ISSN 1392-1258. EKONOMIKA 2013 Vol. 92(4)

COMPARATIVE ANALYSIS OF THE PROSPECTS OF UKRAINIAN COAL MINES BY THE COPRAS-G METHOD

Oksana Zhylinska, Valery Balan*, Tatiana Petrovska

Taras Shevchenko National University of Kyiv, Ukraine

Abstract. *The article covers the elaboration of a methodical toolkit of assessing the prospects of coal mines, which allows for the differentiation of enterprises by an integrated index of their prospects as regards mining and the geological conditions of each coal mine. Is proposed An algorithm for the coal mine prospects assessment, of containing the stages of selecting the characteristics of mining and geological conditions, the use of a multi-attribute assessment by the COPRAS-G interval data, and the rating of coal mines. A comparative analysis of the prospects, employing the COPRAS-G method, was tested on an the example of 14 coal mines of the Central district Donbass of Ukraine.*

Key words*: comparative analysis, prospects, coal mines, multi-attribute assessment, imprecise data, COPRAS-G method, CEE*

Introduction

Together with an increase of mining or extraction of such an exhaustive non-renewable resource as coal from natural environments, the need of it as an energy carrier for different kinds of economic activity and as a raw material for alternative usage increases due to modern technologies. According to statistics, its world consumption over the last ten years has increased almost by 50% (gas consumption increased approximately by 30% and oil and atomic power by less than 10%); this fact is explained by the relative evenness of coal-mining fields across the globe. In the 20th century, the part of coal in the world fuel and energy balance significantly decreased, first at the expence of oil and then of the atomic power and gas, but now its part is about 30%. According to forecasts of international organizations, coal consumption in the nearest 20–30 years shall increase for the average annual rate of 1.4–1.6%, compromising on oil (1.7%) and natural gas (2.7–2.8%), but it still be the main source of electric power generation.

According to the 2012 BP Statistical Energy Survey, Central and Eastern Europe (CEE) had coal reserves of 52579.1 million tons at the end of 2011, i.e. 6.07% of the

* *Corresponding author:*

The Faculty of Economics, Department of Management of innovative and investment activity, Taras Shevchenko National University of Kyiv, 90A, Vasylkivska Str., 03022 Kyiv, Ukraine;

e-mail: balan_v_g@ukr.net

world total. The largest coal producer in Western Europe is Germany and in Eastern Europe Poland. Germany has the largest coal reserves in the EU, of which over 97% are lignite (brown coal), the remainder being bituminous and anthracite (hard coal). Germany had coal reserves of 40699 million tons at the end of 2011, equivalent to 215 years of current production and 4.72% of the world total. Germany is the seventh largest coal producer in the world. Germany's lignite reserves are inexpensive to produce, making it one of the world's largest lignite producers (20% of global output). Germany had coal production of 188.55 million tons and 1.12% of the world total.

Poland had coal reserves of 5709 million tons, equivalent to 40 years of the current production and 0.66% of the world total on the same period. Exploitable resources of bituminous coal and anthracite have been estimated at 60000 Mt of hard coal and 39000 Mt of lignite in 126 separate deposits. Lignite reserves are mainly located in the central parts of the country and account for 40% of the Polish power generation. Poland had coal production of 139.24 million tons in 2011, equivalent to 1.43% of the world total. Coal exports are one of Poland's largest foreign income earners through exports to Europe and the former Soviet Union. Coal is the dominant fuel in Poland.

In the recent years, CEE has suffered a decline in the traditional hard-coal mining industry, based predominantly on underground mining. The Government of Germany announced in 2007 that it planned to shut down its eight remaining black coal mines by 2018. Seven of the remaining mines are in the western state of North Rhine-Westphalia and one is located in the small state of Saarland on the border with France. At present, Germany's federal and regional governments subsidize coal mining by up to €2.5 billion a year, and the deal ensures continued financial support for the sector until the last mine is closed. The plan does not affect Germany's brown coal mining sector which can produce coal more cheaply because it uses open-cast mines.

The hard-coal mining industry in Poland also remains politically sensitive to trends. A new coal mining restructuring law became effective in 2003, providing for the cancellation of debt to a value of some US$4.8 billion, reduction in production levels and closure of certain collieries. The program, aimed to the privatization the country's coal industry, had implemented a formal restructuring of the existing production entities and the setting up of a new company, Kompania Węglowa, incorporating the operations of the five coal-mining companies, and it is the largest mining company in Europe now. Following the period of restructuring, Poland's coal production has stabilized and now is Europe's second largest producer after Germany (Survey, 2012).

The development of the coal mining industry in CEE shows the following trends:

- its countries' mining coalfields in the complex mining and geological conditions (for example, Poland) try to keep the mining volume at the attained level and to provide its profitability;

- countries holding the most complex coal fields for mining decrease theirown coal mining. Unprofitable coal mining is supported on account of state subsidy only in separate countries (Germany, Czech Republic, Hungary) where subsidy volumes and coal mining gradually decrease through closure of mines.

