POLITYKA ENERGETYCZNA
Tom 6 ✦ Zeszyt 1 ✦ 2003
PL ISSN 1429-6675

Marek NIEĆ*

Coal resources and reserves in a changing economy

KEY WORDS: coal, resources, reserves, evaluation

The amount of coal resources and reserves is the constant concern in discussion of coal availability [3, 4, 6]. Varied figures are often presented for the same coal basin or coal deposit, depending on the valuation method or criteria used for definition of coal resources and reserves. For that reason the data presented for various regions are incomparable. The three-dimensional United Nations Framework Classification of Resources and Reserves — UNFCR (fig. 1) offers the most suitable mode of resources and reserve data presentation. It considers resources as total amount of mineral commodity defined on the geological basis, but intrinsic economically mineable and reserves as extractable portion of resources [11].

Since the middle of XX-th century coal resources in Poland are defined uniformly for all coal basins (independently for black coal and lignite). However the criteria used for coal resources delineation varied in time. There was strong believed that with increasing demand for coal the deep seated coal deposits could be mined at a profit and they were explored down to 1500 m depth. There was also believed that thin coal seams, 0,4—0,8 m thick could be effectively mined. These optimistic expectations were not confirmed because of both technical and economic constraints. High geothermic gradient and salinity of mining waters increase with depth, create an insur moun table economic barrier for deep mining. However some mines reachd 1250 depth

* Mineral and Energy Economy Research Institute, Polish Academy of Science, Kraków, Poland.

Revieved by Prof. Roman NEY

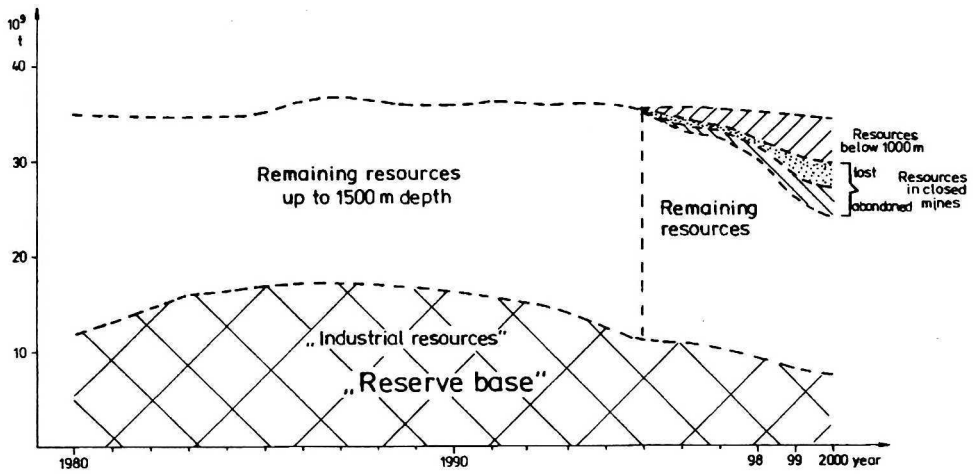

Fig. 1. Variation of data on coal resources explored and demonstrated in existing and closed down mines, within Upper Silesian Coal Basin, in the period between 1980 and 2000 year

Rys. 1. Zmiany wykazywanych zasobów węgla w czynnych i zlikwidownych kopalniach w Górnośląskim Zagłębiu Węglowym w okresie od 1980 do 2000 r.

before closing down all operations. Also it is clear now, that the economic and sometimes technical factors do not allow mining thin coal seams effectively.

Since 1994 yr. the maximum 1000 m depth and the minimum 1 m coal thickness are the basic criteria defining black coal resources as intrinsically mineable from the geological point of view. The maximum 350 m depth, and 1:12 stripping ratio are defining lignite resources respectively. The additional criteria are: calorific value 15 MJ/kg for black coal and 6,5 MJ/kg for lignite and maximum 2% sulphur content for both type of coal, in the seams containing barren interlayers. Defined in such way coal resources located in existing coal mines are diminished by resources inaccessible because of environmental restraints, tectonic position, unmanageable natural hazards and occurring in small amount in distant separated areas. Coal resources defined in such a manner, named "bilansowe", consist the "reserve base" for detailed mine planning and evaluation of real reserves as a feasible their portion. The resources not included into the "reserve base" are classified as sub-economic

The reserve estimation is done in three consecutive steps [1]:

1. Delineation of that portion of resources that are technically mineable in the frame-work of a given mining project and mining methods applied, encountering environmental impact of mining (mostly mining subsidence and the need for establishment of not mineable protective pillars).

