Journal of Sustainable Mining
ISSN 2300-3960
The English-language online version (primary, reference version of J. Sust. Min.)

JOURNAL HOMEPAGE
jsm.gig.eu

J. Sust. Min. Vol. 12 (2013), No. 1, pp. 41–45

http://dx.medra.org/10.7424/jsm130108

Received: 2012.11.26 | **Accepted**: 2013.04.25 | **Available online**: 2013.05.06

ECONOMIC EVALUATION OF MINERAL EXTRACTION PROJECTS FROM FIELDS OF EXPLOITATION DURING OPERATIONAL PERIODS

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Abstract
The exploitation of minerals from fields of exploitation can be treated as a separate investment project. Three stages of such a project should be considered during the decision-making process, the preparation of a field for exploitation, the acquisition of raw materials and the liquidation of the field following mining activities. During the implementation of these various stages, the evaluation of the economic efficiency of static and dynamic methods are taken into account in each of the stages. An essential element is also the evaluation of risks connected with the investment, this is a quantitative measure of the uncertainty of achieving specific objectives. The bases for the correct calculation of economic efficiency include: proper input data, including economic and technological aspects. This article highlights the necessity of an economic evaluation concerning the exploitation of fields during operational periods due to their recognition in higher categories and the ever changing mining and economic conditions. Such changes are analysed with economic efficiency of exploitation systems. The initial value of the project takes into consideration the time value of money proposed as a criterion of economic evaluation. Income and expenditure, which correspond to the liquidity of the company, are assumed as a basis for calculation. Net present value is presented as a sum of values regarding preparation period, exploitation and field liquidation.

Key words
minerals; exploitation; extraction; project; economic evaluation; calculation

1. INTRODUCTION

The order of exploiting and classifying mineral resources (i.e. recognising whether they are industrial or nonindustrial) are described in the field development project (Article, 2001). During the operational period, i.e. during the period of deposit exploitation, natural conditions may change (e.g. through more precise diagnosis of deposits) and mining conditions (i.e. due to a change in exploitation orders), and economic circumstances, resulting from fluctuations in prices and costs.

As a result, the exploitation of every field during the operational period should be preceded by an economic evaluation. Field exploitation may be treated as a separate investment project which would to a large extent involve assets. Under this assumption, obtaining raw materials from a field can be analysed in a variety of exploitation systems, selecting the option which is most preferred. If there are no limits of mining and relevant data is available, some variables characterizing the field can be sometimes optimized, in particular, the size and the layer intended for exploitation.

Net present value (NPV) was proposed for the economic evaluation of field exploitation in the form of updated values from the period of preparing for the exploitation, operating at full capacity, and the liquidation period. NPV is proposed because the time factor (time value of money) must be taken into account during the evaluation of the calculation of cash inflow and expenditure (and not income and expenses) and used to correspond to the company's financial liquidity.

2. ALGORITHM OF ECONOMIC EVALUATION OF FIELD EXPLOITATION PROJECT

Economic efficiency regarding the exploitation of a field can be described by the formula (Wanielista 1995; Butra 2001)

$$NPV = NPV_r + NPV_e + NPV_l \tag{1}$$

where:

- NPV – net present value from the period of preparation, exploitation, and liquidation of the field in zloty (zł);
- NPV_r – net present value from the period required for the preparation of the field, zł;
- NPV_e – net present value from the period of the exploitation of the field, zł;
- NPV_l – net present value from the period of the liquidation of the field, zł.

Net present value from the period of the preparation of the field can be described by the formula

$$NPV_r = \sum_{t=0}^{T_r} \frac{NCF_{rt}}{(1+RADR)^t} \tag{2}$$

wherein

$$NCF_{rt} = CIF_{rt} - COF_{rt} \tag{3}$$

where:

- T_r – a period of field preparation for exploitation, years;
- NCF_{rt} – balance of flow of funds in the *t*-th year, zł;
- $RADR$ – discount rate of risk;
- CIF_{rt} – cash inflow in the *t*-th year zł/year;
- COF_{rt} – expenditure (not to be confused with expenses) in the *t*-th year, zł.

