RESOURCE REQUIREMENTS AND ECONOMICS OF THE COAL-MINING PROCESS: A COMPARATIVE ANALYSIS OF MINES IN SELECTED COUNTRIES

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RR-84-13
June 1984

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International Standard Book Number 3-7045-0069-0

Cover design by Anka James

Printed by Novographic, Vienna, Austria

FOREWORD

The former Energy and Mineral Resources (Resources Assessment and Accounting) Task of the Resources and Environment Area at IIASA had two main concerns: first, quantitative assessments of fossil energy resources as inputs to the IIASA Energy Systems Program; and second, the impacts of large-scale development of energy resources on natural and human resources and the environment, integrating thus with the objectives of environmental studies at the Institute.

This study demonstrates the role of IIASA in addressing long-term issues, in that it combines the development of a methodological framework, in this case the WELMM (water, energy, land, materials, manpower) approach, with the application of such a tool to a problem of truly global nature, thereby synthesizing information and different aspects of the problem from the perspectives of individual countries.

The importance of coal in the future supply of fossil fuels was strongly emphasized in the results of the IIASA Energy Systems Program. However, the large-scale development of coal resources will have considerable impacts on all levels of energy production, conversion, and utilization, all of which require thorough investigation. This report examines the impacts of large coal-mining operations, i.e. at the resource production level, whereas other studies using the WELMM approach have addressed the impacts of conversion of primary resources to the secondary energy carriers required by the consumer.

The impacts associated with utilization of the processed resource by the socioeconomic system (increase in global carbon dioxide concentration, air pollution, and acid precipitation, to name a few key issues) are also being studied at IIASA, within the Project on Impacts of Human Activities on Environmental Systems.

JANUSZ KINDLER
Acting Leader
Institutions and Environmental Policies Program

December 1983

ACKNOWLEDGMENTS

The authors would like to express their sincerest thanks to all those individuals, mining research institutes, and mining companies that provided data and detailed answers to the questionnaire, and without whose help this study would not have been possible. Too numerous to be listed separately here, they can nevertheless be assured that their essential contribution to our study is gratefully acknowledged.

We are particularly indebted to Professor Michel Grenon, the principal developer of the WELMM approach, for initiating this application study. He provided the essential continuous stimulation and interest in this study and made numerous valuable contributions to it.

We would also like to give special thanks to Professor G.B. Fettweis and his Institute of Mining of the Montanuniversität Leoben, Austria for support and contributions throughout the study, and to the US Geological Survey, Reston, Virginia for supplying us with Environmental Impact Statements.

For their contributions to our study, we are deeply indebted to Walter König from the Institute of Mining of Leoben University for his assistance in restructuring the data base and in data collection, and for performing numerous statistical runs; to Serge Medow for his excellent work on organization of the data base and the development of the associated data access/retrieval software; and to Susan Arthur for her advice on statistical problems.

We also wish to thank Diana Barrow for patiently retyping numerous earlier drafts of this report, Helmut Frey for preparing the illustrations, and Steve Flitton for his editorial work on the paper.

Last, but certainly not least, we would like to thank the reviewers, Professor G.B. Fettweis and Academician M.A. Styrikovich, for their continuous interest in and contributions to resource studies at IIASA. Their positive reviews and most useful comments helped to improve very much the substance of this work.

CONTENTS

SUMMARY

This report examines the natural resource requirements and economics of the resource extraction process, taking coal-mining activities as an example. Coal was chosen for the study because it is receiving growing attention as the fossil energy resource with the largest potential to contribute to the world's long-term energy supply. As an initial step, the extraction process is described in terms of process analysis, considering first of all the geological characteristics of the deposit to be mined, the resulting mining technology, and the natural and economic resource flows for the construction and operation of a particular mine. The computerized description of the extraction process is stored in the Coal Mines Data Base (CMDB), which was developed within the framework of this study. The data base currently holds information on 70 mines located in different countries. The analytic approach used is the first of its kind to compare resource requirements and economics of coal mines under such a broad range of geological and socioeconomic conditions.

A general model of the factors influencing resource inputs and impacts of the coal-mining process is presented. Then for each of the main mining methods (opencast, conventional underground, and hydraulic underground) the principal geological and technological factors influencing the resource requirements, economics, and environmental impacts, as well as the comparative advantages and disadvantages of each mining method, are discussed.

For the three main mining methods the resource requirements (including manpower, energy, materials, and land) and the economics (including construction investments and operating costs) are then quantified and their cost structures (i.e. requirements for the different operations at a mine) are examined in detail using data from coal mines in the USA, the USSR, and other selected coal-producing countries (Australia, Austria, and France).

The dependences of natural resource requirements and economics of opencast and underground coal mining upon natural (geological) and technological factors are then quantified in statistical analyses of the data in the CMDB. The analyses present results for the dependence of manpower, energy, material, and land requirements, as well as of some economic factors, upon the main geological variables (overburden to coal ratio for opencast mining, mining depth and seam thickness for underground mining) and upon technological variables (technological system and mine size).

