pits may constitute a threat for the neighboring working mines and for the objects on the surface after water filling [32]. A complex hydro-geological situation then forces the necessity of constant mine dewatering after liquidation [33]. The remaining method of protection of the working mines from water hazards is then to clear junctions between the mines, that is, draining water from the area of the liquidated mine or building dams and hydro-insulation plugs.

Water flows to the mine in variable quantities from orogens, surface reservoirs, and in the course of technological processes. A huge quantity of inflowing water is rather varied [34]. Some of the mines, e.g. salt and clay mines, can be completely dry. In the Upper-Silesian Coal Basin, there is an inflow of 0.3 to 28 m^3/min noted in hard coal mines, in the Lower-Silesian Coal Basin from 0.6 to 12 m^3/min, in copper mines from 3 to 15 m^3/min, in zinc-lead mines from 10 to 65m^3/min, in iron mines from 0.7 to 20 m^3/min, in open-cast lignite mines from 21 to 110 m^3/min, and in sulfur mines from 15 to 40 m^3/min [35].

In light of the above information, protecting working mines from water hazards should be a prior objective to which all the entities connected with the mine liquidation should be subordinated. The cost of system maintenance in the liquidated mines should also be taken into account as they are covered by public sources. However, the public

Table 1. The yearly quantity of water pumped in the stationary and deep regions in the Upper-Silesian Coal Basin in 2002-10 (in million m³/year).

Region No.	Year								
	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	15.22	12.05	9.98	9.05	10.63	12.36	12.90	11.80	15.67
2	16.23	13.78	12.62	12.45	12.50	13.26	12.93	13.96	16.30
3	16.47	14.45	16.24	16.86	17.26	15.34	13.97	12.87	13.00
4	7.29	7.13	7.36	7.46	7.87	8.69	8.22	7.94	8.40
5	1.18	1.23	1.28	1.23	1.13	2.65	2.61	2.52	2.80
6	-	0.72	1.51	1.54	1.57	1.53	1.50	1.57	2.00
7	6.50	6.41	6.23	6.00	5.61	5.09	4.91	5.01	5.00
14	3.24	3.34	3.17	2.98	2.77	-**	-	-	-
Total stationary	62.89	55.77	55.22	54.59	56.57	58.92	57.04	55.67	63.17
8	4.13	3.74	2.51	2.51	3.45	2.95	1.95	1.49	0.05
9	7.91	7.17	6.78	5.48	5.34	5.63	6.07	5.94	4.50
10	1.63	2.97	2.81	2.70	2.54	2.45	2.76	2.57	2.90
11	3.31	3.11	2.82	2.83	3.02	3.06	3.15	3.06	3.20
12	-	-	-	-*	1.30	0.51	0.31	0.86	0.56
13	-*	1.99	4.71	5.52	5.30	4.53	5.22	5.20	5.40
14	-	-	-	-	-**	2.54	2.99	2.79	3.00
15	3.16	3.07	3.10	3.12	3.08	3.17	3.23	3.26	3.10
Total deep	20.14	22.05	22.73	22.16	24.03	24.84	25.68	25.17	22.71
Sum	83.03	77.82	77.95	76.75	80.6	83.76	82.72	80.84	85.88

*water retention in workings
**region was transferred into deep pump in 2007, before it was working as a stationary region
Source: own work based on the accounting data of the examined enterprise.

cannot make decisions about the dewatering cease or the dewatering method used.

The Dewatering Methods Used

The two basic dewatering systems used for pumping mine water are stationary and deep systems. The first of the systems requires a significant number of employees and an extended network of dewatered pits. The second system is practically non-operated. The stationary well pumps are very sensitive to water penetration, which may cause the pump engines or electrical switching station to flood, resulting in the pump's stoppage. Deep-well pumps have engines cooled by water, and they function under water. Switching stations, on the other hand, are located on the surface, which considerably facilitates their functioning and servicing. Despite some undeniable advantages of deep-well pumps, they cannot be used everywhere because of technical and hydro-geological circumstances. These are also much more costly solutions for the stage of bearing investment outlay.

Despite using the dewatering systems presented above, water flow to the liquidated mines is not indifferent for the natural environment [36]. The level of ground water is becoming lower, and the direction and rate of water filtering is changing. This may cause local occurrences of mechanical scouring, colmatage, and erosion. The consequences of these occurrences are non-continuous deformations of the surface in the form of landslides and mining subsidence [37].

