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COAL-MINE LIQUIDATION AS A STRATEGIC MANAGERIAL DECISION: A DECISION-MAKING MODEL BASED ON THE OPTIONS APPROACH

LIKWIDACJA KOPALNI JAKO STRATEGICZNA DECYZJA MENEDŻERSKA: MODEL DECYZYJNY Z WYKORZYSTANIEM PODEJŚCIA OPCYJNEGO

The aim of this paper is to determine the optimal time of coal mine liquidation given the necessity of bearing the costs of post-mining reclamation. In order to consider the volatility of parameters important for making a liquidation decision and the entrepreneur's flexibility in the decision-making process, the real options approach was applied. Mine liquidation, which is inextricably linked to post-mining reclamation, is examined as an American put option on the market value of continuing the mine's operation which plays the role of the underlying asset. In turn, the role of the exercise price is played by expenditures for mine liquidation and post-mining reclamation, which can be avoided if the decision to close the mine is taken before all the deposits are exhausted. The liquidation option is exercised when the value of liquidation and reclamation cost savings significantly exceeds the continuation value. Mine liquidation was additionally made conditional on the value of funds accumulated to finance post-mining reclamation.

Keywords: reclamation of the post-mining area, real options approach, financial calculus in mining

Artykuł dotyczy ustalenia optymalnego momentu likwidacji kopalni w związku z koniecznością ponoszenia kosztów rekultywacji gruntów pokopalnianych. W celu uwzględnienia zmienności wartości parametrów istotnych dla podjęcia decyzji o likwidacji oraz elastyczności w podejmowaniu decyzji przez przedsiębiorcę, wykorzystano podejście opcyjne. Likwidację kopalni, która jest nierozłącznie związana z rekultywacją terenów pokopalnianych, rozpatruje się jako amerykańską opcję sprzedaży (*put)* wystawioną na rynkową wartość kontynuacji działalności kopalni pełniącą rolę instrumentu bazowego. Z kolei rolę ceny wykonania odgrywają nakłady na likwidację kopalni i rekultywację terenów pokopalnianych, poniesienia których można uniknąć, gdy decyzja o wstrzymaniu eksploatacji zapadnie przed wyczerpaniem się złoża. Opcja likwidacji jest wykonywana, gdy kwota nakładów na likwidację i rekultywację znacząco przekracza wartość kontynuacji. Likwidację kopalni uzależniono dodatkowo od wysokości środków gromadzonych w celu sfinansowania rekultywacji gruntów pokopalnianych.

Słowa kluczowe: decyzja o likwidacji kopalni i rekultywacji terenów pokopalnianych, podejście opcyjne, opcja likwidacji kopalni, fundusz na rekultywację terenów pokopalnianych

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Introduction

The popular belief about the mine liquidation is that it should take place at the moment the mine's deposits are exhausted. It has nothing to do with economic calculations, because it does not take into account, among other things, the costs that have to be borne of discontinuing the mine's activity. These costs are mostly a consequence of the necessity of respecting environmental protection requirements mandated by law. Regulations require that mining companies eliminate the effects of a mine's activity. Negative environmental effects of a mine's operations increase together with the length of time the deposits are exploited. Thus, the more the decision to close the mine is postponed, the higher the costs of its liquidation and post-mining reclamation will have to be. Consequently, a decision-making problem of an economic nature arises. By comparing all the benefits of continuing the mining activity and the benefits of avoiding part of liquidation and reclamation costs in the case of discontinuing the mine's operation, it is possible to determine the moment when the mine should be liquidated. The decision to stop the mine's operation should be made when the benefits of avoiding part of liquidation and reclamation expenditures are significantly higher than the benefits of continuing the mining activity. This paper presents a model which allows us to select an economically optimal time of deciding to discontinue the mine's activity. The structure of the paper is as follows: Part I is devoted to the laws regulating environmental issues related to mine operation. In Part II, we present a decision-making model based on the concept of real options valuation. Part III contains the results of calculations based on data illustrating the situation of a mine. The calculations use hypothetical data concerning a lignite mine. Part IV concludes.

1. Legal regulations

Legal regulations resulting from the Constitution of the Republic of Poland and regulating the activity of mining companies at all stages of their operation are present in many legal documents, the most important of which are:

1. The Act of 27 April 2001, Environmental Protection Law (consolidated text of 23 January 2008, Journal of Laws no. 25, item 150, as amended),
2. The Act of 27 March 2003, Spatial Planning and Land Development (consolidated text, Journal of Laws no. 80, item 717, as amended),
3. The Act of 9 June 2011, Geological and Mining Law (Journal of Laws no. 163, item 981),
4. The Act of 3 February 1995, Protection of agricultural and forest land (consolidated text of 2 April 2004, Journal of Laws no. 121, item 1266, as amended).