The particular mining system employed and the overburden to coal ratio were found to have a strong influence on the investment and operating costs of opencast mines, whereas within the data sample analyzed no significant economies of scale were revealed.

For conventional underground mining, the analyses showed that, for instance, underground labor productivity increases with the mine size and seam thickness, but decreases with the mining depth and rate of water

inflow. In the analyses it was shown that the data on labor requirements from a variety of Western and Eastern European countries appeared to be quite comparable. The results suggest that a good possibility of compensating for losses in productivity, caused by worsening geological conditions at greater mining depths, is the concentration of production in high-output mines.

The results of the analyses for underground mining agree closely with similar types of relationship, where they were available, based on an independent analysis of all operating longwall mines in the USSR. Other results of the analyses for conventional underground mining concern the energy and material requirements, as well as the amount of waste rock produced by this mining method.

The results of the analyses are considered satisfactory in view of the limits imposed by the relatively small and inhomogeneous data base available and the treatment of coal-mining operations as a single process, and have demonstrated the clear advantage of WELMM-type physical indicators over economic indicators. This study has also shown an obvious need for establishing and standardizing data systems to support long-term analysis of resource extraction, based on physical indicators.

The quantitative results of this study constitute a first step in a more detailed consideration of the effects of different deposit characteristics and resource depletion phenomena in energy models.

1 THE WELMM APPROACH AND ITS APPLICATION TO THE STUDY OF COAL RESOURCES

One of the main outcomes of IIASA's Energy Systems Program was the recognition that large-scale extraction processes will assume increasing importance in the transition away from natural petroleum toward unconventional oil resources (such as oil shale or tar sands) and synthetic liquid fuels derived from coal (Energy Systems Program Group of IIASA 1981). Large-scale extraction projects have two main consequences, both of which should be studied from a systems perspective.

First, extraction of an energy resource can interfere with other local natural resources, such as energy resources (e.g. methane in coal seams or uranium in oil shales), land or water resources (e.g. surface water and, to an even greater extent, groundwater), and other mineral or material resources. One positive aspect of these interrelationships could be the mining of resources together with coal in certain cases.

Second (and independent of these local interactions), the extraction and upgrading of energy resources require large amounts of water, energy inputs, equipment, materials, and manpower. New energy resources tend also to be increasingly "resource-investment-intensive," either because they are less easily obtainable (such as deep offshore oil or coal in polar areas) or because resources of progressively lower quality are being produced, requiring greater inputs to the resource-processing system. However, in studying resource-processing systems one cannot look at a single resource (such as energy) alone, but has also to consider the qualitative and quantitative interrelationships of natural and processed resources that are inputs to the system, as shown in Figure 1. The requirements for natural and processed resources can be documented, and this has already been done for energy inputs, in the form of "energy analyses" or "energy accounting" (e.g. Slesser 1978).

Such a documentation process can be extended to a general form of "natural resource analysis" or "natural resource accounting" as represented by Figure 1. This task was undertaken by the IIASA research project on Resources Assessment and Accounting. Five main parameters are considered, by means of which the impacts of energy strategies, in particular, are assessed. These are water, energy, land, materials, and manpower (WELMM) (Grenon and Lapillonne 1976, Energy Systems Program Group of IIASA 1981, pp. 279–306).

The WELMM parameters do not cover *all* possible types of impacts (which would include air or water pollution, risk, etc.), but they can provide additional insights in going beyond traditional economic analyses, which have often proved limited in a long-term context. The WELMM approach has two essential components, namely the development of physical resource accounting *tools* and the *application* of the tools in the analysis of selected resource extraction strategies. The WELMM approach uses a consistent methodological

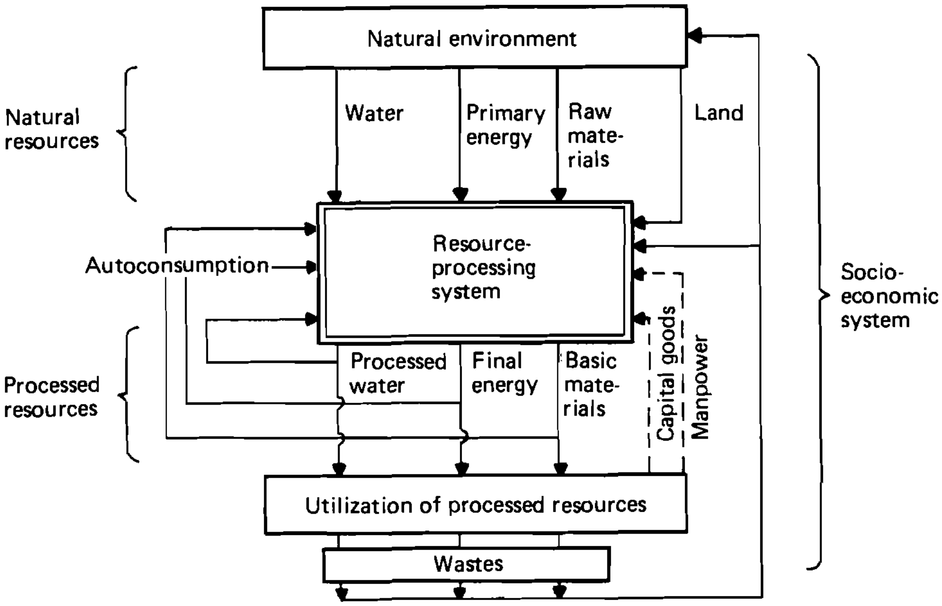

FIGURE 1 The resource-processing system.