In the examined regions, deterioration of water quality may also be observed. In many places a flow of acidic mining water may appear, with low pH levels (even below 3.0) and high contents of iron (up to 2,200 mg/l) and sulfates (up to 8,800 mg/l) [38]. As a result of the decrease in the underground water level, the processes of oxidation of inorganic compounds are intensified, causing precipitation of iron and manganese oxides [39]. This, on the other hand, results in the increase of the mobility of heavy metals released to the groundwater. It limits the possibilities of utilizing water. In the course of water damming, further pollution of water occurs because of the phenomena of dissolving oxidization

Table 2. Employment in the stationary region of dewatering in 2007-10.

Region	Year						
	2004	2005	2006	2007	2008	2009	2010
Total	568	641	622	610	605	645	620
1	207	209	198	204	200	207	180
2	112	111	116	108	99	113	113
3	66	69	66	65	63	62	67
4	109	127	127	120	122	119	115
5*	0	0	0	0	0	0	0
6	55	61	55	49	46	55	57
7	19	64	60	64	75	89	88

* region is serviced by the workers employed in pump No. 6

Source: own work based on the data of the examined enterprise.

products of sulfide minerals. Maintaining the level of groundwater on a safe level weakens the mechanical qualities of the rocks as well [40].

In the characterized Upper-Silesian Coal Basin, there are currently 15 dewatering regions of the liquidated mining enterprises. In 7 of them stationary pumps are used (the regions marked from 1 to 7) and the other 8 use deep-well pumps (the regions marked from 8 to 15). The quantity of water pumped by these pumps in 2002-10 is presented in Table 1.

It follows from the data included in Table 1 that the quantity of water pumped in 2002-10 varied from 76 to 86 million cubic meters. The differences mostly resulted from a different precipitation level and water penetration into the ground, which increases the level of subsoil water [41]. The deep regions drained off from 24% to 32% of the total water pumped. Consequently, they were less burdened than the stationary regions.

The existing regions were supplied with the necessary technical equipment for their functioning. In the stationary regions this equipment mostly consisted of the underground dewatering infrastructure. In of the deep regions it was a deep-well pump equipped with a sufficient number of aggregates. Employment in the stationary regions in 2007-10 is presented in Table 2. In all, the deep regions' employment level was definitely lower than or equal to anywhere from 2 to 8 people.

According to the data in Table 2, employment over the whole analyzed period was stable. A bigger reduction occurred in region 1 in 2010, which was caused by the transfer in progress from a stationary into a deep region.

Ecological, Social, and Economic Benefits of the Maintenance of Dewatering Systems

The benefits of dewatering the liquidated hard coal mines include the following aspects: ecological, social, economic, and political [42]. However, in the ecological and social aspects, the benefits are mostly defined in a context of preventing serious hazards for the environment and society [43].

Conducting mining exploitation and liquidation of coal mines causes water balance disturbance in the environment. As a result, the level of underground water is decreased. Unnatural water basins are created, and uncontrolled flows of underground water occur [44]. As a result of water transfer, there may be also deterioration of quality, pH decrease, and iron and sulfate content increase [45]. The water gathering in the empty pits may also cause free flows that are dangerous for people and objects on the ground. Finally, these practices create a threat of flooding for the neighboring working mines, posing a danger for their equipment and mining crews.

Changes in the water environment have an unfavorable influence on water fauna and flora [46]. Moreover, they provide the possibility deformation of the surface as well as the creation of subsidence basins. This, in turn, triggers damages in the technical infrastructure as well as in buildings and edifices.

The ecological benefits of dewatering, besides avoiding the aforementioned hazards, also include the decrease of underground saline water quantity, usually drained into the surface water [47]. Dewatering results in improvement of the surface water.

Social impacts of hard coal mine dewatering in the first turn include avoiding water hazards in the working hard coal mines. Because of dewatering, the crews working underground are better protected from the uncontrolled underground water penetration and longwall flooding [48]. Thus, the dewatering system of the liquidated mines contributes to the improvement of work safety in the Polish hard coal mining industry [49].

A specific social side benefit also is the provision of workplaces in the dewatering plants for the redundant employees of the liquidated mines. On one hand, it allows for the securing of qualified staff for the dewatering plant, and on the other hand, it facilitates mitigating the restructuring effects in the Polish hard coal mining industry.