We note especially the practice of Great Britain where, within a relatively short period, radical change of the coal-mining industry was carried out: a considerable part of coal mines were closed down and the rest were modernized and privatized with cancelling state subsidy.

Much of the CEE region, especially Eastern Europe, remains heavily dependent on the utilization of indigenous lignite and hard coal as a significant component of primary energy supply.

Thus, the prospects of the development of coal mines in different CEE countries are multivalued and first of all determined by mining and the geological conditions of the formation and occurrence of coal beds and by the profitability level of coalfields. In addition, a different level of the quality of coalfields, taking into account the permanent deterioration of mining and the geological conditions of subsoil use, implicitly contains conditions under which the extraction of natural resources from a definite field is technically impossible or economically unsound. The modern world practice of coal mining increasingly shifts the focus on understanding coal as an economic category. In the modern conditions, it is possible to work out any resources and at any level of complexity of mining and geological conditions, but in this case there appear limitations, first of all of the economic aspects, as each coal mine has its own parameters for the definition of its attractiveness, and its complex characteristics of capability offer an objective assessment of the possibilities of its development.

Thus, the necessity of the assessment of coal mines is actualized according to the defined variety of criteria that enable to get an objective assessment of the state of the functioning mines, advisability of fields' exploitation, to find their resource and prospects for development, to differentiate the problems of an efficient use of funds for supporting and developing coal mines. These aspects are urgent in terms of restructuring coal industry in different CEE countries on the basis of corporatization and privatization for raising investments in coal mines. This, in turn, actualizes carrying out a profound comparative analysis of coal mines, diagnostics on this base of investment prospects of mines, the definition of the integrated index of their prospects.

Literature review

The Ukrainian and foreign researches propose different approaches to developing a toolkit for both assessment of enterprises in general and of coal mines in particular, which were given in many works of I. Alfyorova**,** A. Amosha, L. Baysarov, V. Honcharov, A. Griffen,

M. Illyashov, E. Kolesnichenko, I. Kolesnichenko, V. Makarov, N. Makortetsky, I. Novytsky, I. Pavlenko, N. Perov, G. Pivnyak, O. Pogorelets, D. Pogrebnoy**,** V. Salli, and others.

The increased publishing of studies in the recent years concerning assessment of coal mines' prospects confirms a high relevance level of this problem and the absence of unified approaches to its solution. The known, often inadequate, methods of assessing the prospects of coal mines either characterize insufficiently the coal mining objects or consider only separate aspects of their activity. In particular, a large majority of the existing approaches to solving this problem provides for the usage of exact values under assessment criteria, thus significantly limiting the possibilities of the practical use of these tools and resulting in strained resulting assessments.

A coal mine is a complex industrial structure; its technical and economic indexes of functioning first of all depend on the geological and mining conditions as well as on the arrangement and keeping of mining, a timely fund-raising for changing the equipment and supporting the production facilities. We can name the following reasons among the internal ones that essentially influence the functioning of a mine:

- mining and geological conditions (decrease of capacities due to local changes of geological conditions, gas, and geodynamic manifestations);
- engineering and manufacturing factors (non-conformance to technology and equipment, downtimes of equipment, etc.);
- economic factors (non-conformance of constant and variable expenses);
- organizational factors (weighted semi-fixed expenses, manpower insecurity, non-conformance of preparation work rates to bailing ones);
- informative and managerial factors (unreasonable managerial decisions).

Besides, when determining the ways of coal mines' development, it is reasonable to take into account their abilities concerning carrying out efficient innovative activities.

Thus, the problem of assessment of coal mines' prospects can be characterized by two aspects: the choice of assessment criterian and the elaboration of approaches to the assessment procedure.

Ukrainian authors have proposed an assessment methodology of the modern state of mine capacity concerning investment resources for its re-equipment, which covers only three main criteria: the prime cost of coal mining, the remaining service life of a mine, and the capacity of production links. As the proposed assessment methodology gives only three criteria, its range of application can be limited only by a preliminary assessment of a mine state as regards its prospects for investment (Amosha, 2002).

The authors have improved the classification of the impact factors of the efficiency of coal mines' management, which contains financial and economic factors (the ratios of liquidity, solvency, efficiency, profitability ratios), qualitative factors – geological and industrial ones (the remaining service life of a mine, coal ash, the quality of commercial reserves, production capacity, etc.), social factors – the number of injuries per year, of employees ill through work, the average annual wage, staff motivation), the ecological factors – annual expenses on contamination protection, methane emission, harmfulness of refuse bank dust for air) (Goncharov, 2010).