framework in order to (a) define clearly the boundaries of the system being analyzed (i.e. in terms of direct and indirect requirements, etc.) and (b) ensure that consistently formulated data are used in the resource-accounting process. This framework for quantitative analysis is provided by computerized data bases, which are essential tools of the WELMM approach. The data bases are used to collect information systematically on the WELMM impacts and requirements of industrial processes deployed in converting primary (energy) resources to the commodities required by the consumer. At each of the transformation steps of such a resource-processing system, corresponding industrial processes can be defined. Data on these processes constitute the Facility Data Base (FDB) (Grübler and Cellerier 1983). In addition, as a second type of data base, Resource Data Bases (RDBs) record information on primary resource availability (at the global, national, or regional level) to meet the WELMM requirements of the facilities of a particular resource-processing system.

Within the FDB, the boundaries of each process analyzed are drawn in such a way that the processes correspond to industrial units or facilities along the chain from resource extraction to final use. These units can be considered as typical in the sense that their characteristics, for a given technology and level of industrial development, are independent of their location, and that they fall within certain standard size classes, which can be identified in the increasing trend toward standardization in size and equipment, particularly of energy facilities. Both factors make it possible to keep the number of reference facilities (on which data have to be collected) relatively small, but still allow a particular energy system to be characterized in sufficient detail.

The WELMM data bases, which include economic data as well (although this is not a primary objective), can then be combined either statically or dynamically for comparative studies of various energy strategies, or be used within an optimization framework based on one, or an aggregate, of various WELMM parameters. Applications so far include comparative studies of technologies for the supply of final energy (electricity) and useful energy (i.e. a certain array of energy services) (Grübler 1980), and of different processes for production of synthetic liquid fuels (Merzeau *et al.* 1981), as well as studies of alternative energy supply systems (scenarios) at the national level (Resources Group of IIASA 1979, Grübler 1984). Finally, at the regional level the WELMM approach has been used to design and compare centralized and decentralized solar electricity generating systems (Katsonis and Gourmelon 1983).

However, from these applications it became clear that at the intersection of the data bases on industrial processes and primary resource availability, i.e. for the primary resource extraction process, the definitions of reference processes constitute too high a level of aggregation. This is because the particular (mining) technology employed is not just influenced by the required output, its quality, production economics, and technological developments (as is the case for power plants and other conversion facilities), but is primarily determined by the geology of the mined deposit. Thus, in contrast to conversion facilities upstream of an energy chain, which are *process-* and *size-specific*, the extraction process is *site-specific*. To some extent each mine is therefore unique. Even when mines working similar deposits in different countries are considered, comparison should be based not only on purely economic grounds, especially since most of the coal reserves and resources are located in countries with different socioeconomic systems. There is also a related problem of data availability, despite the fact that inside the extractive industries the use of certain physical indicators has long been recognized as an effective tool for better comparability.

This report describes an attempt to overcome these difficulties but, equally, to gain a better understanding of the impacts of the extraction process on natural resources and insight into the relationships among a complex of natural resources, taking coal as an example. The first objective was to develop a new tool, drawing from the concepts underlying the Facility Data Base and the Resource Data Bases. The result, the Coal Mines Data Base (CMDB), is described in more detail in Section 2. The second objective was to use this tool to examine the coal extraction process and, in particular, its relationship with natural (WELMM) resources, with the resulting approach and conclusions being equally applicable for other energy or mineral resources.

Coal was chosen for two main reasons. First, the increasing importance of coal in the future energy supply, especially for the development of alternative liquid fuel sources, is receiving growing attention worldwide (WOCOL 1980a, Energy Systems Program Group of IIASA 1981). Second, coal resources are a prominent example of a resource whose development does not appear constrained by the known resource base, which is huge both in absolute terms and compared with other energy resources. Problems of development will therefore be primarily with (a) the requirements and availability of certain resources as inputs to the coal production system (special equipment, qualified manpower, etc.), and (b) the increasing impacts on other natural resources (land, water) and the environment, caused by production and processing of the resource itself as well as by its utilization.

Figure 2 presents an overview of the possible applications of the WELMM data bases, as well as their interconnections. The Coal Mines Data Base may be used directly to study the resource requirements of coal mining, in terms of their dependence upon technological or geological parameters (as done in this report), or to study the relationship between extraction technology and coal reserves, i.e. the effective recoverability of the reserves*. Thus the impacts of development of coal resources at various levels (regional, national, and global) can be quantified and, with reference to the Resource Data Base, the compatibility of these requirements and impacts with the resource availability at these levels can be assessed. This type of analysis can also be extended to environmental questions. The Facility Data Base and the Coal Mines Data Base together provide the necessary information base for studies of energy chains based on coal, either at the final energy level, e.g. the production of electricity or synfuels, or at the useful energy level (energy services). In a further step the data bases can be used together to study a combination of various technological routes from the primary resource to the required (mix of) final products, representing a whole energy system or "scenario."