Consequently, it is a benefit not only of a social nature but also a political one.

The possible economic benefits include commercial use of the water drained from the mines [50]. Unfortunately, water quality significantly decreases due to the exploitation conducted, so its use is impossible in most regions. Table 3 shows the characteristics of the water pumped in the particular water regions presented, adopting the following categorization:

class 1 – water of very good quality, without the signs of human influence

class 2 – water of good quality, in which the amounts of physicochemical elements are increased due to the natural processes occurring in the underground water

class 3 – water of satisfactory quality, in which the amounts of physicochemical elements are increased due to the natural processes occurring in the underground water and slight influence of human activity

class 4 – water of unsatisfactory quality, in which the amounts of physicochemical elements are increased due to the natural processes occurring in the underground water and visible influence of human activity

class 5 – water of bad quality, in which the amounts of physicochemical elements prove to be a significant influence of human activity

According to the data from Table 3, the majority of underground water pumped from the hard coal mines is of unsatisfactory quality. Currently, for commercial purposes, only 5.8% of the water pumped is used. From region 1, in which water is the purest, water is delivered to households. From regions 3, 4, 5, and 7, water is used for industrial purposes in the neighboring power plants and coking plants. For further use of the water pumped it is necessary to bear the additional investment outlays and break the local monopoly for water supply to the households [51].

Retrospective Evaluation of Operating Costs of the Current Dewatering Systems

Total and Unit Costs

Significant costs are borne of the need to maintain the dewatering systems. At the moment they are covered by the state, as the liquidated mining plants were the state's properties. However, these costs should be, if possible, rationalized according to the principles of economy in public finance [52]. Therefore, the actions were aimed at the reduction of dewatering costs that form an additional burden for the state budget [53]. The level of dewatering costs in the years 2006-09 in the particular regions is presented in this section. It constitutes a starting point for conducting the cost analysis of the technical and organizational upgrades suggested later in the article, which have been implemented since the year 2010.

Figs. 2 and 3 present the level of total costs borne in the stationary and deep areas in 2006-09.

Table 3. Classes of water pumped in the particular regions, together with their percentage shares in total pumped water.

Regions	Water class	Share in the total water pumped [%]
1	2	9.15
	5	5.45
2	4	17.26
3	3	15.92
4	5	9.82
5	5	3.12
6	5	1.94
7	4	2.15
	5	4.04
8	3	1.84
9	3	7.35
10	3	3.18
11	4	3.79
12	5	1.07
13	5	6.43
14	5	3.46
15	5	4.03

Source: own work based on the accounting data from the examined enterprise

In the stationary regions, the total costs systematically increased over time, which was related mainly to the increase of salaries and prices of electricity, as well as materials and resources used for the modernization and development of the dewatering infrastructure. In the deep regions, the costs were on the level of $7-8 million. However, in 2007 a clear and significant rise occurred, which was related to the exchange of aggregates. The cost of one aggregate, depending on the technical parameters, was between $0.3 and $0.6 million.

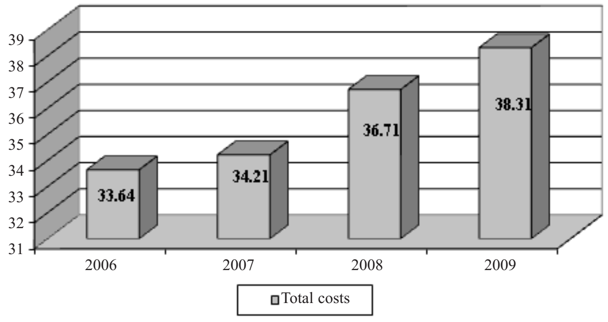

Fig. 2. Total dewatering costs in stationary regions in 2006-09 (in millions of dollars).

Source: own work based on the accounting data of the examined enterprise

The analysis of total costs of the region's maintenance shows that the operating costs of deep-well pumping stations is significantly lower than that of stationary pumps, even after taking into consideration that the latter pumps 2-3 times more water. The total cost is confirmed by the analysis of unit cost of pumping, the results of which are presented in Figs. 4 and 5.

In 2006 and 2008-09 the unit costs of one cubic meter of dewatering were twice that of the deep-well pumps. Even in 2007, with significantly increased investments, the unit cost of the deep-well pumps did not exceed the unit cost of the stationary pumps.