A. Griffen et al., based on the information of mines' passports and economic performance of their activity, for the definition of the integrated index of prospects propose to use data on technological, economic, and natural elements influencing the productive and economic state of mine, such as the rated productive capacity of mine, the real annual mining volume, winning mechanization and the mechanization of preliminary development, the wholesale price and cost per ton of coal, the depth of commercial reserves' calculation, the mean depth of the extraction of seams, the average dynamic seams' thickness, seams' inclination under extraction, the mean value of ash on coal under extraction, water flow, seam gas content (Griffen, Makortetsky, Makarov, Perov, 2003) .

For the assessment of a coal mine prospects, a group of authors propose to use the following criteria: availability of commercial reserves, their quality and periods of completion, mining and geological conditions of dead fields, the level and degree of miners' safety, the efficiency of mines, determined by comparing the costs for one monetary unit of commercial product related to the industry average level of this factor, as well as labour efficiency and supplements for one ton of coal mining, the possibility of a structural transforming of a mine for a stock company or its auction sale.

Authors have also developed a methodology for the assessment of mine prospects, containing three main stages: in the first stage, a preliminary analysis of advisability for the continuation of mine operation is carried out (based on the diagnostics of seam thickness and commercial reserves of coal, methane content, mining and geological faults, as well as technical and economic values, a conclusion is made concerning the advisability of the further assessment of a mine); in the second stage, a calculation of the indices of economic "attractiveness" and the mine's prospects, is made as a result of which the ranking of mines is carried out and the most advanced mines are determined; in the third stage, the growth possibility of economic performance of mines is assessed (particular technical, technological and organizational actions are carried out for this purpose, which can result in a coal mining increase; the investments volume, the period of their payback are determined (from the conditions of commercial attractiveness, an integral effect within the first 2–3 years after investment is determined, it is calculated from the economic performance of mines and the new values of centralized expenses) (Kolesnichenko, Kolesnichenko, Pogrebnoy, 2003).

Authors propose to determine the prospects of mines according to the prospect coefficient R_i calculated by the following formula:

$$R_i = \sqrt[7]{K_{T_i} \cdot K_{E_i} \cdot K_{G_i} \cdot K_{V_i} \cdot K_{Q_i} \cdot K_{S_i} \cdot K_{A_i}},$$

where K_{T_i}, K_{E_i}, K_{G_i}, K_{V_i}, K_{Q_i}, K_{S_i}, K_{A_i} – technological, economic, mining, and geological coefficients, coefficients of vital function, coefficients of enrichment efficiency, the social burden and ecological suitability of mines, where a higher prospect coefficient is an evidence of the prospects of coal mines in comparison with the other ones (Makarov, Perov, Makortetsky, Novytsky, 2010).

Authors give the following parameters among the key parameters influencing the function of a coal mine: the general availability of reserves, the volume weight of seams' reserves, the volume of seams' reserves in more favourable conditions, the volume of seams with a persistent thickness (for an area), seam thickness under extraction, the minimum depth of exploitation, the capacity of main links of a mine, mine capacity, the complexity of underground facilities, the average volume of annual coal mining. However, it is recommended to use two indicators to characterize the prospects of mines: seam thickness under extraction and the capacity of the main links of a mine (Pavlenko, Snadchuk, 2009).

T. Petrovska uses integrated indexes of the attractiveness of coal mines as a tool for the definition of mining rent sizes with the elaborated methodology of calculating the rating of mines by the TOPSIS multi-attribute analysis; unlike the existing practice, it allows differentiation of rental payment accrual in the mining and geological conditions of subsoil use of each separate coal mine (Petrovska, 2012).

In the article, it is proposed to determine the state of mine and its attractiveness using the estimated figures, in particular figures of economic reliability, taking into account three parameters – the economic level, the operational and geological reliability under which it is necessary to divide the mine fund into three groups according to differences in technical and economic, mining and geological parameters (Pivnyak, Salli, Baysarov, 2003).

The purpose of the article is to develop methods of a profound integral assessment of coal mines' prospects by the COPRAS-G method.

Logical basis of the hypothesis

Analysis of the available methodological support allows determining the limited possibilities of using the proposed approaches for the definition of a coal mine state from its development management. One of the tools that eliminates the given fault is a modification of the complex proportional assessment method (COmplex PRoportional ASsessment) COPRAS – COPRAS-G (2008), worked out at the Vilnius Gediminas Technical University by E. Zavadskas and A. Kaklauskas. The basis of this method is the concept