For mining projects which exploit raw materials, a sub-account for the intermediate product or raw materials can be used for the calculation of cash inflow and expenditure, and for rolling costs in relation to the final products. A selling formula is used in the first case, usually negotiated on an external or internal market. A general selling formula for minerals, of which the value does not depend on the contained useful raw materials, can be approximately derived from the profits equation

$$W_k (p_k - c_k) = W_f (p_f - c_f) r_z \tag{4}$$

where

$$p_k = \frac{W_f}{W_k}(p_f - c_f) r_z + c_k \tag{5}$$

or

$$p_k = \gamma_f (p_f - c_f) r_z + c_k \tag{6}$$

where:

- W_k – mineral extraction, Mg/year;
- W_f – final product from the extracted mineral, Mg/year;
- p_k – conventional price of extracted mineral, zł/Mg;
- p_f – market price of the final product, zł/Mg;
- c_k – mineral extraction costs, zł/Mg;
- c_f – rolling costs of producing the final product, zł/Mg;
- γ_f – the final product yield, Mg/Mg;
- r_z – coefficient determining the portion of the profit attributable to mining processes or mining companies ($r_z < 1$).

If the value of minerals depends on the contained useful raw materials, the approximate value of the minerals can be calculated from the formula

$$p_k = 0{,}01\alpha\varepsilon (p - c) r_z \tag{7}$$

where:

- α – content of useful ingredients in the mineral, %;
- ε – total yield of useful ingredient in the final process;
- *pf* – market price of the final product, zł/Mg;
- *cf* – rolling costs of producing the final product, zł/Mg.

Given the above, cash inflow during the preparation of the field for exploitation are determined by the formula

$$CIF_{rt} = W_{rt} p_k \tag{8}$$

where:

W_{rt} – mineral extraction in the period of field preparation for the exploitation in the *t*-th year, Mg/year.

Expenditure during the preparation of the field for exploitation in the *t*-th year can be represented by the formula

$$COF_{rt} = \sum_{i=1}^{n} IC_{rti} + \sum_{j=1}^{m} WC_{rtj} + CO_{rt} + v_{rt} W_{rt} + (F_{kt} - DEP_{kt}) \frac{W_{rt}}{W_{kt}} \tag{9}$$

where:

- n – fixed assets involved in exploitation, pc.;
- IC_{rti} – the price of fixed assets including expenditure on their transport and installation in the exploitation field in the *t*-th year, zł/j.n. (lm., pc.);
- WC_{rtj} – price of the *j*-th current asset (or groups of assets) and the expenditure required for the transportation and eventual installation in the exploitation field in the *t*-th year, zł/j.n.;
- CO_{rt} – other operating expenses to prepare the field for exploitation not included in the expenditure for the purchase of fixed assets and current assets, zł/year;
- v_{rt} – unit variable costs regarding the extraction of ore in the period of preparing a field for exploitation and its possible throughput in the processes not connected with mining, zł/j.n.;
- W_{kt} – total mineral extraction in the *t*-th year, Mg/year;
- F_{kt} – standing costs of the mineral extraction in *t*-th year, zł/year;
- DEP_{kt} – depreciation costs of fixed assets in the *t*-th year, zł/year.

The discount rate can be represented by the formula

$$RADR = WACC + PR \tag{10}$$

where:

- $RADR$ – discount rate of risk;
- $WACC$ – the weighted average cost of capital;
- PR – risk premium.

Net present value from the period of the exploitation of a field can be described by the formula

$$NPV_e = \sum_{t=T_r+1}^{T_e} \frac{NCF_{et}}{(1+RADR)^t} \tag{11}$$

where

$$NCF_{et} = CIF_{et} - COF_{et} \tag{12}$$

where:

- T_e – a period of field exploitation, years;
- CF_{et} – balance of the flow of funds in the *t*-th year, in the period of field exploitation zł/year;
- CIF_{et} – cash inflow in the t-th year from the field exploitation, zł/year;
- COF_{et} – expenditure in the *t*-th year from the field exploitation, zł/year.

The period of the field exploitation is represented by the formula

$$T_e = \frac{W_{ep}}{W_e} \tag{13}$$

where:

- W_{ep} – exploitation of mineral resources extracted in the period of the field exploitation, Mg;
- W_e – an average annual exploitation in the period of the field exploitation, Mg/year.

