An approach to differentiation and evaluation of mineral resource potential in coal mining

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Abstract. A mining company is a complex probabilistic system which functions in-between the geological and market environments. These environments are the carriers of various uncertainties which have influence on the business success. The authors discuss the background of differentiation of the mineral resource potential in terms of a coal field as transformation of a natural possibility to the manmade reality. It is distinguished between the limit, achievable and investment potentials. This type design takes into account the stages of geological exploration, study of coal properties and actual mining of the subsoil use object. The static, ergodic and non-ergodic categories of uncertainty are discussed.

1. Conceptual reasons for differentiation of mineral resource potential

Striving toward resource-saving mining and use of minerals, both theory and practice strenuously absorb various nature’s intrinsic analogies—uncertainty, chaos, adaptability, extreme limit. The paradigm connected with resolution of the global conflict between the techno-sphere and bio-sphere in the field of mineral resources and mineral reserves (MRMR) using nature-like mining technologies [1] brings the associated research to the next level of rationality. Advanced science has ‘split the integer existence into nature, technology and society’ which exist in the conditions of fundamental mutual collisions’ [2]. A subsoil user persistently aspires to overcoming of nature’s complexities via optimized conversion of potentiality into reality to relax severity of the mentioned conflict.

Present-day mining is carried out in the increasing complicated ground conditions and transformation processes. An increased investment is required as a consequence, and the investors want true information on returns of the investment project. An indicator for the investment is MRMR which naturally is a subsoil use object possessing probabilistic characteristics. On this basis, the authors suggest an approach to differentiation of an MRMR potential as metrics of valuation per phases of mineral mining.

We substantiate the MRMR potential differentiation by representing a mineral mining procedure as a successive transition from a possibility to a reality, then to a new possibility originated in the latter, and to a new reality. A possibility is what yet does not exist but, by virtue of laws of evolution, can appear and become a reality. The degree of development of a possibility, as an indicator of its relation to the reality, is expressed in terms of the notion probability which points at the time-to-time variability of human perceptions of capacities of nature. A possibility and a reality are inter-related and mutually dependent, and attributed with an uncertainty of both occurrence and estimate. A
measure for a possibility and a reality, as kinds of existence, is their potential defined as a concentration of energy [4]. It is easy to parallel these evolution laws and the stage-wise process of subsoil use, when new possibilities to improve the quality of a mineral and to increase the completeness of extraction of the mineral appear right in the course of mining.

On this basis, we hypothesize that a natural possibility and a reality arising from it, and a new possibility produced by this reality carry different-level potentials and uncertainties. This hypothesis substantiates the logic of the MRMR potential differentiation. For deciding on the depth of the MRMR potential differentiation, we address the key objectives of mineral mining (formation of a reality) as the determinants of existence and development of mineral-producing companies: (1) maximum extraction and efficient use of a mineral; (2) maximum profit of a subsoil user, governed by economic interest and market requirements. Meeting of these objectives follows a very strict procedure: if the first objective is unrealized in the course of the formation of a reality, achieving of the second objective is highly uncertain. The possibility offered by nature, and the reality generated on this basis, should be assessed using the measure of completeness and cost of mineral extraction.

As a consequence, we have three indicators for the differentiation and standardization of a potential for coal fields:

—maximum transition of possibilities of a subsoil use object into reality;
—degree of materialization of this reality using existing and advanced technologies;
—commercial value of this reality.

2. Typology of a mineral resource potential

The theory and practice of evaluation of geological resources commonly define a mineral resource potential (MRP) as the integrated mineral resources in a body, region, country, including probable expansion of mineral resources and mineral reserves [5].

Natural MRP is defined as a possibility, shaped into an object of subsoil use and is subjected to the material and cost evaluation for the decision-making on its profitability. Regarding proved resources of coal, expected value of natural MRP is found based on the quality standards: from temporal to constant; from appraisal to operating [6]. Within the multi-stage examination of a deposit and inside the appraisal limits, morphology, quality and occurrence conditions of coal seams are amended. The constant appraisal quality standards are determined using the investors method based on finding the ratio of investment outlay and future earnings of mineral mining [7]. The economic evaluation criterion is assumed to be NPV (net present value). The feasibility study of the constant appraisal quality standards reduces to estimating natural MRP of a coal field as a natural possibility expressed in terms of coal resources and represented as a subsoil use object intended for economic activity.