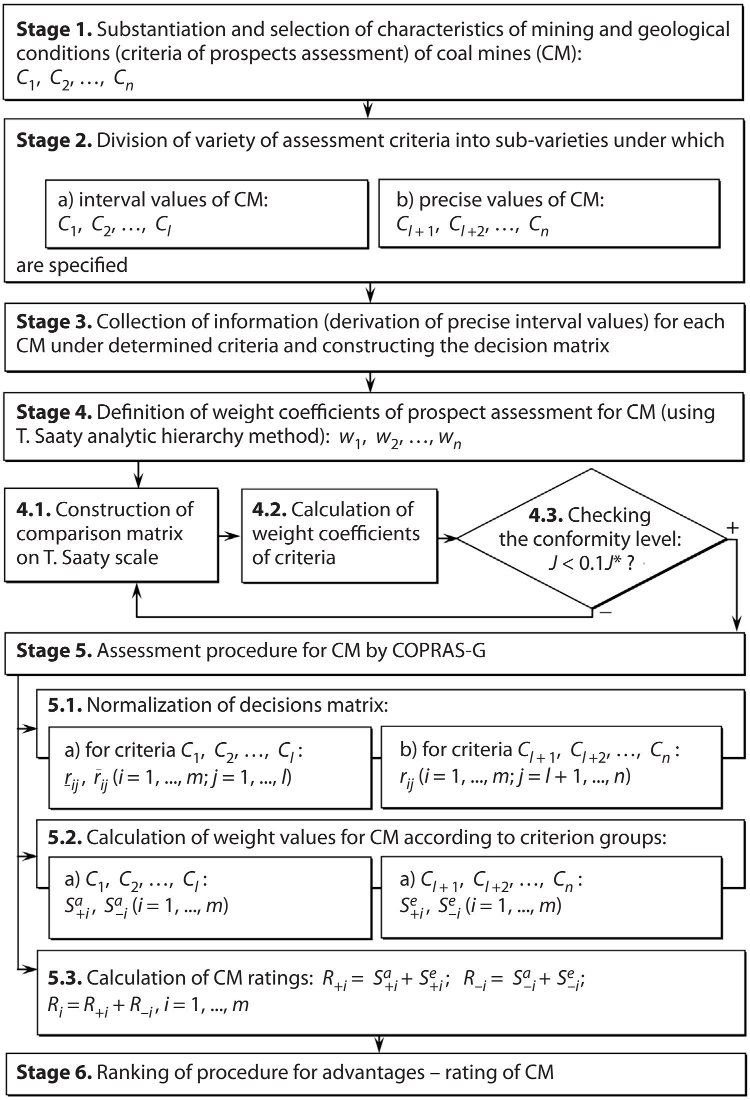

FIG. 1. **Stages of coal mine prospect assessment**

Source: compiled by the authors.

according to which an integral assessment of each alternative under examination is directly proportional to the effect of a criterion holding the monotonic increasing target function and is inversely proportional to the amount of the rated values under criterion, which have a monotonic descending target function (Zavadskas et al., 2008, 2009).

The procedure of using the of COPRAS-G method for a comparative analysis of coal mines and the determination of their prospects is performed by certain stages (see Fig. 1).

The 1st stage, upon involving specialists and experts, covers the substantiation and selection of a variety of assessment criteria for coal mines (CM). Note that the whole of coal mine parameters can be divided into natural uncontrolled elements (mining and geological conditions and the natural quality of coal) and industrial ones – controlled elements (machinery, technologies, and industrial management). The main stress in the research is laid exactly on mining and geological conditions which, in the authors' opinion, are essential in the context of coal mine prospects as other constituents concerning the industrial factors that can be improved by means of managerial actions. Thus, there was selected a group of criteria, which determine mining and geological conditions of mine fields (geological thickness of seams, commercial reserves of coal, excavation depth, balance sheet reserves of coal, wall length, length of mine section, excavation depth, seam inclination, mine gas content, mine water flow) and the quality of coal (combustion heat, humidity, ash and sulfur content). Fourteen coal mines of Ukraine were the objects of the research.

We renumbered assessment criteria at the **2nd stage** for separating criteria with the interval and precise values of CM in such a way that the criteria under which the interval values of CM were specified had numbers from 1 to *l,* and the criteria under which the precise values of CM were specified had numbers from $l + 1$ to n.

At the **3rd stage,** according to geological and explorative data, statistical and expert information, according to the determined criteria we formed a decision matrix: in general, the matrix was in the form presented in Table 1, and for the selected CM it was in the form presented in Table 2.

TABLE 1. **Decision matrix of multi-attribute assessment**

		Criteria under which interval values of CM are specified				**Criteria under which precise values of CM are specified**			
Criteria		C_1	C_2	...	C_l	C_{l+1}	C_{l+2}	...	C_n
Weight		w_1	w_2	...	w_l	w_{l+1}	w_{l+2}	...	w_n
CM value	CM_1	$[\underline{x}_{11}; \bar{x}_{11}]$	$[\underline{x}_{12}; \bar{x}_{12}]$	...	$[\underline{x}_{1l}; \bar{x}_{1l}]$	$x_{1,l+1}$	$x_{1,l+2}$	...	x_{1n}
	CM_2	$[\underline{x}_{21}; \bar{x}_{21}]$	$[\underline{x}_{22}; \bar{x}_{22}]$	...	$[\underline{x}_{2l}; \bar{x}_{2l}]$	$x_{2,l+1}$	$x_{2,l+2}$	...	x_{1n}
	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.
	CM_m	$[\underline{x}_{m1}; \bar{x}_{m1}]$	$[\underline{x}_{m2}; \bar{x}_{m2}]$	...	$[\underline{x}_{ml}; \bar{x}_{ml}]$	$x_{m,l+1}$	$x_{m,l+2}$	...	x_{mn}