Mining activities have to be carried out in compliance with the principles of sustainable development, which is reflected in the provisions of the *Environmental Protection Law* and the *Law on spatial planning and land development*.

The Geological and Mining Law specifies the rules and conditions for undertaking, conducting and stopping mining activities. Significant emphasis is placed on the stage of discontinuing a mine's operation and its liquidation (closure). In the process of mine liquidation, the owner is obliged to:

– protect or eliminate the excavation, technical equipment, installations and facilities,
– protect the unused part of mineral deposits,

– protect neighbouring deposits,
– take necessary measures to protect the excavations of neighboring mines,
– take necessary measures to protect the environment and rehabilitate the post-mining area.

It should be noted that the Act does not define the term "liquidation" limiting itself to the description of the owner's obligations during the process.

The amount of capital required to finance the actions related to liquidation and post-mining reclamation depends mainly on the scale of land transformation, the duration of the work and its complexity.

An entrepreneur conducting his business on the basis of a concession is obliged to establish a mine-liquidation fund and raise funds deposited in a separate bank account. In the case of surface mining, no less than 10% of the exploitation fee is to be allocated for the fund. Allowances may be used only to cover the costs of mine liquidation. As can be seen, this special-purpose fund is used to cover the costs of, among other things, environmental protection as well as rehabilitation of degraded and devastated agricultural and forest land.

Another source of financing mine liquidation and post-mining reclamation is a special provision based on *International Accounting Standards, Provisions, Contingent Liabilities and Contingent Assets* accounting standard (IAS 37, point WP2). A provision should be recognized when:

– the entity has a present obligation (legal or constructive) as a result of a past event;
– it is probable that an outflow of resources embodying economic benefits will be required to settle the obligation; and;
– a reliable estimate can be made of the amount of the obligation.

According to the IAS 61, the provision should be used only for purposes for which it was originally recognized. The total value of the fund created for mine liquidation and the provision created in accordance with IAS should correspond with the estimated total costs of reclamation. It should be noted, however, that creating a provision is an accounting procedure only, not affecting a company's cash flows.

It can be concluded, therefore, that compliance with laws is not a sufficient condition for raising enough cash to finance mine liquidation and post-mining reclamation. It is suggested that a model for determining the time of mine liquidation should include a parameter specifying the amount of the annual cash allowance for liquidation and reclamation. Furthermore, the solution obtained thanks to using such a model, indicating the time when mine closure becomes financially profitable, should be supplemented by checking whether the accumulated money is sufficient to carry out the liquidation and reclamation.

2. Model

To arrive at a decision to close a mine, we suggest applying the real options approach. The approach, also known as a real options method, is a concept of valuation which takes into account managerial flexibility resulting from active management. A real option can be defined as its owner's right to carry out specific actions related to non-financial assets and sources of their financing (Mizerka, 2005, p. 62). Using real options to determine the value of a mine or to make strategic decisions regarding a mine's activity is reflected in an extensive subject literature.

A seminal study of the real options approach was a paper by M. Brennan and E. Schwartz titled *Evaluating Natural Resource Investments* (Brennan & Schwartz, 1985). According to its authors, in case of high price volatility, making a decision on the basis of forecasts that use the expected values may lead to incorrect forecasts and, in consequence, to wrong decisions. To model the price of a given resource, the authors of the paper applied a stochastic process known as geometric Brownian motion. The Brennan and Schwartz model is a continuous time model. The model may be used not only to evaluate the mine but also to create an optimal policy of mine's development and management, or even suspending or stopping its activity. However, the model does not explicitly include post-mining reclamation expenditures. Therefore, it does not take into account the correlation between the life of the mine and the amount of reclamation expenditure.

Improved versions of the model continue to appear (Moel & Tufano, 2000; Shafiee et al., 2009). Using data from 285 North American gold mines, A. Moel and P. Tufano confirmed the conclusions relating to the policy of opening and closing a mine derived from the option model (Moel & Tufano 2000). Later on, using data from the 1992-1995 period, D. Colwell, T. Henker and J. Ho conducted similar studies concerning a gold mine in Australia. Also the results of these studies confirmed the accuracy of the conclusions based on the application of the option model (Colwell et al., 2002). In addition, the options approach can be used to assess the level of resources suitable for opencast mining under uncertainty (Akbari et al., 2009).