In each of these cases the CMDB and the analysis it supports can contribute to assessing more thoroughly the impacts of coal mining on resources and especially how these impacts change with increased coal production levels, i.e. the consequences of resource depletion**.

Whether we are dealing with the $6.9 \cdot 10^9$ or even $12.9 \cdot 10^9$ tonnes of coal equivalent (tce) of primary energy supplied by coal by the year 2030, as studied in the scenarios of the Energy Systems Program Group of IIASA (1981), or whether we assume even a tripling of 1980 world coal production by the year 2000, as presented in the World Coal Study (WOCOL 1980a), the effects of such large-scale mining and subsequent fuel conversion and use require a thorough examination, especially as regards resource impacts. To illustrate the scale of such operations and their possible impacts: the above-mentioned $7-13 \cdot 10^9$ tce (the actual tonnage would be still higher, since a significant share of this energy production would be from coal of lower ranks) can be compared with an estimated $12 \cdot 10^9$ cubic meters of solids transported worldwide annually by rivers. The unprecedented scale of these mining operations and their possible impacts call for an analysis that considers all the qualitative and quantitative interrelationships of natural resources. The present report is intended to contribute to this comprehensive approach.

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*Here we refer not only to the technically and economically recoverable reserves but also to issues such as effects of "cream-off," i.e. that part of the reserve base that, under certain economic conditions and associated systems for mine opening and exploitation, may be irrecoverably lost. This phenomenon is discussed sporadically in the literature; see, for instance, the classic article by Therme (1963), from whom the term *écrémage* has been taken.

**For a treatment of the *economic* impacts of resource depletion inside the US coal industry see, for instance, the work by Zimmerman (1977, 1979).

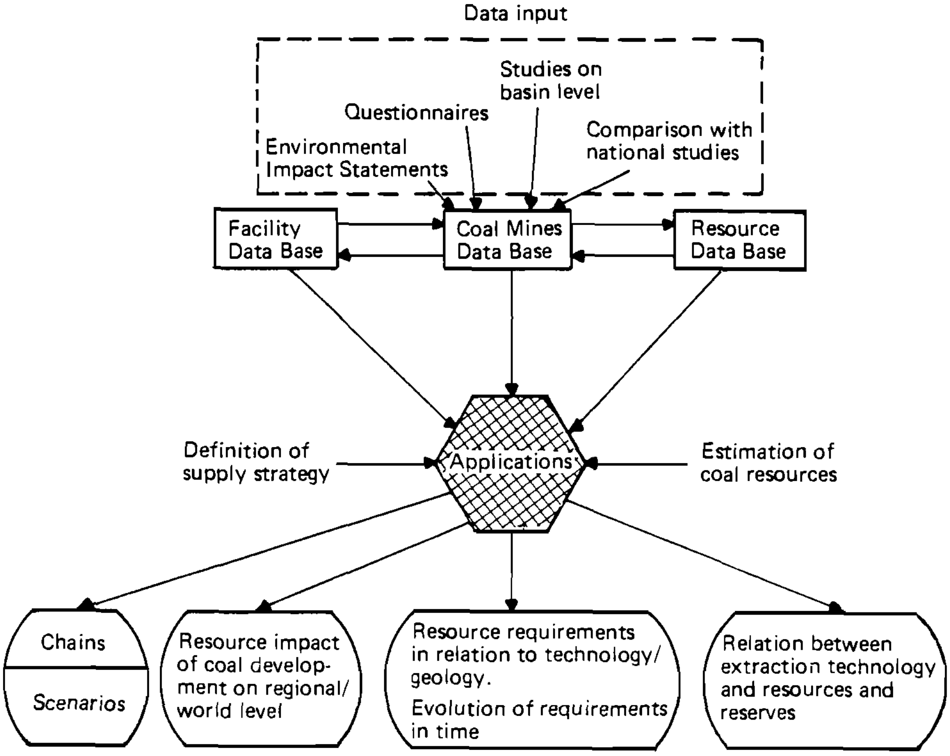

FIGURE 2 Connections between the WELMM data bases, and possible applications to the study of coal resources.

2 THE COAL MINES DATA BASE

As already outlined in Section 1, the concept of "typical" facilities, with respect to technology and size, has to be reconsidered in describing the mining of energy (and non-energy) materials. Here, the individual deposit characteristics determine the technology and size of any mining facility and make each coal mine unique in that sense. However, for this study we have tried to identify at the level of the coal basin some generic types of mines working similar deposits with the same mining technology.