Generic Costs

Due to a different specificity of stationary and deep regions, the two are dominated by different elements of generic costs. Historic analysis of generic costs, conducted in 2006-10, shows that in the stationary regions the generic costs were dominated by the following components: energy use, salaries, and foreign services. The cost structure was supplemented by amortization as well as fees and taxes.

On the other hand, in the deep regions the highest share of generic costs was clearly held by the energy use and amortization. Salaries and foreign services only supplemented this element. In both systems, other generic costs, the shares of which usually do not exceed 5%, have to be considered insignificant.

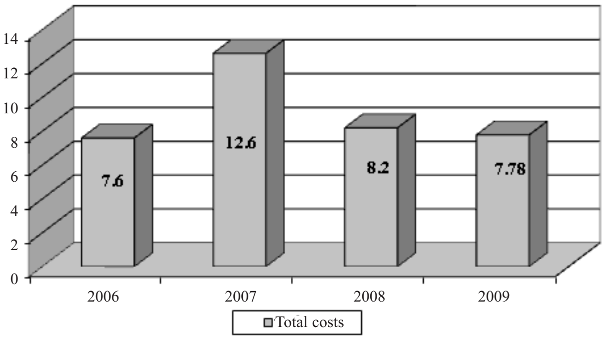

Fig. 3. Total dewatering costs in deep regions in 2006-09 (in millions of dollars).
Source: own work based on the accounting data of the examined enterprise.

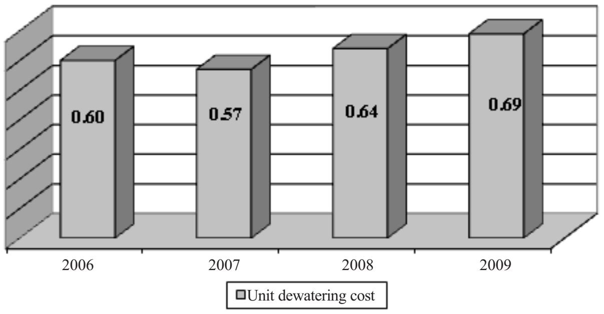

Fig. 4. The average unit cost of dewatering in stationary regions in 2006-09 (in dollars/m^3).
Source: own work based on the accounting data of the examined enterprise.

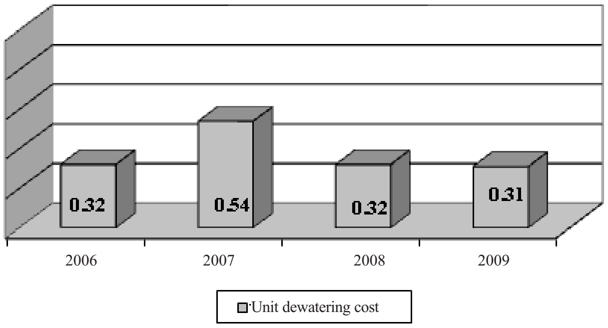

Fig. 5. The average unit cost of dewatering in stationary regions in 2006-09 (in dollars/m^3).
Source: own work based on the accounting data of the examined enterprise.

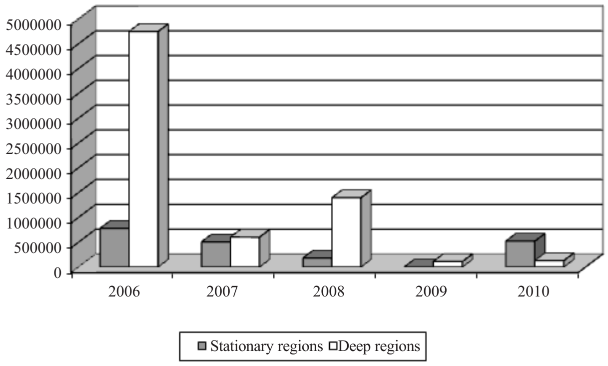

Fig. 6. Investment expenditures in 2006-10, taking into consideration stationary and deep regions (in US dollars).
Source: own work based on the accounting data of the examined enterprise.

Investment Expenditures

In order to conduct a full analysis of the maintenance costs of both regions, it also is good to compare the level of investment expenditures necessary for their maintenance and development (Fig. 6).