An inclusion of elements related to environmental protection in the option model for deciding to close a mine creates an interesting research area.

Using the options approach requires finding an analogy between elements of the option pricing model and the mine valuation model. The role of the underlying asset is played by the value of a mine's continued activity. A basis for estimating the continuation value is free cash flows (*FCF*), equated with a net operating profit after tax (*NOPAT*). The model assumes that *NOPAT* is influenced by the following factors: the volume of output in a given year, the price of coal in a given year, the variable cost markup, the amount of fixed costs, and the rate of income tax. If we additionally assume that the volume of output in particular years until the deposits are exhausted can be determined with high probability, and that, to make things simple, the amount of fixed costs and the variable cost markup are fixed and not subject to change, then the only significant risk factor is the price of the mineral[1].

We treat the price of the mineral, i.e. of coal, as a twin security. The process of coal price formation, can be illustrated by means of a binomial tree, as it is assumed that a coal price may rise or fall at nodes j and k, neighbouring the i-th, according to the following formulas:

$$coal\_price_{t,t+1;j} = coal\_price_{t-1,t;i} \bullet u \text{ – in the case of a price increase} \quad (1)$$

$$coal\_price_{t,t+1;k} = coal\_price_{t-1,t;i} \bullet d \text{ – in the case of a price decrease} \quad (1A)$$

and:

$$u = e^{\sigma} \quad (2)$$

$$d = e^{-\sigma} \quad (2A)$$

where:

σ — coal price volatilty measured by standard deviation.

$t = 1 \ldots N-2$, we additionally assume that N is the beginning of a period in which mining is no longer carried out because the deposits have been exhausted; we assume that when the deposits are exhausted, the coal mining concession expires.

[1] Further down the article, by referring to *mineral* we will mean brown coal as the data illustrating the working of the proposed model are taken to a large extent from a brown coal mine.

Having made a coal price the only risk factor, it is easier to justify the assumption of market completeness, ie the assumption of the possibility of finding a financial instrument whose price is perfectly correlated with the value of the underlying asset for which a given option is issued (Dzieża, 2011). By adopting such an assumption, we can illustrate the formation of the underlying asset by using a binomial tree with parameters corresponding to the parameters of a tree describing the value of a twin security. At particular nodes of the tree, the value of the underlying asset, i.e. the value of continuing the mine's activity, is dependent on cash flows. Cash flows at the i-th node of this binomial tree in particular years $(t, t+1)$ are estimated as follows:

$$FCF_{t,t+1;i} = NOPAT_{t,t+1;i} = EBIT_{t,t+1;i} \cdot (1-T) = \\ = \begin{bmatrix} coal\ price_{t,t+1;i} \cdot coal\_output_{t,t+1} \\ \cdot (1 - variable\_cost\_\_markup) - fixed\_costs \end{bmatrix} \cdot (1-\mathrm{T}) \tag{3}$$

where:

T — income tax rate,
$t = 1 \ldots N-1$.

An algorithm for estimating the continuation value is as follows:

1) Estimating the updated continuation value ($Cont_{N,i}$) at moment N at each node of the tree. The calculation is based on cash flows in period $(N;N+1)$ and in subsequent periods. These values obviously equal zero ($Cont_{N,i} = 0$, $i = 1 \ldots I_N$) because in these periods the deposits will no longer be exploited. We additionally assume that the liquidation value of the assets used in the mining process is zero.
2) Determining the updated continuation value $Cont_{N-1,i}$ at moment $N-1$ according to formula (2).

$$Cont_{N-1,i} = \left[\frac{q \cdot \left(Cont_{N,i,increase} + FCF_{N-1,N;i;increase}\right) + \\ +(1-q) \cdot \left(Cont_{N,decrease} + FCF_{N-1,N;i;decrease}\right)}{(1+r_F)} \right] \tag{4}$$

where:

r_F — interest rate of risk-free financial instrument,
$Cont_{N,i,increase} = Cont_{N,i,decrease} = 0;\ i = 1 \ldots I_N$

It should be added that q and $1-q$ denote arbitrage probabilities of, respectively, an increase and a decrease in the value of a twin security (coal price). Increase probability q is calculated according to formula (5) (Cox et al., 1979):

$$q = \frac{e^{r_F} - d}{u - d} \tag{5}$$

where: u, d — ratios of, respectively, an increase and a decrease in the value of a twin security (underlying asset).