Within the WELMM approach a general scheme has been developed for describing an energy deposit and its natural environment (Grenon 1980, Grenon and Gourmelon 1980) (Figure 3). With this scheme and the facility description format of the FDB, the CMDB consists of a set of files describing the coal deposit itself (resources, reserves, geology, etc.), the geotechnical conditions for mining, environmental characteristics (land, hydrology, climate, population, etc.), mine parameters (for surface and underground mines), and a list of main equipment items. In addition, files record the direct WELMM requirements for construction and operation of a mine (including cost data when available).

The data are collected with the help of a questionnaire (Appendix A), which was developed at IIASA. The questionnaire and the CMDB are similarly structured to make data entry and retrieval easier. As a first step, questionnaires were completed using data from the literature (such as Environmental Impact Statements and studies by the US Bureau of Mines). Additional questionnaires were then sent to coal-mining companies and mining research institutes, or the information was collected directly on field trips. Another reason for collecting data from industry as well as from literature was to permit an evaluation of the data quality (in terms of data format, availability, and consistency) of literature sources (which are especially abundant in the case of the United States).

The mines chosen are considered to represent typical mining conditions in the basins where they are located. The number of mines for a given basin can therefore vary. Most attention has of course been devoted to basins that can contribute significantly to the national or international energy market, but the list is still far from exhaustive. In addition to this survey of representative mines at the basin level, a WELMM analysis was carried out for a basin as a whole (the Lorraine basin in France).

At present the CMDB contains data on 70 mines. The data were entered into the data base according to the structure of the questionnaire. Table 1 is a computerized list of the mines, classified by technology (surface or underground), location, and annual output of raw coal (in millions of tonnes*).

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*Tonnes (metric tons, t) are used throughout this report.

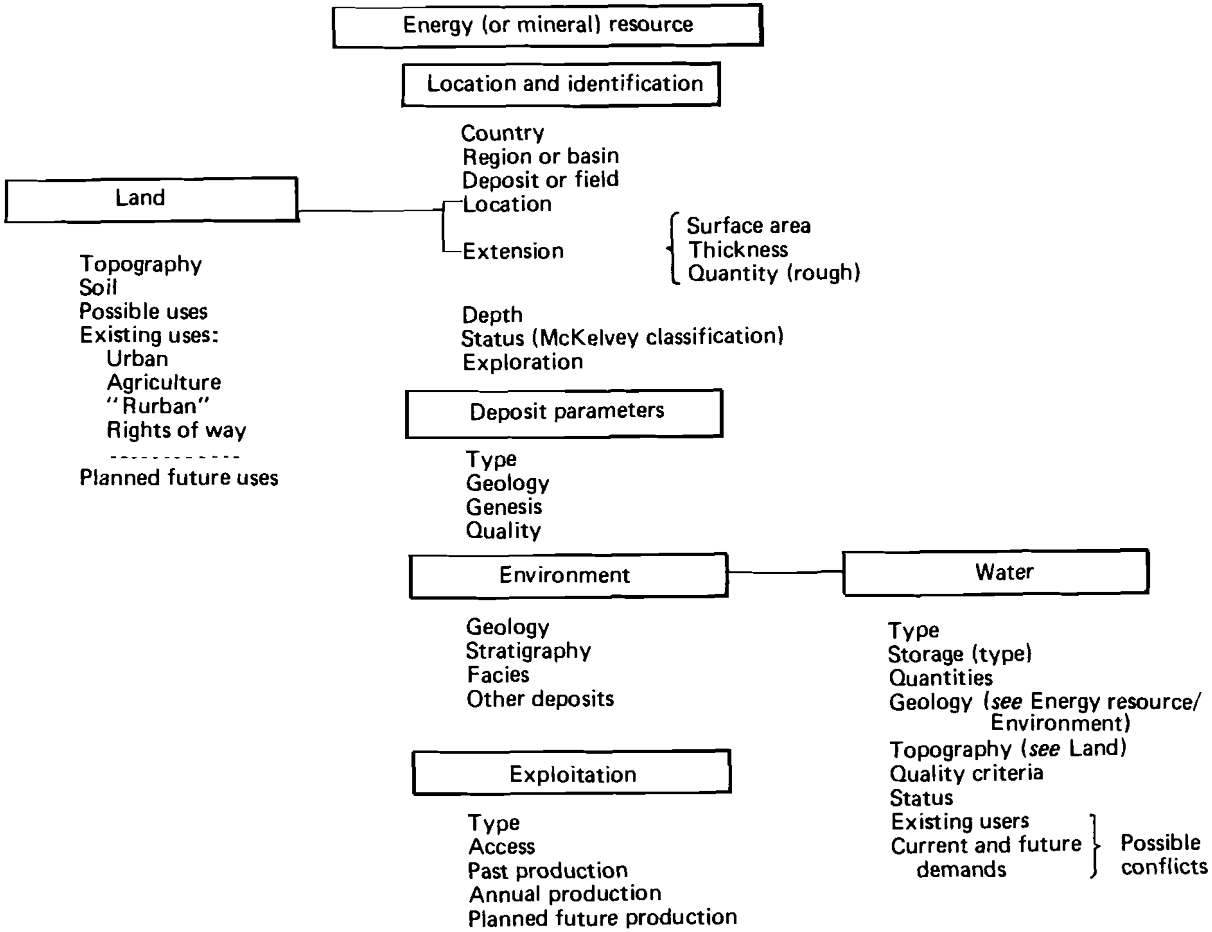

FIGURE 3 The basic concept of the WELMM Resource Data Base. ("Rurban": new types of human settlements in rural areas.)