Total exploitation resources may be calculated by the formula

$$W_p = W_{rp} + W_{ep} + W_{lp} \tag{14}$$

where

$$W_{ep} = W_p - W_{rp} - W_{lp} \tag{15}$$

wherein

$$W_{rp} = W_r T_r \tag{16}$$

$$W_{lp} = W_l T_l \tag{17}$$

where:

- W_p – total exploitation resources of the field, Mg;
- W_{rp} – exploitation resources of the field, extracted during the period of the exploitation, Mg;
- W_{lp} – exploitation resources of the field extracted during the period of field liquidation, Mg;
- W_r – average annual mineral exploitation in the period of the field preparation for the exploitation, Mg/year;
- W_l – average annual exploitation in the period of field liquidation, Mg/year;
- T_l – period of the field liquidation, years.

Correlation between exploitation resources and industrial resources of the field are represented by the formula

$$W_p = Q_p - S + U \tag{18}$$

where

$$S = 0{,}01 s Q_p \tag{19}$$

$$U = 0{,}01 z W_p \tag{20}$$

By substituting (19) and (20) to (18) the formula will change into

$$W_p = Q_p - 0{,}01 s Q_p + 0{,}01 z W_p \tag{21}$$

where

$$W_p = Q_p \frac{100 - s}{100 - z} \tag{22}$$

and

$$Q_p = W_p \frac{100 - z}{100 - s} \tag{23}$$

where:

- Q_p – field industrial resources, Mg;
- S – exploitation loss, Mg;
- U – rock contaminating the mineral, Mg;
- s – exploitation loss, %;
- z – mineral contamination, %.

Cash inflow from exploitation in the t-th year can be represented by the formula

$$CIF_{et} = W_{et} p_k + \sum_{i=1}^{n} VL_{eti} \tag{24}$$

wherein

$$VL_{eti} = P_{ei} - DEP_{eti} \tag{25}$$

where:

- W_{et} – annual mineral extraction from the exploited field, Mg/year;
- VL_{eti} – liquidation value (withdrawal from use) the i-th fixed asset in the t-th year of exploitation, zł/j.n.;
- P_{ei} – purchase or production price of the i-th fixed asset with its transport and installation in the exploited field in the t-th year, zł/j.n.;
- DEP_{eti} – the depreciation value of the i-th fixed asset value as at the t-th year of exploitation, zł/j.n.

Expenditure in the period of the field exploitation in the t-th year is represented by the formula

$$COF_{et} = \sum_{i=1}^{n} IC_{eti} + \sum_{j=1}^{m} WC_{etj} + v_{et} W_{et} + \left(F_{kt} - DEP_{kt}\right) \frac{W_{et}}{W_{kt}} \tag{26}$$

where:

- IC_{eti} – an investment expenditure for the purchase of the i-th new or replacement of an old fixed asset in the t-th year of the field exploitation, zł/j.n.;
- WC_{etj} – purchase of the j-th new current asset, which changes initial levels of current assets, zł/j.n.;
- v_{et} – unit variable costs for mineral extraction in the period of field exploitation and its possible throughput in the processes not connected with mining, zł/j.n.

Net present value from the period of the field liquidation can be calculated by the formula

$$NPV_l = \sum_{t=T_r+T_e+1}^{T_l} \frac{NCF_{lt}}{(1 + RADR)^t} \tag{27}$$

wherein

$$NCF_{lt} = CIF_{lt} - COF_{lt} \tag{28}$$

where:

- T_l – a period of the field liquidation, years;
- NCF_{lt} – cash inflow in the t-th year from the field exploitation, zł/year;
- COF_{lt} – expenditure in the t-th year from the field exploitation, zł/year.

Cash inflow in the t-th year of field liquidation is presented by the formula

$$CIF_{lt} = W_{lt} p_k + \sum_{i=1}^{n} VL_{lti} \tag{29}$$

wherein

$$VL_{lti} = P_{li} - DEP_{lti} \tag{30}$$

where:

W_{lt} – the mineral extraction in the t-th year of the field liquidation, Mg/year;

VL_{lti} – liquidation value of the i-th fixed asset in the t-th year of exploitation, zł/j.n.;

P_{li} – purchase or production price of the i-th fixed asset with its transport and installation in the exploited field in the t-th year, zł/j.n.;

DEP_{lti} – the value of the depreciation of the i-th fixed asset value as at the t-th year of exploitation, zł/j.n.