We note that $[\underline{x}_{ij}; \bar{x}_{ij}]$ is the interval of change of the values of an *i*-coal mine ($i = 1, ..., m$) under the *j* criterion ($\underline{x}_{ij}$– low border, $\bar{x}_{ij}$ – upper border) ($j = 1, ..., l$), and x_{ij} is the value *i* of CM ($i = 1, ..., m$) under the *j* criterion ($j = l + 1, ..., n$).

TABLE 2. **Characteristics of mining and geological conditions for the functioning of coal mines of the Central district of Donbass of Ukraine under criteria of their prospect assessment**

Coal mine (CM)	Criteria under which CM interval values are specified																Criteria under which precise CM values are specified				
	Geological thickness of seams, m (C_1)		Wall length, m (C_2)		Length of mine section, m (C_3)		Depth of excavation, m (C_4)		Seam inclination, grade (C_5)		Mine gas content m^3/t of extracted coal (C_6)		Mine water flow, thous. m^3/year (C_7)		Coal humidity, % (C_8)		Commercial reserve of coal, thous. t (C_9)	Balance sheet reserves of coal, thous. t (C_{10})	Combustion heat, ccal/kg (C_{11})	Ash content of coal, % (C_{12})	Sulphur content in coal, % (C_{13})
	$\underline{x}$	$\bar{x}$ *	$\underline{x}$	$\bar{x}$	$\underline{x}$	$\bar{x}$	$\underline{x}$	$\bar{x}$	$\underline{x}$	$\bar{x}$	$\underline{x}$	$\bar{x}$	$\underline{x}$	$\bar{x}$	$\underline{x}$	$\bar{x}$					
CM 1	1	1.2	90	95	1100	1130	950	1000	55	60	21	23	420	440	1.3	1.6	15100	21076	8500	36.94	2.22
CM 2	1	1.1	110	115	411	418	1050	1100	45	50	20	21	570	610	1.8	2.1	47470	65851	8195	37.7	3.4
CM 3	0.9	1.1	97	105	765	770	900	975	50	55	21	22	450	500	1.6	1.8	17100	20499	8347	37.3	2.8
CM 4	0.9	1.2	95	103	764	769	975	1020	45	55	22	23	410	430	1.7	1.8	32500	36917	8347.5	37.3	2.8
CM 5	1.3	1.5	82	89	1998	2002	1100	1150	55	65	20	22	220	250	4	4.3	14600	17520	8300	36.86	2.3
CM 6	1.1	1.2	93	98	1175	1180	1000	1050	55	60	21	23	200	220	2.5	2.7	3050	3660	8331.7	37.2	2.7
CM 7	1.2	1.3	90	95	1585	1595	1050	1100	55	65	21	22	30	40	3	3.5	1900	2300	8315.8	37	2.5
CM 8	1.2	1.3	89	94	1580	1599	1070	1100	55	60	21	23	210	240	3	3.5	15000	76800	8315.8	37	2.5
CM 9	0.5	0.7	127	132	630	640	950	100	60	66	26	28	250	270	6	6.3	22200	30087	8600	37.1	3.6
CM 10	0.9	1	133	140	345	355	500	530	55	60	22	24	220	230	2	2.5	14300	23000	8500	34.75	2
CM 11	0.8	0.9	130	140	490	495	700	770	60	65	22	26	330	355	4	4.4	32900	36281	8550	35.9	2.8
CM 12	1	1.1	112	118	930	935	870	900	60	63	23	24	220	250	3.5	4	16100	20765	8456.3	36.4	2.7
CM 13	0.9	1	118	125	798	804	830	860	55	62	24	25	230	250	3.6	4.1	11800	14322	8484.4	36.2	2.7
CM 14	1	1.1	100	108	525	525	400	450	63	67	25	27	160	180	4	5	7400	10538	7500	36.35	2
Weight	0.0377		0.0295		0.0209		0.1021		0.0702		0.1053		0.1011		0.0306		0.1810	0.1668	0.0746	0.0471	0.0331
Monot.	↗		↗		↗		↘		↘		↘		↘		↘		↗	↗	↗	↘	↘

Source: Petrovska, 2012.