TABLE 1 Coal mines for which data have been entered into the Coal Mines Data Base.

code	country	basin	minename	outrom
SURFACE MINES :				
s-ad-app01	united states	appalachia	model fluor utah	4.709
s-ad-app02	united states	appalachia	model fluor utah	4.653
s-ad-fcr01	united states	4 corners	model fluor utah	6.585
s-ad-fcr02	united states	4 corners	el paso consol	17.000
s-ad-ftu01	united states	fort union	model fluor utah	8.392
s-ad-ftu02	united states	fort union	projected mine	8.340
s-ad-grr01	united states	green river	model fluor utah	5.788
s-ad-il101	united states	illinois	model fluor utah	4.944
s-ad-il102	united states	illinois	model bechtel sri	3.630
s-ad-pow01	united states	powder river	model fluor utah	7.236
s-ad-pow02	united states	powder river	model bechtel sri	5.440
s-ad-pow03	united states	powder river	east gillette	7.258
s-ad-pow04	united states	powder river	eagle butte	18.144
s-ad-pow05	united states	powder river	cordero	10.886
s-ad-pow06	united states	powder river	caballo	10.886
s-ad-pow07	united states	powder river	coal creek	9.072
s-ad-pow08	united states	powder river	pronghorn	4.536
s-ad-pow09	united states	powder river	absaloka tract III	9.072
s-ad-pow10	united states	powder river	east decker	6.078
s-ad-pow11	united states	powder river	east decker alternate B	7.258
s-ad-pow12	united states	powder river	north extension	2.087
s-ad-txg01	united states	texas gulf	model fluor utah	8.452
s-ad-zzz01	united states		projected mine	4.350
s-ad-zzz02	united states		projected mine	6.100
s-ad-zzz11	united states		projected mine	2.720
s-eb-vkk01	austria	voitsberg-koefl.	oberdorf	1.250
s-ee-rhe01	germany west	rheinland	fortuna garsdorf	42.000
s-em-ndy01	united kingdom	north derbyshire	furnace hillock	0.141
s-fi-eki01	ussr	ekibastuz	projected mine	30.000
s-fi-kak01	ussr	kansk-achinsk	projected mine	60.000
s-fi-kuz01	ussr	kuzbass	projected mine	30.000
s-fi-kuz02	ussr	kuzbass	projected mine	20.000
s-kb-bow01	australia	bowen	gregory	3.750
s-kb-bow02	australia	bowen	projected mine	4.900
s-kb-bow03	australia	bowen	projected mine	10.000
s-kb-bow04	australia	bowen	projected mine	6.000
s-kb-gip01	australia	gippsland	yallourn	13.900
s-kb-gip02	australia	gippsland	loy yang	36.000
UNDERGROUND MINES:				
u-ad-il103	united states	illinois	model bechtel sri	1.810
u-ad-zzz03	united states		projected mine	0.930
u-ad-zzz04	united states		projected mine	1.860
u-ad-zzz05	united states		projected mine	2.810
u-ad-zzz06	united states		projected mine	0.960
u-ad-zzz07	united states		projected mine	1.850
u-ad-zzz08	united states		projected mine	2.900
u-ad-zzz09	united states		projected mine	4.540
u-ad-zzz10	united states		projected mine	4.550
u-eb-hau01	austria	hausruck	trimmelkam	0.614
u-eb-hau02	austria	hausruck	schmitzberg-hinterschlag	0.610
u-ed-lor00	france	lorraine	basin total/average	13.800
u-em-nyo01	united kingdom	north yorkshire	selby	2.000
u-fc-mar01	bulgaria	maritza	marishki bassein	2.423
u-fi-don01	ussr	donbass	projected mine	1.800
u-fi-don02	ussr	donbass	abakumov	1.370
u-fi-don03	ussr	donbass	krasnoarmeyskaya cap	2.200
u-fi-don04	ussr	donbass	rossiya	1.150
u-fi-don05	ussr	donbass	50-letiya oktyabrya	1.800
u-fi-don06	ussr	donbass	gukovskaya	1.480
u-fi-don07	ussr	donbass	num1 zhdanovskaya cap	3.600
u-fi-don08	ussr	donbass	novopavlovskaya	0.750
u-fi-kar01	ussr	karaganda	lenin	3.250
u-fi-kar02	ussr	karaganda	kostenko	2.860
u-fi-kar03	ussr	karaganda	kazakhstanskaya	2.300
u-fi-kar04	ussr	karaganda	gorbachov	2.370
u-fi-kuz03	ussr	kuzbass	num2 yubileynaya	3.580
u-fi-kuz04	ussr	kuzbass	karagaylinskaya	1.560
u-fi-kuz05	ussr	kuzbass	zaryechnaya	0.860
u-fi-kuz06	ussr	kuzbass	num1 inskaya	1.470
u-fi-pec01	ussr	pechora	intinskaya	1.450
u-kb-syd01	australia	sydney	tahmoor	2.610