The cost-related approach to evaluation of natural MRP of coal fields goes with the material evaluation to disclose the value of coal toward its most efficient commercial use. Based on this indicator, MRP is categorized into: power-generating, metallurgical, carbon and chemical potentials [8]. The power-generating potential is quantitatively estimated by the calorific effect and reactivity in combustion, as is assumed as the measure of value of power-generating coal. The metallurgical potential is characterized by the properties of coking capacity of coal blends and burden, and is the estimate of coking coal reserves. The carbon potential is evaluated to find coal applicability in production of special carbon and composite materials. The chemical potential is the estimate of coal efficiency in different chemical processes, including new technologies. The material evaluation of MRP is a landmark for a consumer and, therefore, the material-based approach should precede the cost-related approach of evaluation. [9].

Development of coal MRP starts with a surface / underground mine planning and design. Geological paperwork, which is the project basis, provides basic description of a coal field: spatial geometry, types of coal and properties of rocks, averaged qualities (as content, combustion heat, sulfur content, volatile yield, etc.) and process properties (dressability, coking capacity). An MRP has a certain degree of reliability and is a probabilistic value. Using the geological information, the mine
construction project determines the most efficient conversion of mineral reserves into a product, with evaluation of its equivalent in money, or the MRP cost, with regard to opportunities and limitations of the fuel market. The project-determined MRP fist the first criterion of the MRP differentiation: maximum transition of a possibility into a reality based on the knowledge on the subsoil and its peculiarities, got within a specific time period. 

A question naturally arises: what is the category or the type of a project-determined MRP? To answer this question, we choose such categories as the boundary and the limit [10]. Each object of subsoil uses has an appraisal-set boundary (mining lease). The boundary delineates the domain of insight into the nature of a mineral deposit (its possibilities. The transition of the delineated possibility into a reality has a limit. The limit is an essence of an object, the maximum measure of possible, as beyond the limit, this is something other than that, without value in a certain time period. On this basis, we arrive at the **Limit MRP**. The basic property of a limit and a boundary is that both are changeable.

As soon as a deposit is put into operation, the created reality transforms into a new reality—a technological environment subject to uncertainty and chaos of the geological and economic environments (Figure 1).

![Figure 1. A model of a mining company environment.](image)

The models of a company’s functioning have changed from the SPOD reality (Steady–Predictable–Ordinary–Definite) to the VUCA world (Volatility–Uncertainty–Complexity–Ambiguity) [11, 12].

The natural consequence of the changes in these environments is a path from the limit potential to an **Achievable MRP** of coal fields. To implement the achievable potential mining companies should promptly respond to the conditions of the company’s functioning in order to compete on the fuel market [13].

The limit/achievable potential ratio equals or exceeds one, and depends on the mining and processing technology and equipment, management model and the product implementation. New possibilities which are generated within the created reality (exploration, advanced sampling, quality standards and loss reduction) expand the limits on knowledge on MRP, and can expand or diminish the limit potential by pushing or pulling its project limits.

In the chaotic and turbulent environment, the VUCA-world properties, either explicit or inexplicit, dictate that business converts the achievable potential into an **Investment MRP** which defines both the current and future commercial and industrial life. Optimization of the investment potential should join hands with scenario planning and implementation of an engineering and management package targeted at elimination of factors that complicate business activities.

Regarding the listed above notions, the **Limit MRP** is the maximum possible value of standard quality mineral resources in a certain time, producible using the modern mining and processing technologies which ensure complete extraction of the mineral (coal, in our case), at the preserved
natural quality, and conversion in to a marketable product being in demand to provide financial backing of a mining company, starting from own financing an up to financial soundness. The **Achievable MRP** is the value of proven coal reserves given the key common and advanced technologies of mining, preparation and dressing of coal are available and ensure complete extraction of coal, preservation of natural quality, enhanced conversion of coal to a marketable product being in demand to ensure financial backing of a mining company, starting from internal financing and up to sustained expansion of solvency. The Achievable MPR defines strategic reserves of a mine or the industry for a certain period of time. The **Investment MRP** is the commercial value of mineable mineral reserves on the ground of a mining company’s capability to produce and supply a demandable product to expand the capital reserve and to improve competitiveness of the company in the conditions of commercial subsoil management.

These types of MRP (Table 1) govern the value of phases in a dynamic model of mineral mining: from the natural possibility (natural potential) to the created reality (limit potential) and to this reality implementation possibility (achievable potential) and capitalization (investment potential). This proves the first provision of the hypothesis above that a possibility and a reality possess certain potentials. This type design is reflective of stages of knowledge gathering on MRP of coal deposits and the MRP evaluation, starting from exploration of a natural object and determination of its possibilities and finishing with the commercial value of coal products sold.