Stage 4. Determination of the weight coefficients of assessment criteria for coal mines (CM). It is possible to use the expert evaluation method of criteria on a 10 rating scale with the following normalization or a scale of paired comparison proposed by T. Saaty in the frame of the analytical hierarchy method (Saaty, 1980). When using the second approach, the matrix of a paired comparison for the criteria should be as follows:

$$
\begin{array}{c}
\\
C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \\ C_{10} \\ C_{11} \\ C_{12} \\ C_{13}
\end{array}
\begin{array}{c}
\begin{array}{ccccccccccccc}
C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 & C_{10} & C_{11} & C_{12} & C_{13}
\end{array}
\\
\begin{pmatrix}
1 & 2 & 3 & 1/3 & 1/2 & 1/3 & 1/3 & 2 & 1/4 & 1/4 & 1/3 & 1 & 2 \\
1/2 & 1 & 2 & 1/3 & 1/2 & 1/3 & 1/3 & 1 & 1/4 & 1/4 & 1/2 & 1/3 & 1 \\
1/3 & 1/2 & 1 & 1/4 & 1/3 & 1/4 & 1/4 & 1/2 & 1/5 & 1/5 & 1/3 & 1/2 & 1/2 \\
3 & 3 & 4 & 1 & 2 & 1 & 1 & 3 & 1/2 & 1/2 & 2 & 3 & 3 \\
2 & 2 & 3 & 1/2 & 1 & 1/2 & 1 & 3 & 1/3 & 1/3 & 1 & 2 & 3 \\
3 & 3 & 4 & 1 & 2 & 1 & 1 & 3 & 1/2 & 1/2 & 2 & 3 & 3 \\
3 & 3 & 4 & 1 & 1 & 1 & 1 & 3 & 1/2 & 1/2 & 2 & 3 & 3 \\
1/2 & 1 & 2 & 1/3 & 1/3 & 1/3 & 1/3 & 1 & 1/4 & 1/5 & 1/4 & 1/2 & 1 \\
4 & 4 & 5 & 2 & 3 & 2 & 2 & 4 & 1 & 2 & 3 & 4 & 4 \\
4 & 4 & 5 & 2 & 3 & 2 & 2 & 5 & 1/2 & 1 & 3 & 4 & 4 \\
3 & 2 & 3 & 1/2 & 1 & 1/2 & 1/2 & 4 & 1/3 & 1/3 & 1 & 2 & 3 \\
1 & 3 & 2 & 1/3 & 1/2 & 1/3 & 1/3 & 2 & 1/4 & 1/4 & 1/2 & 1 & 2 \\
1/2 & 1 & 2 & 1/3 & 1/3 & 1/3 & 1/3 & 1 & 1/4 & 1/4 & 1/3 & 1/2 & 1
\end{pmatrix}
\end{array}
$$

The sought weight coefficients of the criteria are the own numbers of the formed matrix $A = \left\| a_{ij} \right\|_{n \times n}$, but they can be calculated by the approximate formula:

$$w_i = \frac{\sqrt[n]{a_{i1} \times a_{i2} \times \ldots \times a_{in}}}{\sum\limits_{k=1}^{n} \sqrt[n]{a_{k1} \times a_{k2} \times \ldots \times a_{kn}}}, \quad i = 1; 2; \ldots; n \ (n = 13), \text{ where } \sum_{i=1}^{n} w_i = 1.$$

As a result, we receive a weight vector: $w_1, w_2, \ldots, w_n$.

We note that the Saaty method supposes a possibility of checking the interrater consistency by means of calculating the consistency index J and comparing it with the master value J^*. In case of breaching the condition $J \le 0{,}0J^*$ (for $n = 13$ value $J^* = 1{,}56$) it is necessary to reconsider the values of a paired comparison for the criteria (Saaty, 1980).

Stage 5 – the procedure of CM prospects' assessment is carried out directly on the basis of the COPRAS-G method.

First, it is necessary to carry out the normalization of the decision matrix. At this step, it is necessary to turn criteria to dimensionless ones allowing a comparison of CM in future.

We use the following ratios for criteria under which CM values are specified:

$$\underline{r}_{ij} = \frac{\underline{x}_{ij}}{\frac{1}{2}\cdot\left(\sum_{k=1}^{m}\underline{x}_{kj} + \sum_{k=1}^{m}\overline{x}_{kj}\right)} = \frac{2\cdot\underline{x}_{ij}}{\sum_{k=1}^{m}\underline{x}_{kj} + \sum_{k=1}^{m}\overline{x}_{kj}}$$

$$\overline{r}_{ij} = \frac{\overline{x}_{ij}}{\frac{1}{2}\cdot\left(\sum_{k=1}^{m}\underline{x}_{kj} + \sum_{k=1}^{m}\overline{x}_{kj}\right)} = \frac{2\overline{x}_{ij}}{\sum_{k=1}^{m}\underline{x}_{kj} + \sum_{k=1}^{m}\overline{x}_{kj}},$$

where $i = 1, \ ...; m, \ j = 1, \ ...; l$.