2. Delineation of that portion of formerly defined resources which are economically feasible.

3. Evaluation of extractable reserves.

Technically and economically mineable portion of resources is called in Poland "industrial resources" which may be also named "reserves in place". Some concept of their economic mineability is introduced in their delineation too, but as it is based on expert opinions its application is not uniform.

TABLE 1. Relationship of UN Framework Classification and Polish Classification for Coal Resources and Reserves

TABELA 1. Porównanie Międzynarodowej Ramowej Klasyfikacji Zasobów ONZ (UNFCR) z klasyfikacją polską

<table>
<tr><td colspan="2">UN International Framework</td><td>Detailed Exploration</td><td>General Exploration</td><td>Prospecting</td><td>Reconnaissance</td></tr>
<tr><td></td><td>Polish system</td><td>Rozpoznanie szczegółowe A+B</td><td>Rozpoznanie wstępne C1*</td><td>Poszukiwania C2, D1</td><td>Penetracja D2, E (D3)</td></tr>
<tr><td rowspan="2">Feasibility Study, Mining Report</td><td rowspan="2">Plan Ruchu Zakładu Górniczego, Operat Ewidencyjny Zasobów</td><td>(111) a Proved Mineral Reserves (Zasaoby operatywne)
(111) b Proved Mineral Reserves in Place (Przemysłowe – Industrial Resources)</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>(211) Feasibility Mineral Resources (Nieprzemysłowe – Not Industrial Resources)</td></tr>
<tr><td rowspan="4">Prefeasibility Study</td><td rowspan="4">Projekt Zagospodarowania Złoża,</td><td>(121) a</td><td>(122) a</td><td colspan="2" rowspan="4"></td></tr>
<tr><td colspan="2">Probable Mineral Reserves in Place (Przewidywane przemysłowe - Probable Industrial Resources)</td></tr>
<tr><td>(221)</td><td>(222)</td></tr>
<tr><td colspan="2">Prefeasibility Mineral Resources Niezakwalifikowane do przemysłowych (nieprzemysłowe i pozabilansowe) (Probable Not Industrial Resources)</td></tr>
<tr><td>Geological study, Opportunity study</td><td>Dokumentacja geologiczna złoża</td><td>(331) Measured Mineral Resources Geologiczne**</td><td>(332) Indicated Mineral Resourcess Geologiczne**</td><td>(333) Inferred Mineral Resources Geologiczne</td><td>(334) Reconnaissance Mineral Resources Perspektywiczne</td></tr>
</table>

* Partly category C2 if fulfil the general exploration requirements.

** Economic and potentially economic (bilansowe i pozabilansowe).

The detailed economic evaluation of resources excludes substantial their portion designed as technically mineable. It is well visible in changing economic conditions, especially in Poland, due to transition from a central planned to a market oriented economy [2, 4, 9]. In the central planned economy the reserves evaluation considered predominantly the technical factors of mineability. The economic factors were accounted in very general manner. Experts eliminated these coal seams or their parts that were evidently not feasible at anticipated profit. During the transformation to the market oriented economy the more attention is put on economic profitability of mining, although detailed economic evaluation of coal reserves is still seldom realised. The

exaggerated costs of mining due to several indirect costs components and increasing debts and liabilities [10] force the mines management to consider as coal reserves only that coal seams and portions of coal seams where mining allow to decrease production cost. It became obvious the necessity of closing down of the oldest mines, more than 100 years old, and some younger ones, where future profitability was doubtful. This policy is however disputable in some cases. In operating mines only the thickest coal seams (mostly over 1.5 m thick) are considered as reserves. Moreover, financial conditions of mines exclude new investments and new, still undeveloped portions of coal deposits (e.g. on lower levels) are not considered as reserves. These factors caused strong decrease of reported reserves during last 10 years from about $16.8 \cdot 10^9$ tons (metric), which may be considered technically mineable to about $7.85 \cdot 10^9$ tons at the end of 2000 year [7, 8], the figure still constantly decreasing. It is the consequence of restructuring of coal industry that should gain market profitability.