3) Determining the updated continuation value at moment $N - t(t = 2 \dots N)$ at the i-th node according to formula (6).

$$Cont_{N-t,i} = \left[\frac{\begin{matrix} q \cdot \left(Cont_{N-t+1;increase} + FCF_{N-t,N-t+1;i;increase} \right) + \\ + (1-q) \cdot \left(Cont_{N-t+1,decrease} + FCF_{N-t,N-t+1;i;decrease} \right) \end{matrix}}{(1+r_F)} \right] \tag{6}$$

where:

$Cont_{N-t+1,increase}$, $Cont_{N-t+1,decrease}$ – continuation values at moment $N-t+1$, assuming, respectively, an increase and a decrease in the price of coal in relation to the situation at the i-th node in period $N-t$, $N-t+1$,

$FCF_{N-t,N-t+1;i;increase}$, $FCF_{N-t,N-t+1;i;decrease}$ – amounts of cash flows in period ($N-t$, $N-t+1$), assuming, respectively, an increase and a decrease in the price of coal in relation to the situation at the i-th node in the previous period,

4) Estimating the intrinsic values of mine liquidation options, $Liqintr_{t,i}$, according to formulas (7) and (7A).

$$Liqintr_{N,i=0} \tag{7}$$

$$Liqintr_{t,i} = \max(Avoidcost_t - \max(Cont_{t,i} - Recult_t;0);0) \tag{7A}$$

$$t = 1 \dots N-1$$

where:

$Avoidcost_t$ – strike prices, i.e. updated – at moment t – costs of mine liquidation and post-mining reclamation, costs which can be avoided by deciding at moment t to liquidate the mine.

$Recult_t$ – updated – at moment t – costs of mine liquidation and post-mining reclamation.

The benefits of lowering (not bearing) costs decrease over time, because the longer the decision to liquidate the mine is postponed, the higher are the costs of mine liquidation and post-mining reclamation that have to be borne. Thus, in the last period:

$$Avoidcost_N = 0 \tag{8A}$$

In earlier periods, the costs avoided, $Avoidcost_{N-t}$, are estimated as the sum of costs related to liquidation and reclamation, *Savings*, which would have to be borne in a given period if the decision to liquidate the mine were not taken during this period, and analogues costs which will be borne in the next periods.

$$Avoidcost_t = \sum_{i=t}^{N-1} \frac{Savings_{i,i+1}}{(1+k)^i}, t = 1 \dots N-1 \tag{8B}$$

where: k — discount rate including a risk premium.

step 5) Estimating the option's total value

The total value of the mine-liquidation option, $Totliq_t$, is determined as the maximum of the intrinsic value of the option previously established for a given period and node, and the weighted average value of the option in the next period for nodes neighbouring a given one. For estimation of the total value of the options following formulas can be used:

$$Totliq_{N,i} = Liqintr_{N,i} \tag{9}$$

$$Totliq_{N-t,i} = \max\left(Liqintr_{N-t,i}, \frac{q \cdot Totliq_{N-t+1,decrease} + (1-q) \cdot Totliq_{N-t+1,increase}}{(1+r_F)} \right) \tag{9A}$$

step 6) Verifying a necessary condition for mine liquidation and posy-mining reclamation

The algorithm for determining the total value of the liquidation option helps to define the moment of mine liquidation and post-mining reclamation – t^{liq}. The liquidation should be carried out when a non-zero total value of the liquidation options becomes equal to its intrinsic value:

$$Totliq_{t,i} > 0 \quad \text{and} \quad Totliq_{t,i} = Liqintr_{t,i} => t = t^{liq} \tag{10}$$

Step 7) Verifying a sufficient condition for mine liquidation and post-mining reclamation

Indicating the moment of liquidation and the beginning of reclamation by using the option pricing algorithm does not mean, however, that these actions will be undertaken. Fulfilling condition (10) can be treated as meeting a necessary – but not sufficient – condition for liquidation and reclamation. A sufficient condition is collecting an amount of money that will allow us to finance all activities involved in liquidation and reclamation. The inequality formula which is preceded by the condition of the option's total value becoming equal to its intrinsic value is as follow:

$$Recult_{t^{likw}} \le Cumreserve_{t^{liq}} \tag{11}$$

where:

$$Cumreserve_1 = Histreserve \tag{12}$$

$$Cumreserve_t = Cumreserve_{t-1} \bullet (1 + reinvestrate_t) + Allow_{t-1,t},\ t = 2 \ldots t^{liq} \tag{12A}$$

$$Allow_{t-1,t} = average\_coal\_price_{t-1,t} * coal\_output_{t-1,t} \bullet \%Allow \tag{13}$$

where:

- $Cumreserve_t$, $Cumreserve_{t^{likw}}$ – accumulated financial reserves dedicated for financing liquidation and reclamation; opening balance at the beginning of periods t, t^{likw}, respectively,
- $Histreserve$ – level of funds collected as a reserve dedicated for liquidation and reclamation, balance at the beginning of period 1,
- $Allow_{t-1,t}$ – amount of allowance as a reserve dedicated for financing liquidation and reclamation in period $(t-1,t)$,
- $\%Allow$ – rate of allowance as a reserve dedicated for financing liquidation and reclamation.
- $average\_coal\_price_t$ – average coal price in period t, calculated as the arithmetic mean of coal prices at all nodes of the binomial tree,
- $reinvestrate_t$ – rate of return on the reinvested reserve of cash.

3. Calculations

3.1. Assumptions

Calculations based on the model were conducted using data concerning one of Poland's brown coal mines. For the purposes of calculation, the following assumptions have been made:

Z1. The investment-analysis period is 2013-2038; the time step is one year.

Z2. The identified option to liquidate the mine (and start post-mining reclamation) is an American put option referred to as the option to continue the mine's activity. Exercising the option means stopping the mine's activity.

Z3. The underlying asset for which the option is issued is the value of continuing the mine's activity, calculated on the basis of formulas (3)-(6). We calculate continuation value *Cont* as the sum of discounted cash flows reflecting the future benefits of continuing the mine's activity, assuming, however, that future benefits are decreasing owing to deposit depletion. We identify cash flows (*FCF*) with net operating profit after tax (*NOPAT*). When calculating cash flows, it was assumed that operating costs are divided into variable costs (50% of revenues from coal sales) and fixed costs (PLN100m per year). The distribution of continuation value on the binomial tree was obtained by assuming that the volatility of continuation value measured by standard deviation σ is 10% per annum. The variation value was obtained by observing the historical volatility of the underlying asset, which is the price of (brown) coal. Table 3 (Attachment 2) presents continuation-value levels.

Z4. The arbitrage probabilities (of an increase- q, of a decrease- $1-q$) of the underlying asset were estimated using formula (5) on the basis of the volatility of the twin security, which is the price of brown coal. It was estimated that the arbitrage probability of an increase in the underlying asset's value is 0.7837. Therefore, the probability of a decline in the value of the underlying asset is 0.2163.

Z5. The role of strike prices *Avoidcost* is played by increasing expenditures on reclamation, which can be avoided if at a given moment a decision is made to liquidate the mine. Savings in expenditures vary from period to period. We are dealing, therefore, with an option with a variable strike price. Strike prices in particular periods are determined on the basis of formulas (8A) and (8B). Attachment 1 contains Table 1 presenting strike prices.

Z6. Annual allowances as a reserve *Allow*, intended to finance the cost of mine liquidation and post-mining reclamation, are defined as a fixed percentage of sales revenue in a given year. For the purpose of calculating allowances as a reserve, sales revenue is calculated on the basis of the average price in a given year. It is assumed that each year, within the forecast horizon, 1% of revenue is deducted as a reserve (*%Allow* =1%). The total amount accumulated in reserve funds, apart from allowances made every year within the forecast horizon, is also influenced by the amount of funds accumulated in the period preceding the forecast period, *Histreserve*. It is assumed that the amount at the beginning of the forecast period is approximately PLN521m. Additionally, the amount of the reserve is also influenced by the rate of reinvesting the accumulated funds, *reinvestrate*. The rate is 5% per annum. Table 2 in Attachment 1 contains the amounts accumulated in the reserve in particular periods within the forecast horizon.

3.2. Calculation results

Underlying asset

Possible values of the underlying asset, ie values of continuing the mine's activity, are shown in Table 3, Attachment 2. The values range from PLN17,881m in 2013 to a maximum of PLN8,179m in 2037. It is worth noting that until 2028 the values of continuing the mine's activity increase together with increasing coal prices. From the year 2029, an increase in the price of coal no longer compensates for a decline in output owing to deposit depletion. At the end of 2038, the value of continuing the mine's activity is zero because of deposit depletion and the zero liquidation value of the assets used in the mining process.