In the deep regions, the highest investment expenditures occurred in the first three years of analysis, which is related mainly to the purchase of deep-water units. In the last two years the expenditures in these regions decreased significantly. In the stationary regions, the investment expenditures were significantly lower and experienced an increase in 2007 and 2010, which is mainly related to the need for rebuilding region 1 and adjusting it to the needs of deep pumping stations. However, it should be emphasized that the high investment expenditures in deep-well pumps were incidental and allowed an efficient and low-cost pumping of water in the perspective of the next several dozen years.

Total Unit Costs and their Determinants in the Stationary and Deep Regions

The range of unit costs is significant in both stationary and deep-well pumps. The average value of these costs,

Table 4. Average unit costs in 2006-09 for stationary regions together with cost determinants.

Rank	Region number	Cost value [USD/m^3]	Determinants	Characteristics of determinants
1	3	0.28	high water inflow, one pumping station of the main dewatering	In this region there is one stationary dewatering system maintained with one main pumping station of the main dewatering on the level of 270, and there are about 7.3 km of workings with a yearly water inflow amounting to 14.86 million m^3 in 2006-09.
2	1	0.42	simple structure of workings, high water inflow	Water inflow in 2006-09 equaled 47.70 million m^3 in region 1 and 52.65 million m^3 in region 2. In region 2 the unit cost was higher than that in region 1 by 41%. This was caused by the fact that the structure of region 2 is much more complicated than the structure of region 1. In region 1 on the level of 210 m, there are two stationary pumps as well as a functioning pumping station, as well as, among others, 5,690 m of longwall maintained with two shafts. In region 2 there are two functioning stationary systems of dewatering, which are required to service 15,365 m of workings (over 2.5 times more than in region 1), 4 shafts, 2 mini-shafts, and 4 stationary pumps.
3	2	0.59	average complicated structure of workings, high water inflow	
4	4	0.79	average complicated structure of workings, average water inflow	The system consists of two main pumps of the main dewatering on the levels of 575 m and 825 m, 3 pumping stations, and 3 shafts with longwalls 11,450 m long.
5	7	1.17	complicated structure of workings, expanded infrastructure of pumping stations	In this region there are two maintained shafts of a total depth of 1,399.4 m, longwalls on 6 levels of a total length of 8,671 m, and 3 pumps of the main dewatering.
6	5	1.32	large depth of pumping, wide structure of workings	The water is pumped from a very deep level (two pumps of the main dewatering on the level of 630 m and 790 m). There is also 6,590 m of longwall maintained and 1 shaft 838.1 m deep, which has influence on a high cost of region maintenance however, water inflow is rather low, and in 2006-09 it totaled 8.91 million m^3.
7	6	1.85	low water inflow, two pumps of the main dewatering	With a relatively low water inflow, equaling about 1.54 million m^3 in 2006-09, it was necessary to maintain two pumps of the main dewatering on the levels 500 m and 650 m, one pumping station 601 on a sublevel 760 m, and about 17 km of workings.
8	14	2.23*	water retention in abandoned workings, reconstruction of pumps	In this period only 1.15 million m^3 of water wast pumped using the stationary system due to conducting the water retention in the abandoned workings from May to August 2009, connected with the construction of a deep-well pump in this region. Although the quantity of pumped water decreased, the cost of maintenance had to be borne as well as the costs connected with building the deep-well pump, such as: shaft adaptation for the deep-well pump, equipment purchase for the deep-well pump, reconstruction of the electric grid, network system development, renovation of water-pipes, establishment, and installations. The total cost of additional works amounted to $0.35 million.

*until the year 2007, in connection with the region transfer into a deep pump
Source: own work based on the accounting data from the examined enterprise.

together with the basic determinants of their amounts, is ranked in Table 4 for the stationary regions and in Table 5 for the deep regions.

According to the above information, the unit cost depends mostly on the quantity of water pumped as well as on the technical factors, the most important of which include: complexity of the dewatering system, number of pumps and pumping stations, length of longwalls, depth of pumping, and number of shafts and mini-shafts. The lowest costs are specific for the regions of high water inflow and non-complicated structure of dewatering. Table 5 includes the ranking together with the determinants of unit costs for the deep-well pumps.