However, the CMDB is not yet complete, i.e. not all the data on the parameters of the actual data base structure were available. In particular, WELMM requirements for the construction of a mine are difficult to obtain, if they exist at all (as is the case for mines built many years ago). In addition, as the questionnaire is already quite detailed, some mining companies are reluctant to release the information (this applies particularly to cost data, which are sometimes unavailable or are excluded from the data base if they are to be kept confidential). Generally, data collection is a very long process and probably the best method for data collection would be systematic field trips, since experience has shown that the questionnaire can be filled out within a few hours in discussion with mine managers and chief mining engineers.

2.1 DATA CONTAINED IN THE COAL MINES DATA BASE

Data on 115 basic parameters describing the general characteristics of the coal deposit, the mine, and its environment are stored in 14 files. (In fact, the number of parameters in the data base is bigger, since for certain parameters, such as coal quality, a range of values is stored.) Each file contains the mine code at the beginning. Additional, nonnumerical information (e.g. on geology and genesis) is provided in a footnote. Appendix A.1 presents the parameters of the files storing the general characteristics of a mine. Appendix A.2 consists of the part of the questionnaire relating to the construction and operational requirements of the mine, and is equivalent to the actual data base in structure. Appendix A.3 is a sample listing of all the information included in the CMDB on a particular (opencast) mine.

2.2 DATA STORAGE AND RETRIEVAL

The files of the CMDB are stored using a relational data base management system called INGRES (developed at the University of California, Berkeley (Held *et al.* 1978, Woodfill *et al.* 1979)), which is implemented in addition to the normal UNIX* system operating on the PDP 11/70 and VAX 11/780 computers at IIASA. The files (or *relations* in INGRES) have a matrix structure in which the columns represent the individual parameters and each mine is displayed on one line. Each column, or *domain*, has a name label (*attribute name*) associated with it, and the lines of the matrix are called *tuples*. Within the INGRES natural query language QUEL, the individual domains are retrieved with the help of their attribute names, whereas the individual data items contained in the domains can be used as selective or filtering mechanisms. Another great advantage is that required information can be retrieved into new relations that automatically take the original format of the source domains (character, integer, or floating). This feature proves very useful, for instance, in preparing INGRES input files for statistical analysis programs.

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*UNIX is a trademark of Bell Laboratories.

Of course, it is evident that with a large number of attribute names for only the CMDB (around 140) it is practically impossible to memorize all of them, although we have tried to use mnemonic principles as far as possible (e.g. attribute names like *landscape* or *methane* are easy to interpret and memorize). Therefore, it requires a certain amount of user experience to work on the data base without some preparation. This preparation is in fact quite simple since, in addition to the user relations, INGRES includes systems relations with all the necessary information. Therefore, to obtain, for example, precise information about the relation *cminesa* one would simply type *help cminesa* and information about this file would be displayed (e.g. number of tuples and all attribute names with their formats). In addition to this information contained in INGRES relations, which are – as part of a data base management system – adapted more to storing numerical data or short and precise indicators or keywords than extensive text, we have prepared a text file (footnote) for each mine, which contains additional, textual information, comments, and references. This was made to be analogous to the layout of the Facility Data Base.

A number of UNIX subprograms have also been added. Figure 4 shows the various data files and subprograms of the CMDB. As mentioned previously, the great number of parameters revealed the necessity of retrieving data not only individually, but so that one could also look at all the information on any particular mine at once. This is done by using a subprogram called COALQ, which accesses all the INGRES relations containing information on the mine, combines this information with the complete names and units of the various parameters (from the input files for the data entry program) and WELMM data, and, in addition, accesses the relevant UNIX footnote text files and edits all these data to produce a printout for the mine. All that the user has to do to obtain this printout is to call the COALQ subprogram and to type the code of the mine(s) required. The resulting output of this program is stored in a special UNIX directory and is also connected to the TREE system (Medow 1983), and thereby to the other WELMM data bases (FDB, RDBs).

For statistical analyses, interactive programs for stepwise polynomial and stepwise multiple linear regression have been implemented. The user has to specify in an interactive session the name of the INGRES relation from which the input data are to be taken (normally a temporary relation containing the various parameters to be studied) and the attribute names of the dependent and independent variables to be analyzed. Furthermore, the user has to say whether he/she wishes to plot the results. The program then carries out the regression analysis. Intercepts, regression coefficients, the table of variance, and the (multiple) correlation coefficients and residuals are printed and the regression function and the observations are plotted on a graph.