The coal resources in undeveloped, but explored, deposits are constant figures during last few years because new discoveries are lacking and new mines are not planned. The reported their changes are due to elimination from official data files the resources that are:

1. Explored below 1000 m.
2. Insufficiently explored, evaluated with possible error over 40%.

Closure of several mines does not affect coal resources considerably. Not extracted resources and reserves remained in those mines still consist reserve base for eventual future mining if and only if economic factors, i.e. financial conditions of mines and new investment possibilities, allow their mining. They should be re-evaluated from the point of view of their feasibility, however not within the formerly existing mine boundaries but in conjunction with other mines or unmined fields in the neighbourhood (table 2).

TABLE 2. Technical favourability for mining of coal resources, abandoned in closed mines

TABELA 2. Atrakcyjność zasobów węgla pozostawianych w likwidowanych kopalniach

	Thin coal seams (<1.5 m thick)		Thick coal
	remote, separate	numerous	seams (>1.5 m thick)
Resources dispersed within mining field	Doubtful mining possibilities	Doubtful mining possibilities	**Mining possible in conjunction with resources in neighbour mines**
Resources in uniform areas	Doubtful mining possibilities	**Mining possible in the new mine or in conjunction with resources in neighbour mines**	**Mining possible in the new mine**

Extractable reserves delineation needs detailed evaluation of mining losses [1], what is possible when the mode of coal extraction is scheduled (fig. 1). Formerly they can be evaluated through extraction factor, that is the percentage of expected reserves, recoverable from evaluated "reserves in place". The recoverability between 0.7—0.75 (and sometimes up to 0.8) of "reserve in place" is reported in long-wall mining [2, 9]. The reserve evaluation for undeveloped coal

deposits and undeveloped portions of deposits within existing mines can be estimated using such recoverability factor only.

Because reserves estimation is realised in two following steps: delineation of reserves in place and evaluation of extractable reserves, it is reasonable to report the both figures of reserves:

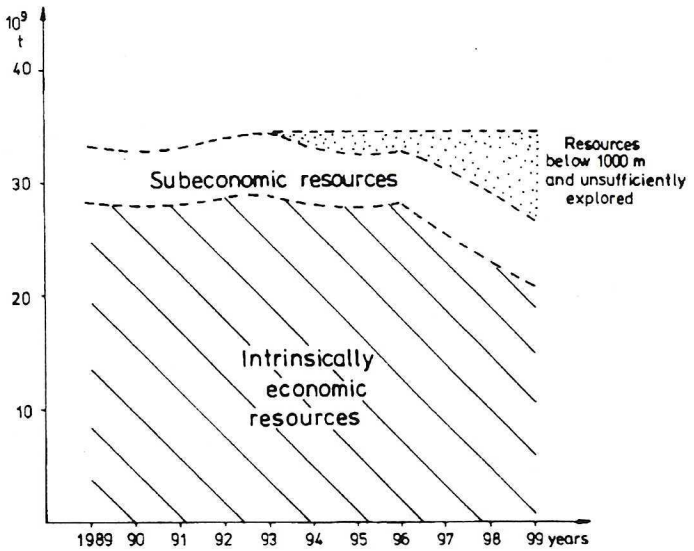

Fig. 2. Variation of data on coal resources in undeveloped, explored deposits within Upper Silesian Coal Basin

Rys. 2. Zmiany wykazywanych zasobów węgla w rozpoznanych, niezagospodarowanych złożach w Górnośląskim Zagłębiu Węglowym

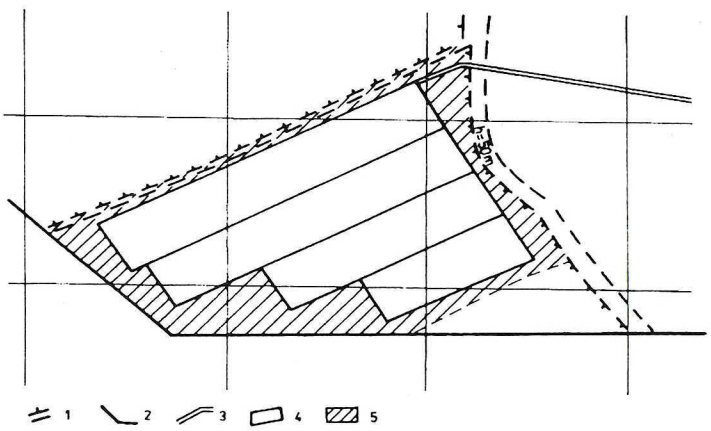

Fig. 3. Resources vs. reserves in place in longwall mining
1 — faults, 2 — mining field boundary, 3 — access gallery, 4 — resources engaged in longwall mining, 5 — lost resources (mining losses)