According to the above information, the periodical radical changes in costs in the deep regions are mainly caused by investments linked to the purchase of aggregates with fittings. The fluctuations of unit cost are also influenced by changes connected with the quantity of water pumped, which are caused by the water accumulation in the particular regions. Without the inclusion of investment outlays, the unit dewatering cost did not exceed 0.44 dollar/m^3.

Table 5. Average unit costs in 2006-09 for deep regions together with cost determinants.

Rank	Region number	Cost value [USD/m^3]	Determinants	Characteristics of determinants
1	9	0.19	purchase of aggregates	In region 9, in 2006 the unit cost equaled 0.34 dollar/m^3, in 2007 it amounted to 0.14 dollar/m^3, in 2008 0.11 dollar/m^3, and in 2009 it was 0.17 dollar/m^3. The rise of unit cost in 2006 was affected by the purchase of 4 aggregates in the amount of $0.97 million.
2	13	0.34	purchase of aggregates	In region 13, in 2006-09 the unit cost was maintained at a stabilized level (0.24 dollar/m^3 in 2006, 0.24 dollar/m^3 in 2008, 0.31 dollar/m^3 in 2009). In the year 2007 it increased to the level of 0.62 dollar/m^3, which was induced by the purchase of 3 aggregates in the amount of $1.27 million.
3	8	0.36	purchase of aggregates, water accumulation	In region 8, in 2006 the unit cost amounted to 0.23 dollar/m^3, in 2007 it was 0.32 dollar/m^3, in 2008 0.68 dollar/m^3, and in 2009 0.36 dollar/m^3. A significant cost increase in 2008 was caused by the purchase of 1 aggregate with fittings in the amount of $0.83 million. The realization of the purchase, together with the decrease of pumped water (due to accumulation) at the same time, more than doubled the unit cost.
4	15	0.37	purchase of aggregates	In region 15, in 2006-09 the unit cost remained at a comparable level (0.32 dollar/m^3 in 2006, 0.28 dollar/m^3 in 2007, 0.34 dollar/m^3 in 2009). In 2008 it increased to the level of 0.55 dollar/m3, which was caused by the purchase of 1 aggregate with fittings in the amount of $0.56 million.
5	12	0.42	purchase of aggregates, water accumulation	In region 12, in 2006 the unit cost equaled 0.42 dollar/m3, in 2007 0.39 dollar/m^3, in 2008 0.50 dollar/m^3, and in 2009 it was 0.38 dollar/m^3. In 2006, this region had 1 aggregate with fittings purchased in the amount of $0.27 million. The cost of region maintenance in 2006-09 amounted to $1.23 million, including $0.55 million in 2006, in 2007 $0.20 million, in 2008 $0.16 million, and in 2009 it was $0.32 million. In 2007-09 there was no purchase of aggregates and equipment; however, because of water accumulation completed on 17-03-2009, there was a decrease in the quantity of water pumped. In 2006 1.30 million m^3 of water was pumped, in 2007 0.51 million m^3, in 2008 0.31 million m^3, and in 2009 2.98 million m^3. In connection with the completion of water accumulation in March 2009, the costs of regional maintenance increased.
6	11	0.41	purchase of aggregates	In region 11, in 2006-09 the unit cost was at a similar level (0.32 dollar/m^3 in 2006, 0.26 dollar/m^3 in 2008, 0.30 dollar/m^3 in 2009). In 2007 it almost doubled to the level of 0.77 dollar/m^3, which was caused by the purchase of 2 aggregates in the amount of $1 million.
7	10	0.58	purchase of aggregates, overhaul, and modernization	In region 10, in 2006 the unit cost equaled 0.5 dollar/m^3, in 2007 1.24 dollar/m^3, in 2008 0.24 dollar/m^3, and in 2009 it was 0.37 dollar/m^3. In 2006 this region realized a one-time ditch overhaul and repair project in the amount of $0.41 million. In 2007 there were 3 aggregates with fittings purchased, and there was redundant equipment liquidated in the shaft, an operational platform was built in the shaft along with the reinforcement of supporting construction for building the new aggregates for a total amount of $1.62 million (including aggregates of $1.39 million). The investments above induced a significant unit cost increase in 2006-07.
8	14	0.63	completion of works connected with transferring to a deep pump	In region 14, in 2007 the unit cost equaled 1.15 dollar/m^3 however, in 2008 it decreased to the level of 0.54 dollar/m^3, and in 2009 0.48 dollar/m^3. A deep-well pump was launched in August 2007, and in that year the last costs connected with dewatering system alteration were borne in the amount of $0.32 million.