**Table 1.** Types of mineral resource potential (for coal fields)

| Availability of mineral resource | Industrial efficiency       | Economic efficiency |
|---------------------------------|----------------------------|---------------------|
| Current                         | Power-generating           | Natural             |
| Total                           | Metallurgical              | Limit               |
| Natural (initial, possible)     | Carbon                     | Achievable          |
|                                 | Chemical                   | Investment          |

3. **Uncertainty categories of the environment and technology**

The notion and causes of the external environment and technological systems hereditably belong to the types of MRP. Uncertainty is “not an abnormality but a fundamental condition of development” [14]. Semantically similarly, “uncertainty is a factor of the external reality, and characterizes nonuniqueness and multiplicity of variants of development and progression” [15]. The types of cognition uncertainty are static, ergodic and non-ergodic [14]. The static uncertainty is the condition of reality at each moment of time, from sporadic and, rarely, distributed information. When events which lead to changeability are generated in a random way, this is an ergodic uncertainty and its level is determined from a ‘distributed estimate’ [16]. The non-ergodic uncertainty is information obtained in the past and having no value for understanding the present and future.

The geological environment represented using the data of sampling is a chaos analogy, with intrinsic capacities for alterations and transformations, including transition into the opposite, i.e. an order. The morphology of a mineral deposit is determined, the geostatistic estimation of changeability of occurrence, structure and quality of coal seams is performed, and, then, a digital model of the deposit as a subsoil use object and its geoinformation model are constructed. Considering formalization and advanced digitalization of the geological environment, we assume that the geological environment is a natural resource and a carrier of the ergodic uncertainty.

The market environment is multi-subject, reflexive and dynamic, and filled with chaos and uncertainty. This is a model of the non-ergodic world, where uncertainty means unpredictability of events, and unavailability and inopportunity of information, while foreseeable future is multi-variate and ambiguous. The market-inherent uncertainties (price, demand, competition) are assumed as the source information for mining companies to develop strategy and tactics in the sphere of coal mining technologies and use. Finally, the market environment with the non-ergodic uncertainty conditions
functioning of mining companies ‘at the edge of order and chaos’. At every moment of time, a company exists in a business situation which is carrier of the static or ergodic uncertainty caused by destabilizing factors. Quality of management depends on the number of destabilizing factors, their similarities and differences, variability or persistency.

Conversion of a mineral into a product features internal uncertainty, as well. There are a parametric uncertainty, caused by exogenous and endogenous factors, and a frequency uncertainty, caused by frequency of random events (failure of machines, unpreparedness of mining front, ill-timed mapping of mineral reserves, interrupted communication with suppliers, consumers, dealers and other participants in the business environment).

Based on the afore-said, we come to a conclusion that any type of MRP is a variable and a carrier of an uncertainty as it inherits the properties of the geological, production and market environments, which generate this MRP and participate in its formation and growth. Regarding the world’s top companies, it is commonly acknowledged that commercially successful companies are the companies which can damp uncertainties thanks to developed adaptability and which belong in the class of Complex Adaptive Systems—CAS.

While stimulating mining companies to use nature-like technologies, it is necessary to develop their flexibility and adaptability as these are the basic and common properties of a system of any origin. The theory of evolution interprets adaptation as “a result of accomplished development, which can be defined as an ensemble of properties of a whole, which ensure sustainability and reproducibility of this whole” [18]. Digital technologies expand capabilities of real-time MRP evaluation and re-evaluation for coal fields [19], which can enhance efficiency of business in the framework of its competitive advance.

The confidence of investors, stockholders and stakeholders in the cost evaluation of a coal deposit MRP should be based on the limit/achievable/investment potential concept and advanced methods of valuation of a business entity under condition of the free market economy.

4. Conclusions
Mining of complex structure and quality of coal fields in increasing difficult ground conditions these days calls for the higher certainty, reliability and confidence of knowledge on the mineral resource potential of coal seams for the efficient and competitive conversion into a marketable product.

Differentiation of a mineral resource potential of a subsoil use object is a methodological approach to splitting a complex whole entity into an aggregate variety as per stages of mineral mining. The indicators of the differentiation are the maximum measure of transition of a possibility of a mineral deposit into a reality (limit potential); implementability of the created reality using appropriate mining technologies (achievable potential); commercial value of this reality (investment potential).

Expansion of the knowledge on the types potentials of a coal field consists in matching the uncertainties of the geological/production/market environments with the known static, ergodic and non-ergodic uncertainties of the objective reality. As a consequence, it is possible to undertake the verbal, material and cost estimation of coal resources and coal reserves in multi-stage mining.

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