Cash inflow from the liquidation of fixed assets concerning assets (e.g. machines), which will be sold or are intended to be used further.

Expenditure in the t-th year of field liquidation is represented by the formula

$$COF_{lt} = IC_{lt} + CO_{lt} + v_{lt}W_{lt} + \left(F_{kt} - DEP_{kt}\right)\frac{W_{lt}}{W_{kt}} \quad (31)$$

where:

IC_{lt} – expenditure according to the schedule for the liquidation of used fixed assets (not intended for further use) in the t-th year field liquidation, zł/year;

CO_{lt} – expenditure on used current assets in the t-th year of field liquidation, zł/year;

v_{lt} – unit variable costs of mineral extraction in the t-th year of field exploitation, zł/Mg;

W_{lt} – the mineral extraction in the t-th year of the field liquidation, Mg/year.

3. AN EXAMPLE APPLICATION OF THE ALGORITHM

Below you will find an example of an economic evaluation for exploiting a field of copper ore, industrial resources Q = 1 200 000 Mg and ore mineralization α = 3.51% Cu.

1) The calculation of the initial net value from the field preparation period for exploitation

Data:

$W_k = 30{\cdot}10^6$Mg ore/year; p = 15 000 zł/MgCu; c = 10 000 zł/MgCu; α = 3.51%; ε = 0.7; r_z = 0.9;

$$\sum_{i=1}^{n} IC_{r1i} = 10\cdot 10^6\,\text{zł}\,;\sum_{i=1}^{n} IC_{r2i} = 12\cdot 10^6\,\text{zł};$$

$$\sum_{i=1}^{m} WC_{r1i} = 2\cdot 10^6\,\text{zł};\sum_{i=1}^{m} WC_{r2i} = 3\cdot 10^6\,\text{zł};$$

CO_{r1} = $0.5{\cdot}10^6$ zł; CO_{r2} = $0.5{\cdot}10^6$ zł; $v_{r1} = v_{r2}$ = 25.0 zł/Mg ore;

$W_{r1} = W_{r2} = 80{\cdot}10^3$ Mg ore/year;

$F_{k1} = F_{k2} = 500{\cdot}10^6$ zł/year;

$DEP_{k1} = DEP_{k2} = 300{\cdot}10^6$ zł/year;

$W_{k1} = W_{k2} = 6{\cdot}10^6$ mg/year;

$T_r = 2$; $RADR = 0.12$.

a) ore price calculation (7):

$$p_k = 0.01\cdot 3.51\cdot 0.7(15\,000 - 10\,000)\cdot 0.9 = 110.6$$

zł/Mg ore;

b) cash inflow calculation (8):

$$CIF_{r1} = CIF_{r2} = 80\cdot 10^3\cdot 110.6 = 8.848\cdot 10^6 \text{ zł/year};$$

c) expenditure calculation (9):

$$COF_{r1} = 10\cdot 10^6 + 2\cdot 10^6 + 0.5\cdot 10^6 + +25\cdot 80\cdot 10^3$$

$$+(500-300)\cdot 10^6\cdot\frac{80\cdot 10^3}{6\cdot 10^6} = 17.1\cdot 10^6 \text{ zł/year},$$

$$COF_{r2} = 12\cdot 10^6 + 3\cdot 10^6 + 0.5\cdot 10^6 + 25\cdot 80\cdot 10^3 +$$

$$+(500-300)\cdot 10^6\cdot\frac{80\cdot 10^3}{6\cdot 10^6} = 20.1\cdot 10^6 \text{ zł/year};$$

d) annual balance of funds flow calculation (3):

$$NCF_{r1} = 8.848\cdot 10^6 - 17.1\cdot 10^6 = -8.252\cdot 10^6 \text{ zł/year},$$

$$NCF_{r2} = 8.848\cdot 10^6 - 20.1\cdot 10^6 = -11.252\cdot 10^6 \text{ zł/year};$$

e) calculation of initial net value of the field preparation period for exploitation (2):

$$NPV_r = \frac{-8.252\cdot 10^6}{1.12} + \frac{-11.252\cdot 10^6}{1.25} = -16.37\cdot 10^6 \text{ zł}.$$