Intrinsic values of options

Intrinsic values of options are presented in Table 4, Attachment 3. A positive intrinsic value of options may indicate the profitability of discontinuing the mine's activity. In turn, zero values of the liquidation option suggest the profitability of continuing the mine's activity. It is worth noting that in recent years, within the forecast horizon, intrinsic values of options have been decreasing. This is despite a decline in the value of the underlying asset, ie the value of continuation. The reason is a significant decrease in the strike price (reclamation costs which can be avoided) owing to the forthcoming end of exploitation because of the depletion of deposits. As for the case under analysis, it can be said that the decision to liquidate the mine and start post-mining reclamation should not be taken in the period 2013-2025. In 2026 such a decision could be considered, but only if the coal price drops to the lowest level. Starting from 2026, there are more and more positive values at the nodes of the tree, and from 2035 the number of nodes with positive values exceeds the number of nodes with zero values. However, even in 2037, the last year the option can – but does not need to – be exercised, there are zero values indicating the profitability of continuing the mine's activity. These values occur at the nodes denoting a situation where the price of coal is high.

Total value of the option

The obtained total values of the option are not very high. The higher level of the option's total value than its intrinsic value suggests that it is profitable to postpone the decision to exercise the option. However, as the time of deposit exhaustion is approaching, with coal prices being low, the total values of the option are approaching its intrinsic values. Table 5 in Attachment 4 presents the total value of the option. It should be noted that only at a few nodes does the total value of the option equal zero. Such a situation takes place when the price of coal is so high that its possible decreases in the next periods will not reduce the continuation value below the strike price, even if there are only a few years left until the deposits are exhausted.

The time of option exercise

Comparing the intrinsic values of the option with its total values allows us to determine the time the mine should be liquidated. The results of this comparison, shown in Table 6, Attachment 5, indicate that the decision to liquidate the mine can be taken not earlier than in 2026, but only when the coal price reaches the lowest possible level. In subsequent years, there are more and more situations where the decision to liquidate the mine should be made. However, even in 2037, the last year when the decision-maker has the choice of continuing the mine's activity or liquidating it, the decision to liquidate should not be made without regard to the price of coal.

Option exercise financing

The total value of the liquidation option becoming equal to its intrinsic value does not automatically mean exercising the mine-liquidation option. We still need to check whether the funds accumulated as a reserve to finance liquidation and reclamation are sufficient to carry out these activities (see inequality 11). The results of this check are given in Table 7, Attachment 6. As can be seen, the area including the tree nodes at which to decide to exercise the liquidation option (Table 6) does not overlap with the area including the nodes at which, in addition to the fact that the option is worth exercising, the accumulated financial resources are sufficient to finance the operation. The obtained results suggest that, owing to the level of funds accumulated, the option can be exercised only from 2034 onwards.

4. Conclusions

Using the model should provide an answer to the following question: From the economic point of view, when should we liquidate the mine? An answer to this question is possible only if the model takes into account flexibility, understood as being able to postpone the decision to liquidate the mine. The necessity of taking this into account justifies the application of the options approach. The results obtained by applying the model of valuing the option to close the mine confirm the intuitive conjecture that, from the economic point of view, it may be more profitable for the decision-maker to stop the activity earlier than the moment of deposit exploitation.

The calculations made using the proposed options model are part of a process of developing trust in the soundness and usefulness of the model. To confirm its legitimacy and validity, it should undergo a validation process. Such validation should include:

- verifying the working of the model using different variants of data,
- checking the functioning the model and possibly adapting it to data from other mines (extracting bituminous coal, salt, etc).

The model constructed here is based on a simplified picture of reality. When creating it, we were aware that real-life decisions should take into account technical (e.g., geological and geotechnical conditions), social (e.g., impact on unemployment), organizational (e.g., belonging to a larger organizational structure) and environmental aspects (e.g., impact on ecosystems), as well as the government's energy strategy (e.g., energy security), etc. To develop the model further, these aspects should be taken into consideration.

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Attachment 1.

TABLE 1

Strike price - updated (discounted) values of cost savings of liquidation and reclamation costs in case of early closure of the mine (million PLN)

Years	201:	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
	827	823	818	817	814	809	802	791	779	763	744	720	692	658	618	572	519	457	423	384	339	288	229	162	86	0

Source: Own calculations

TABLE 2

Level of reserve to finance the mine liquidation and reclamation of post-mining area (million PLN)

Years	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Reserve	521	568	618	668	721	777	836	899	964	1 034	1 107	1 185	1 268	1 356	1 450	1 549	1 654	1 766	1 868	1 975	2 088	2 207	2 334	2 467	2 609	2 758

Source: Own calculations

Attachment 2.