We use the following transformation for criteria under which the precise values of CM are specified:

$$r_{ij} = \frac{x_{ij}}{\sum_{k=1}^{m} x_{kj}},$$

where $i = 1, \ ...; m, j = l + 1, \ ...; n$.

The next step is the calculation of the weight values of coal mines with consideration of the nature of criteria monotonicity.

It is necessary to divide each of the varieties of criteria $C_1, C_2, \ldots, C_l$ and $C_{l+1}, C_{l+2}, \ldots, C_n$ for carrying out this stage, for two sub-varieties: criteria that have a monotonic increasing target function and criteria with a monotonic descending target function (see Table 3).

TABLE 3. **Sub-variety of multi-attribute assessment depending on the monotonicity nature of their target functions**

Criteria	$C_1, C_2, \ldots, C_l$		$C_{l+1}, C_{l+2}, \ldots, C_n$	
Nature of monotonicity	Monotonic increasing (↗)	Monotonic descending (↘)	Monotonic increasing (↗)	Monotonic descending (↘)
Sub-varieties	$C_1, \ldots, C_s$	$C_{s+1}, \ldots, C_l$	$C_{l+1}, \ldots, C_t$	$C_{t+1}, \ldots, C_n$

We calculate the following amounts:

$$S_{+i}^{a} = \frac{1}{2}\sum_{j=1}^{s} w_j \cdot (\underline{r}_{ij} + \overline{r}_{ij});$$

$$S_{-i}^{a} = \frac{1}{2}\sum_{j=s+1}^{l} w_j \cdot (\underline{r}_{ij} + \overline{r}_{ij}),$$

where S_{+i}^{a}, S_{-i}^{a} are weight amounts of assessments under criteria which have monotonic increasing and monotonic descending target functions, respectively (for criteria with the interval values of CM);

$$S^{e}_{+i} = \sum_{j=l+1}^{t} w_j \cdot r_{ij};$$

$$S^{e}_{-i} = \sum_{j=t+1}^{n} w_j \cdot r_{ij},$$

where S^{e}_{+i}, S^{e}_{-i} are weight amounts of assessments under criteria which have monotonic increasing and monotonic descending target functions, respectively (for criteria with the precise values of CM).

The following step is the calculation of $S_{+i} = S^{a}_{+i} + S^{e}_{+i}$, $S_{-i} = S^{a}_{-i} + S^{e}_{-i}$ and R_{+i} i R_{-i} values by the following formulas:

$$R_{+i} = S_{+i}, \qquad R_{-i} = \frac{\sum_{k=1}^{m} S_{-k}}{S_{-i} \cdot \sum_{k=1}^{m} \frac{1}{S_{-k}}}.$$

According to those calculations, we can calculate the sought ratings of coal mines by determining the integrated index of their prospects:

$R_i = R_{+i} = R_{-i}$, $i = 1, ..., m$.

Results of a comparative analysis are presented in Table 4.

TABLE 4. **Rating of coal mines of the Central district of Donbass of Ukraine under the level of their prospects on the basis of the COPRAS-G method**

Coal Mine	S^{e}_{+i}	S^{e}_{-i}	S^{a}_{+i}	S^{a}_{-i}	R_{+i}	R_{-i}	R_i	Rank
1	2	3	4	5	6	7	8	9
CM 1	0.0256	0.0054	0.0064	0.0319	0.0320	0.0324	**0.0644**	9
CM 2	0.0683	0.0065	0.0056	0.0357	0.0739	0.0287	**0.1026**	1
CM 3	0.0267	0.0059	0.0058	0.0323	0.0324	0.0316	**0.0640**	10
CM 4	0.0450	0.0059	0.0058	0.0316	0.0508	0.0322	**0.0830**	4
CM 5	0.0235	0.0054	0.0084	0.0301	0.0320	0.0340	**0.0660**	8
CM 6	0.0091	0.0058	0.0067	0.0277	0.0158	0.0361	**0.0519**	14
CM 7	0.0077	0.0056	0.0075	0.0243	0.0152	0.0404	**0.0557**	13
CM 8	0.0499	0.0056	0.0075	0.0290	0.0574	0.0349	**0.0923**	2
CM 9	0.0347	0.0066	0.0051	0.0293	0.0398	0.0337	**0.0735**	5
CM 10	0.0258	0.0050	0.0057	0.0239	0.0315	0.0419	**0.0734**	6
CM 11	0.0451	0.0058	0.0056	0.0308	0.0507	0.0331	**0.0838**	3
CM 12	0.0261	0.0057	0.0064	0.0288	0.0325	0.0350	**0.0676**	7
CM 13	0.0202	0.0057	0.0061	0.0287	0.0263	0.0351	**0.0614**	11
CM 14	0.0148	0.0051	0.0056	0.0250	0.0203	0.0402	**0.0605**	12

Source: compiled by the authors.