2) The calculation of initial net value from the field exploitation period

Data:

Q_p = 1 200 000 Mg; s = 10%; z = 5%; $W_r = 80{\cdot}10^3$ Mg/year;

T_r = 2 years;

$W_l = 20{\cdot}10^3$ Mg/year; T_l = 2 years; $W_{et} = 400{\cdot}10^3$ Mg/year;

v_{et} = 25.0 zł/Mg;

$F_{kt} = 500{\cdot}10^6$ zł/year; $DEP_{kt} = 300{\cdot}10^6$ zł/year;

$W_{kt} = 6{\cdot}10^6$ Mg/year;

$$\sum_{i=1}^{n} IC_{eti} = 0;\ \sum_{j=1}^{m} WC_{etj} = 0, \sum_{i=1}^{n} VL_{eti};$$

a) supplementation of data from calculations (22), (15), (13):

$$W_p = 1\,200\,000\,\frac{100-10}{100-5} = 1\ 140\ 000 \text{ Mg/field};$$

$$W_{ep} = 1\ 140000 - 2\cdot 80\cdot 10^3 - 2\cdot 20\cdot 10^3 = 940000 \text{ Mg/field};$$

$$T_e = \frac{940\ 000}{400\ 000} = 2.35 \text{ year};$$

b) cash inflow calculation (24):

$$CIT_{e1} = CIF_{e2} = 110.6\cdot 400\ 000 = 44.24\cdot 10^6 \text{ zł/year};$$

$$CIF_{e3} = 110.6\cdot 0.35\cdot 400\ 000 = 15.484\cdot 10^6 \text{ zł/year};$$

c) expenditure calculation (26):

$$COF_{e1} = COF_{e2} = 25.0\cdot 400\,000 +$$

$$+(500-300)10^6\,\frac{4\cdot 10^5}{6\cdot 10^6} = 23.3\cdot 10^6 \text{ zł/year};$$

$$COF_{e3} = 25{,}0\cdot 0{,}35\cdot 400\cdot 10^3 +$$

$$+(500-300)10^6\,\frac{0{,}35\cdot 400\cdot 10^3}{6\cdot 10^6} = 8.16\cdot 10^6 \text{ zł/year};$$

d) annual balance of cash inflow calculation (12):

$$NCF_1 = NCF_2 = 44.24\cdot 10^6 - 23.3\cdot 10^6 = 20.94\cdot 10^6 \text{ zł/year};$$

$$NCF_3 = 15.484\cdot 10^6 - 8.16\cdot 10^6 = 7.324\cdot 10^6 \text{ zł/year};$$

e) the calculation of the initial net value from the field exploitation period (11):

$$NPV_e = \frac{20.94 \cdot 10^6}{1.4} + \frac{20.94 \cdot 10^6}{1.57} + \frac{7.324 \cdot 10^6}{1.76} = 32.46 \cdot 10^6 \text{ zł.}$$

3) Calculation of net value from the field liquidation period

Data:

$W_{l1} = W_{l2} = 20 \cdot 10^3$ Mg/year; $IC_{l1} = 0.5 \cdot 10^6$ zł;

$IC_{l2} = 5.3 \cdot 10^6$ zł;

$CO_{l1} = 0.3 \cdot 10^6$; $CO_{l2} = 0.4 \cdot 10^6$ zł; $p_k = 110.6$ zł/Mg;

$v_{l1} = v_{l2}$ 25.0 zł/Mg;

$F_{k1} = F_{k2} = 500 \cdot 10^6$ zł; $DEP_{k1} = DEP_{k2} = 300 \cdot 10^3$ zł;

$W_{k1} = W_{k2} = 6 \cdot 10^6$ zł/year.

a) supplementation of data from calculations (VL_{lt} calculation)

It was adopted schematically that the life of all fixed assets is five years, this corresponds to a 20 percent depreciation rate.