TABLE 3

The value of the continuation of the mine operation (million PLN)

Year 201	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
																									0
																								8 179	0
																							14 802	6 680	0
																						20 090	12 086	5 452	0
																					24 235	16 400	9 862	4 446	0
																				27 405	19 779	13 378	8 041	3 623	0
																			29 749	22 361	16 131	10 905	6 550	2 949	0
																		31 393	24 267	18 231	13 144	8 880	5 330	2 398	0
																	32 448	25 601	19 779	14 850	10 699	7 222	4 330	1 946	0
																33 011	26 454	20 859	16 105	12 082	8 696	5 864	3 512	1 576	0
															33 166	26 904	21 546	16 977	13 096	9 816	7 057	4 753	2 842	1 273	0
														32 984	27 021	21 904	17 528	13 798	10 633	7 960	5 715	3 843	2 294	1 025	0
													32 527	26 862	21 989	17 810	14 238	11 196	8 616	6 441	4 616	3 098	1 845	822	0
												31 850	26 479	21 850	17 870	14 458	11 544	9 065	6 965	5 197	3 717	2 488	1 477	656	0
											30 997	25 916	21 527	17 746	14 497	11 714	9 339	7 321	5 614	4 178	2 980	1 988	1 176	520	0
										30 007	25 209	21 058	17 473	14 386	11 736	9 468	7 534	5 893	4 507	3 345	2 377	1 579	930	409	0
									28 914	24 392	20 471	17 080	14 154	11 636	9 475	7 628	6 056	4 723	3 601	2 662	1 883	1 245	728	318	0
								27 747	23 490	19 794	16 592	13 824	11 436	9 383	7 624	6 122	4 845	3 766	2 859	2 103	1 479	971	563	243	0
							26 528	22 527	19 049	16 030	13 416	11 157	9 211	7 540	6 109	4 889	3 854	2 982	2 252	1 646	1 148	746	428	182	0
						25 279	21 523	18 254	15 413	12 948	10 815	8 974	7 390	6 030	4 868	3 879	3 043	2 340	1 754	1 271	877	563	317	132	0
					24 014	20 494	17 425	14 755	12 436	10 425	8 686	7 187	5 898	4 794	3 852	3 053	2 379	1 815	1 347	964	655	412	226	91	0
				22 750	19 453	16 577	14 070	11 890	9 998	8 359	6 943	5 724	4 677	3 782	3 020	2 376	1 835	1 385	1 014	713	474	289	152	57	0
			21 496	18 413	15 719	13 370	11 324	9 545	8 003	6 668	5 516	4 526	3 677	2 953	2 340	1 822	1 390	1 032	741	507	325	188	91	30	0
		20 262	17 381	14 862	12 662	10 744	9 075	7 625	6 369	5 283	4 348	3 545	2 859	2 275	1 782	1 369	1 025	744	517	339	203	106	41	7	0
	19 055	16 366	14 012	11 955	10 159	8 594	7 234	6 053	5 031	4 149	3 391	2 742	2 188	1 720	1 326	997	727	508	335	201	104	38	3	0	0
17 881	15 373	13 176	11 254	9 574	8 109	6 834	5 726	4 766	3 936	3 221	2 608	2 084	1 640	1 265	952	693	483	315	185	89	26	0	0	0	0

Source: Own calculations

Attachment 3.

TABLE 4

The intrinsic value of the liquidation (million PLN)

Years	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
																										0
																									0	0
																								0	0	0
																							0	0	0	0
																						0	0	0	0	0
																					0	0	0	0	0	0
																				0	0	0	0	0	0	0
																			0	0	0	0	0	0	9	0
																		0	0	0	0	0	0	0	9	0
																	0	0	0	0	0	0	0	0	9	0
																0	0	0	0	0	0	0	0	0	9	0
															0	0	0	0	0	0	0	0	0	18	9	0
														0	0	0	0	0	0	0	0	0	0	18	9	0
													0	0	0	0	0	0	0	0	0	0	0	18	9	0
												0	0	0	0	0	0	0	0	0	0	0	28	18	9	0
											0	0	0	0	0	0	0	0	0	0	0	0	28	18	9	0
										0	0	0	0	0	0	0	0	0	0	0	0	39	28	18	9	0
									0	0	0	0	0	0	0	0	0	0	0	0	50	39	28	18	9	0
								0	0	0	0	0	0	0	0	0	0	0	0	0	50	39	28	18	9	0
							0	0	0	0	0	0	0	0	0	0	0	0	0	63	50	39	28	18	9	0
						0	0	0	0	0	0	0	0	0	0	0	0	0	76	63	50	39	28	18	9	0
					0	0	0	0	0	0	0	0	0	0	0	0	0	90	76	63	50	39	28	18	9	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	113	90	76	63	50	39	28	18	9	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	87	113	90	76	63	50	39	28	18	9	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	77	137	113	90	76	63	50	39	28	18	9	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	89	163	137	113	90	76	63	50	39	28	18	9	0

Source: Own calculations

Attachment 4.