Source: own work based on the accounting data from the examined enterprise

Results of the Retrospective Analysis of Economic Costs as a Premise for Technical-Organizational Changes

It clearly follows from the conducted analysis of dewatering system maintenance in the Upper-Silesian Coal Basin that there is a necessity to retain all the previous benefits of social and environmental nature [54, 55]. The possibility for improving effectiveness and unburdening the state is mostly embedded in the cost reduction of the already functioning dewatering regions [56]. This, in turn, is possible with consideration of the following actions:

- transferring stationary pumps into deep-well pumps with the inclusion of hydro-geological conditions
- shortening the maintained pits in the stationary pumps
- directing some of the pumped water to the working mines neighboring the pits of the liquidated mines

Table 6. The comparison of total dewatering costs in a no-investment option and in the one including BPR in 2011-30 (in thousands of dollars).

Specification	Year						
	2011	2012	2013	2014	2015	2016	2017
No investment	45,285	46,544	46,679	46,638	46,942	47,854	48,052
After BPR	46,907	51,411	50,776	45,701	37,190	37,856	37,846
Difference	-1,622	-4,867	-4,097	937	9,752	9,998	10,206
Specification	Year						
	2018	2019	2020	2021	2022	2023	2024
No investment	49,145	50,448	51,752	51,995	52,279	52,564	52,850
After BPR	38,638	39,220	40,315	40,530	40,745	40,962	41,180
Difference	10,507	11,228	11,437	11,465	11,534	11,602	11,670
Specification	Year						
	2025	2026	2027	2028	2029	2030	Total
No investment	53,139	53,311	53,486	53,662	53,840	54,019	1,010,492
After BPR	41,400	41,519	41,640	41,762	41,885	42,009	839,500
Difference	11,739	11,792	11,846	11,900	11,955	12,010	170,992
Specification	Year						
	2011	2012	2013	2014	2015	2016	2017
No investment	153,517	157,785	158,242	158,104	159,135	162,227	162,897
After BPR	159,017	174,285	172,132	154,928	126,077	128,334	128,299
Difference	-5,500	-16,500	-13,890	3,176	33,058	33,893	34,598
Specification	Year						
	2018	2019	2020	2021	2022	2023	2024
No investment	166,604	171,021	175,442	176,265	177,226	178,192	179,164
After BPR	130,984	132,957	136,670	137,397	138,128	138,864	139,603
Difference	35,620	38,064	38,772	38,868	39,098	39,328	39,561
Specification	Year						
	2025	2026	2027	2028	2029	2030	Total
No investment	180,141	180,727	181,319	181,916	182,519	183,127	3,425,570
After BPR	140,346	140,751	141,160	141,573	141,991	142,412	2,845,908
Difference	39,795	39,976	40,159	40,343	40,528	40,715	579,662

Source: own work

A wide-scale analysis of the existing technical-organizational solutions would facilitate the creation of several options for a dewatering system modernization in the Upper-Silesian Coal Basin. These include:

1. Completing the transfer of region 1 from a stationary to a deep well, resulting in employment reduction from 180 to 10 workers
2. Simplifying the construction of stationary dewatering system No. 3, enabling employment reduction from 67 to 40 workers
3. Closing some pits in stationary region 5
4. Moving water from stationary region 6 to a neighboring working mine and reducing employment to 10 workers
5. Transferring region 7 into a newly launched private mine
6. Liquidating the deep-well pumps Nos. 8 and 9 and directing water to a modernized pump No. 1
7. Liquidating pump No. 11 and transferring the water drained by it to pump No. 10

The actions presented above are possible concerning both technical and hydrological issues. They also enable maintaining the contemporary benefits stemming from dewatering of the liquidated mining plants.

Economic Effects of the Suggested Technical-Organizational Changes

As mentioned previously, the proposed changes in the current dewatering systems allow maintenance of a defined benefits package of ecological and social nature. Therefore, in the effectiveness account, the cost side is mostly subject to changes [57].

The scale of cost reduction in a maximum variant, in which there is a maximum quantity of water pumped yearly from a particular region, in a perspective up to the year 2030 is presented in Table 6.