At the beginning of the first year, fixed assets worth $10 \cdot 10^6$ zł were installed, which were withdrawn from the field at the end of the first year of the field liquidation. The period of their use was: 2 + 2.35 = 4.35 years.

The annual cost of depreciation was $10 \cdot 10^6$ zł: 5 = $2 \cdot 10^6$ zł. The liquidation value of the assets was: $10 \cdot 10^6 - 4.35 \cdot 2 \cdot 10^6 = 1.3 \cdot 10^6$ zł.

At the end of the second year of the field preparation, fixed assets were installed (VL_{lt}) worth $12 \cdot 10^6$ zł and they were withdrawn from use at the end of the second year of the liquidation, the period of use was also 4.35 years. The annual cost of depreciation was $12 \cdot 10^6$: 5 = $2.4 \cdot 10^6$ zł. The liquidation value of the assets was $12 \cdot 10^6 - 4.35 \cdot 2.4 \cdot 10^6 = 1.56 \cdot 10^6$ zł.

b) income calculation (29):

$$CIF_{l1} = 20 \cdot 10^3 \cdot 110.6 + 1.3 \cdot 10^6 = 3.51 \cdot 10^6 \text{ zł/year;}$$

$$CIF_{l2} = 20 \cdot 10^3 \cdot 110.6 + 1.56 \cdot 10^6 = 3.77 \cdot 10^6 \text{ zł/year;}$$

c) expenditure calculation (31):

$$COF_{l1} = 0.5 \cdot 10^6 + 0.3 \cdot 10^6 + 25 \cdot 20 \cdot 10^3 + \\ + (500 - 300)10^6 \frac{20 \cdot 10^3}{6 \cdot 10^6} = 1.96 \cdot 10^6 \text{ zł;}$$

$$COF_{l2} = 5.3 \cdot 10^6 + 0.4 \cdot 10^6 + 25 \cdot 20 \cdot 10^3 + \\ + (500 - 300)10^6 \frac{20 \cdot 10^6}{6 \cdot 10^6} = 6.86 \cdot 10^6 \text{ zł;}$$

d) annual cash balances calculation (28):

$$NCF_{l1} = (3.51 - 1.96)10^6 = 1.55 \cdot 10^6 \text{ zł/year;}$$

$$NCF_{l2} = (3.77 - 6.86)10^6 = -3.09 \cdot 10^6 \text{ zł/year;}$$

e) calculation of an initial net value of the field liquidation (27):

$$NPV_l = \frac{1.55 \cdot 10^6}{(1 + 0.12)^{5,35}} - \frac{3.09 \cdot 10^6}{(1 + 0.12)^{6,35}} = -0.66 \cdot 10^6 \text{ zł;}$$

4) Calculation of an initial net value of the project (1)

$$NPV = (-16.37 + 32.46 - 0.66)10^6 = 15.43 \cdot 10^6 \text{ zł.}$$

Conclusion: Exploitation of the project is profitable.

4. ENDING CONCLUSION

The extraction of minerals from the exploitation field can be treated as an investment project and a standard method can be applied for its evaluation. In the field exploitation, as in many other projects, there are three periods: 1) preparing for the exploitation, especially gallery and chamber works, 2) actual exploitation and 3) field liquidation. In this way, the level of extraction of minerals is differentiated, pointing out its absence in the period of preparation and liquidation. The initial period is typically characterized by high levels of investment expenditure, and the period of liquidation is associated with large expenditures, but also with low cash inflow due to the withdrawal of equipment to other fields.

Net present value was proposed for the economic evaluation of the exploitation of the fields, which is treated as the sum of the updated values of the three periods. This allows using the inflows and outflows, having a close relationship with the liquidity of companies and taking into account the time value of money. While evaluating the project exploitation field, it is recommended to limit the bill to the mining processes using conventional mineral prices, based on the price of the final product. This simplification is justified in the projects connected with raw materials because non-mining processes have a negligible impact on the operating efficiency of the field. Exploitation projects are analysed in many different exploitation systems, and if the relationship between the variables characterizing the field allow, its dimensions or the parameters of the layer intended for exploitation can be optimized.

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