TABLE 5

Total value of the liquidation option (million PLN)

Years	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
																										0
																									0	0
																								0	0	0
																							0	0	0	0
																						0	0	0	0	0
																					0	0	0	0	0	0
																				0	0	0	0	0	0	0
																			0	0	0	0	0	0	9	0
																		0	0	0	0	0	0	0	9	0
																	0	0	0	0	0	0	0	0	9	0
																0	0	0	0	0	0	0	0	0	9	0
															0	0	0	0	0	0	0	0	0	18	9	0
														0	0	0	0	0	0	0	0	0	0	18	9	0
													0	0	0	0	0	0	0	0	0	0	0	18	9	0
												0	0	0	0	0	0	0	0	0	0	0	28	18	9	0
											0	0	0	0	0	0	0	0	0	0	0	0	28	18	9	0
										0	0	0	0	0	0	0	0	0	0	0	0	39	28	18	9	0
									0	0	0	0	0	0	0	0	0	0	0	0	50	39	28	18	9	0
								0	0	0	0	0	0	0	0	0	0	0	0	0	50	39	28	18	9	0
							0	0	0	0	0	0	0	0	0	0	0	0	0	63	50	39	28	18	9	0
						0	0	0	0	0	0	0	0	0	0	0	0	0	76	63	50	39	28	18	9	0
					0	0	0	0	0	0	0	0	0	0	0	0	0	90	76	63	50	39	28	18	9	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	113	90	76	63	50	39	28	18	9	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	87	113	90	76	63	50	39	28	18	9	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	77	137	113	90	76	63	50	39	28	18	9	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	89	163	137	113	90	76	63	50	39	28	18	9	0

Source: Own calculations

Attachment 5.

TABLE 6

Moment of the liquidation and start of reclamation of the post-mine areas

Years	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
																										0
																									0	0
																								0	0	0
																							0	0	0	0
																						0	0	0	0	0
																					0	0	0	0	0	0
																				0	0	0	0	0	0	0
																			0	0	0	0	0	0	9	0
																		0	0	0	0	0	0	0	9	0
																	0	0	0	0	0	0	0	0	9	0
																0	0	0	0	0	0	0	0	0	9	0
															0	0	0	0	0	0	0	0	0	18	9	0
														0	0	0	0	0	0	0	0	0	0	18	9	0
													0	0	0	0	0	0	0	0	0	0	0	18	9	0
												0	0	0	0	0	0	0	0	0	0	0	28	18	9	0
											0	0	0	0	0	0	0	0	0	0	0	0	28	18	9	0
										0	0	0	0	0	0	0	0	0	0	0	0	39	28	18	9	0
									0	0	0	0	0	0	0	0	0	0	0	0	50	39	28	18	9	0
								0	0	0	0	0	0	0	0	0	0	0	0	0	50	39	28	18	9	0
							0	0	0	0	0	0	0	0	0	0	0	0	0	63	50	39	28	18	9	0
						0	0	0	0	0	0	0	0	0	0	0	0	0	76	63	50	39	28	18	9	0
					0	0	0	0	0	0	0	0	0	0	0	0	0	90	76	63	50	39	28	18	9	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	113	90	76	63	50	39	28	18	9	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	87	113	90	76	63	50	39	28	18	9	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	77	137	113	90	76	63	50	39	28	18	9	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	89	163	137	113	90	76	63	50	39	28	18	9	0

Source: Own calculations

Attachment 6.

TABLE 7

Feasibility of the liquidation options

Years	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
																									FS
																								FS	FS
																							FS	FS	FS
																						LoM	FS	FS	FS
																					LoM	LoM	FS	FS	FS
																				LoM	LoM	LoM	FS	FS	FS
																			LoM	LoM	LoM	LoM	FS	FS	LP
																		LoM	LoM	LoM	LoM	LoM	FS	FS	LP
																	LoM	LoM	LoM	LoM	LoM	LoM	FS	FS	LP
																LoM	LoM	LoM	LoM	LoM	LoM	LoM	FS	FS	LP
															LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	FS	LP	LP
														LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	FS	LP	LP
													LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	FS	LP	LP
												LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
											LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
										LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
									LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
								LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
							LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
						LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
					LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
				LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
			FS	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
		FS	FS	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP
	FS	FS	FS	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LoM	LP	LP	LP

Source: Own calculations

- Funds sufficient (FS)
- Lack of Money (LoM)
- Liquidation possible (LP)