According to the performed calculations, most attractive by the prospects' level among 14 coal mines of Central Donbass of Ukraine is CM 2, followed CM 8 and others. A comparison of the rating of coal mine prospects, obtained by the COPRAS-G method, with other results allows stating a high level of their concordance (Petrovska, 2012).

Conclusions

The article covers working out a methodical toolkit of assessment for the prospects of coal mines, which allows for the differentiation of enterprises on the ground of the integrated index of their prospects under mining and geological conditions of subsoil use of each coal mine. An algorithm for prospects' assessment of coal mines is proposed, containing the fllowing stages: selection of the characteristics of mining and geological conditions, the use of a multi-attribute assessment by the COPRAS-G interval data, and the rating of coal mines. A comparative analysis of the prospects of the by the COPRAS-G method was tested on an example of 14 coal mines of Central district Donbass of Ukraine.

The obtained results allow implementation of strategic approaches to determining the prospects of enhancing the efficiency of coal mines in general and substantiation of their participation in the performance of programs of the future development of the branch for the long-run period in terms of reconstruction, privatization, winding up, temporary shut-down or the further development of each separate coal mine in particular; this will increase the objectivity in allocating the of state funds for support of these coal mines and the efficiency of their use.

Rating values can also be useful for investment prioritization when developing investment projects (programs) of the technical re-equipment of coal mines for the purpose of the total use of their production capability by means of their reconstruction, restoration, capital development, renewal of mining equipment, adoption of energy-efficient, ecological technologies, and building new technological complexes.

Thus,So results of a comparative analysis by the multi-attribute COPRAS-G method can be used for the determination of coal mine prospects, their general investment attractiveness, ratings, as well as sizes of differential payment by these mines of mining rents allowing for their mining and geological conditions.

The proposed methodical toolkit for prospects assessment of mines allows for a consideration of imprecision of presenting data under criteria of prospects' assessment in the form of interval which is more distinctive for applied problems. A comparative analysis carried out in the form of calculation pattern under EXCEL allows researching the sensibility of ratings for coal mine prospects depending on the weight values of the coefficients of assessment criteria and in cases of correcting the ranges of values' variation under certain criteria.

The further studies on the topic of this article can be aimed at the detailing and substantiation of the criteria of prospects' assessment for coal mines, in particular taking into consideration the resulting assessment, except natural (uncontrolled) elements as well as industrial factors – controlled elements in the form of machinery, technologies, and industrial management. The proposed methodical approach can be used as a simulating model allowing a research of the impact of human factor (expert assessments of the importance of criteria) on the possible results of assessment, as well as in case of values' variation for coal mines according to certain criteria. A comparative analysis of coal mines' prospects by the COPRAS-G method can be used for the assessment of any industrial enterprises according to the determined variety of criteria for substantiating the prospects of their development.

REFERENCES

Coal Mining in Europe. (2012). Overview. http://www.mbendi.com/indy/ming/coal/eu/p0005.htm

Amosha A., Ilyashov M., Salli V. (2002). System analysis of mine as an investment project. Donetsk: Institute for Industrial Economics of the National Academy of Science of Ukraine, 68 p.

Goncharov V., Alfyorova I., Pogorelets O. (2010). Improvement of classification of values influencing coal mine management. Gazette of Zaporizhzhya National University, № 3(7), p. 24–29.

Griffen A., Makortetsky N., Makarov V., Perov N. (2003). Methodological bases of determination of prospects for mines of Ukraine. Geotechnical mechanics: Inter-agency collection of scientific papers. Dnipropetrovsk, Publication 44, p. 60–64.

Hwang C., Yoon K. (1981). Multiple attributes decision making methods and applications. Springer: Berlin Heidelberg.

Kolesnichenko E., Kolesnichenko I., Pogrebnoy D. (2003). Methodology for economic value of investment state and prospects for coal mines and companies. Mining Industry, № 4.

Makarov V., Perov N., Makortetsky N., Novytsky I. (2010). Ranging methodology for mines of Ukraine on prospects. Problems of general power industry. Publication 2(22), p. 26–30.

Pavlenko I., Snadchuk G. (2009). System of selection of advanced mines for investment and support of their capacity. Scientific Gazette of National State University, Economics, № 11, p. 83–86.

Petrovska T. (2012). Management of the innovative development process of coal industry enterprises in Ukraine. PhD thesis. Donetsk, National University of Donetsk.

Pivnyak G., Salli V., Baysarov L. (2003). Coalmining investments: reality and forecasts. Coal Mines of Ukraine, № 5, p. 4–8.

Saaty T. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill.

Zavadskas E., Kaklauskas A., Turskis Z., Tamosaitiene J. (2009). Multi-attribute decision-making model by applying grey numbers. Informatica, 20(2), p. 305–320.

Zavadskas E., Turskis, Z., Tamosaitiene J., Marina V. (2008). Multicriteria selection of project managers by applying grey criteria. Technological and Economic Development of Economy, 14(4), p. 462–477.