Rys. 3. Relacja między zasobami dokumentowanymi i wydobywalnymi w przypadku eksploatacji ścianowej
1 — uskoki, 2 — granice obszaru górniczego, 3 — przekop udostępniający, 4 — zasoby eksploatowane (pola ścianowe), 5 — zasoby tracone (straty)

evaluated in place and extractable (designed in classification presented in table 1 by additional letters "a" an "b"). In the official data files in Poland, the reserves in place are reported only [8]. The real extractable reserves can be evaluated when detailed mining plan is scheduled, what is possible for short time span only. The reserves and resources figures presented in table 3 should be considered as having dynamic nature and are changing in time.

TABLE 3. Black coal resources and reserves (in place) in Upper Silesia and Lublin Coal Basins (million metric tons)

TABELA 3. Zasoby węgla kamiennego w Górnośląskim i Lubelskim Zagłębiu Weglowym [mln ton]

UN International Framework		Detailed Exploration	General Exploration	Prospecting	Reconnaissance
	Polish system	Rozpoznanie szczegółowe A+B	Rozpoznanie wstępne C1	Poszukiwania C2, D1	Penetracja D2, E (D3)
Feasibility Study Mining Report	Plan Ruchu Zakładu Górniczego,	(111)b **1335** **59**			
	Operat Ewidencyjny Zasobów	(211)b **656** **15**			
Prefeasibility Study	Projekt zagospodarowania złoża	(121) b **151**	(122)b **2851** **210**	(123)b **2515** **64**	
		(221) b **222**	(222) b **8805** **261**	(223) b **9099** **160**	
Geological study, Opportunity study	Dokumentacja geologiczna złoża	Measured Coal Resources (331) **1341*** -	Indicated Coal Resources (332) **5299*** **2229***	Inferred Coal Resources (333) **17880*** **5565***	Reconnaissance Coal Resources (334) **74333**** **38734****

* Supposed economic as "reserve base" ("bilansowe") only.

** Total geologic (supposed economic and potentially economic).

The real reserves can be evaluated only for the parts of deposits that are sufficiently explored (at the stage of detailed exploration) and when the both technical and economic conditions of mining are known or can be predicted with sufficient accuracy. In the case of undeveloped deposits, especially poorly explored, it is possible to evaluate expected reserves only, considering different possible their quantity depending on possible costs of coal extraction. Such approach should lead to set of reserve values for each mine, undeveloped deposit and whole coal basin, forming a scenario of possible reserves variations.

The global figures of coal resources within particular mines or basins may be misleading for predictable reserve evaluation. The both resources and reserve figures are burdened with several uncertainties, decreasing with exploration advancement, but constantly existing up to the final

deposit exhaustion. It is mostly uncertainty of geological structure of deposit: tectonic framework, correlation of coal seams, and thickness variations of coal. Underestimated is the resources partition between particular coal seams. Limited area of occurrence of some coal seams and their small resources often preclude considering them in reserve estimation.

Coal resources and reserves as based on exploration data are evaluated with limited accuracy depending of the degree of exploration. The reported their figures has statistical (or exactly geo-statistical) nature. They represent average values estimated within predictable confidence limits, which are up to ±10%, and ±20% of estimated resources and reserves at detailed and general exploration stage respectively, and may be up to ±40% at the prospecting stage [5]. Coal resources and reserves availability cannot be therefore precisely evaluated, as well for the whole basins as for particular coal deposits because of:

1. Limited accuracy of geological model of coal deposits based on exploration data (mostly because unknown in details tectonic framework of deposit, unsure correlation of particular coal seams and unpredictable coal seams thickness variations).

2. Varied in time technical and socio-economic factors of deposit development.

The changing economic factors have the predominant impact on reserve evaluation, which should be considered both in coal availability predictions and evaluation and management of coal resources and reserves.

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