According to the data in Table 6, during the first three years the difference between a non-investment option and the option concerning technical-organizational changes was negative. This was presented by the results from the increased investment outlays for conducting the modifications. The return rate of outlays borne equaled 5 years. Finally, in 2030 the project brings savings in the amount of $170,991,000, which constitutes 17% of the total maintenance costs of currently functioning dewatering regions.

Discussion and Conclusions

This article is mostly focused on the economic aspects of the issue presented, as currently it is a basic piece of evidence for introducing changes into the existing dewatering systems. The need for reducing the dewatering costs of the mines being liquidated comes mainly from an urgent need to reduce public expenditures and search for budget savings. Therefore, the public and economic aspects of the conducted analysis are presented in the foreground. One may suspect that, without this evidence, the continuation of dewatering would not be possible unless the changes and modifications suggested in the article are implemented.

Such an approach has an important restriction. First of all, the social and ecological aspects are considered to be less important in the analyses and considerations conducted. They are not a priority and serve only as boundary conditions for designing the changes and technical and organizational modifications. However, it must be emphasized that they were taken into consideration in the evaluation and analysis conducted in the form of the assumption that the existing social and ecological equilibrium should not be deteriorated. Thus, it was decided that the package of non-economic benefits would be maintained, while the operating costs of the dewatering regions would be reduced. The advantage of such an approach is an attempt to reconcile the urgent economic and public needs as well as to search for the optimal technical and organizational changes.

The analysis of economic costs orients the decision makers' thinking toward two key aspects. First, it forces them to identify the benefits stemming from the adopted solutions and to make an attempt to value these benefits. Second, it leads to estimating the economic costs of realizing these undertakings in a public, social, and ecological sphere. The results of the comparative analysis are a starting point for considerations of the purpose, rationality, and effectiveness of using financial sources in the areas where a maximization of economic benefits is not a priority.

In this article, the analysis of economic costs method serves the dewatering costs rationalization of liquidated hard coal mines in Poland. In the Upper-Silesian Coal Basin, many hard coal mines were closed down during restructuring. Their liquidation necessitates the protection of the neighboring mines as well as the natural environment from water hazards. The main sources of this hazard are the large underground water reservoirs in the post-exploitation workings and headings and in the layers of the cracked sandstones. The gathering of water in these areas brings the possibility of a rapid and catastrophic retention flow of water to the neighboring mines through the hydraulic junctions, which cannot receive the additional quantity of water.

Protection from water hazards has been conducted by a state-owned partnership for dewatering of the liquidated mines since 2000. In its structures there are 15 dewatering regions functioning: 7 stationary and 8 deep-well. The maintenance of these regions costs over $30 million yearly for the state budget. This cost may be reduced due to the modification of the existing technical–organizational solutions. The cost reduction forecast in this article will be possible after conducting the transformation of some stationary pumps into deep-well ones. This transformation must include hydro-geological conditions, shortening the headings maintained in the stationary pumps and directing some of the pumped water to the working mines neighboring the longwalls of the liquidated mines.

Changes in the dewatering systems that were elaborated using BPR will enable a 17% reduction in costs, which are currently covered by the state in a perspective up to 2030. Additionally, a group of ecological and social benefits will not be altered, which means in practice that the condition of natural environment in the Upper-Silesian Coal Basin will not deteriorate and this region will not be endangered by an ecological catastrophe.

Nevertheless, it should be clearly emphasized that mine dewatering does not limit the harmful influence of the liquidated mines on the natural environment. It is only a method that allows for reducing the scale of possible hazards. Dewatering causes a decrease in underground water level, and direction and speed of water infiltration is changed. Additionally, the quality of underground water is deteriorated and the mechanical properties of rocks are weakened.

Taking into account a multinational context of dewatering the liquidated mining enterprises, it should be stated that this problem can be solved systematically and in a complex way only with suitable legal regulations and government involvement. Legislation should then determine the rules of responsibility for the damage caused by exploitation after its final stoppage, in both the state-owned mines and the private ones.

Further research in this field should be oriented toward the improvement and universal nature of benefit and cost estimation methods in the revitalization of post-industrial regions. It is also worth analyzing the influence of legal regulations on costs and benefits of maintaining and revitalizing post-industrial regions on a multinational scale. When analyzing the applicability of the presented solutions, a longer perspective should be considered concerning the increasing usability of drained water for commercial purposes, which would enable further effectiveness of the dewatering systems.

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