In order to ease the entry of new data, the part of the questionnaire dealing with the general characteristics of a mine has been entered in various UNIX files (an example from Appendix A.1 is given in Table 2) containing the questions from the questionnaire, the relevant INGRES attribute names, the range of answers to be accepted by the entry program, data to be put into the INGRES files, and the explanations and units of the parameters (which in turn are used also for the COALQ subprogram). The program that is called *entering*

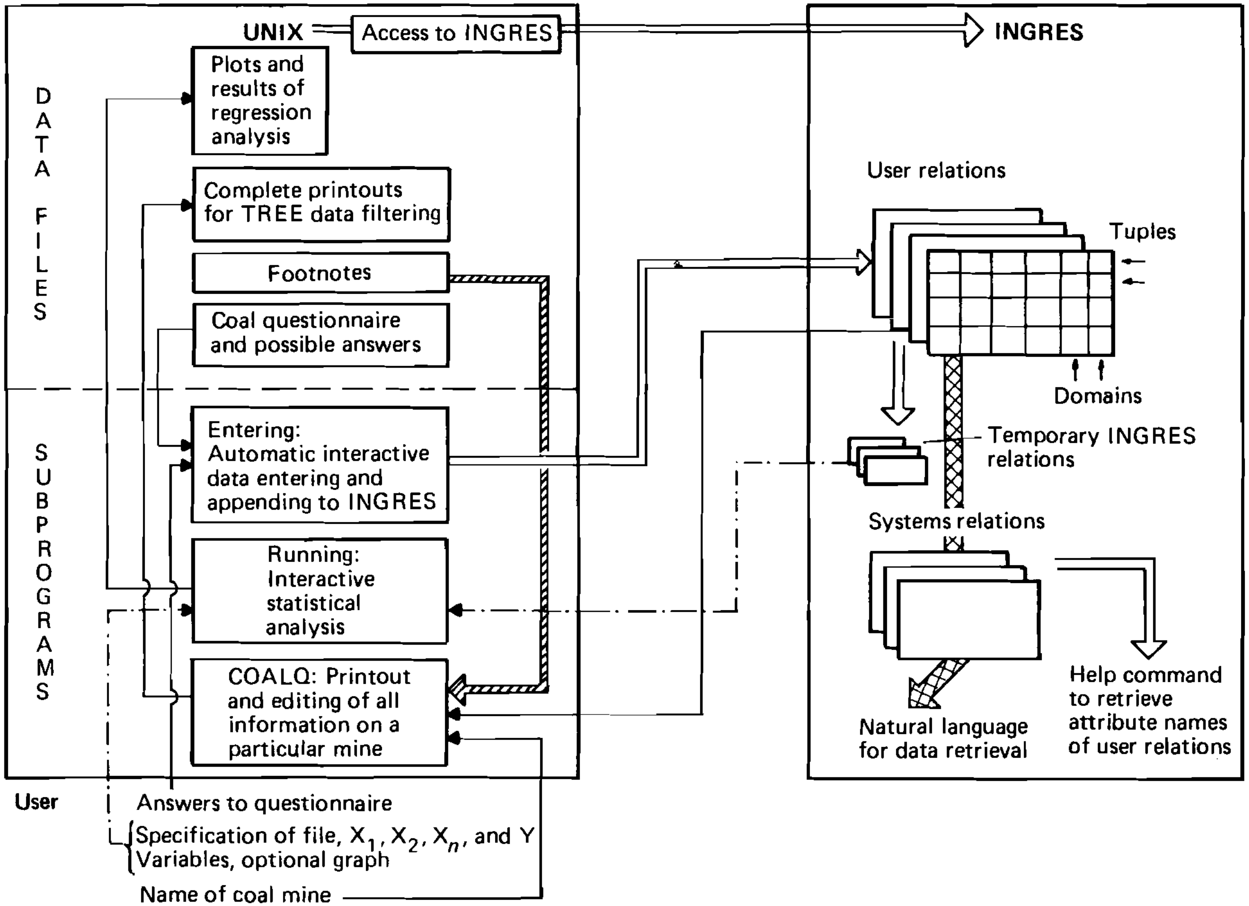

FIGURE 4 Organization of files and programs of the Coal Mines Data Base.

TABLE 2 Example of questionnaire file for interactive data entry program, *entering*.

QUESTION TO BE ASKED	DOMAIN NAME	FRMT	RANGE OF ANSWER	RESPONSE	NAME OF UNITS OF MEASUREMENT	BUFFER
code of mine	code	c10	s-* u-*			sto a sto a rcl a
tectonic distortions	tectonic	c8	-1 dist* hi* reg* some* go*	-1 dist highdist regbed somedist good	data not available disturbed highly disturbed regular bedding some distortions very good conditions	
coal density in situ	coaldens	f4	-1 n* > 5 > 0.5	-1 -1 ~	data not available data not available metric tons per cu meter metric tons per cu meter	
type of rocks	rocks	c8	-1 n* sa,si,sh sa,cl sh,sa sa,si s,cla sa,s,cla	-1 -1 sa,si,sh sa,cl sh,sa sa,si s,cla sa,s,cla	data not available data not available sand-,siltstone,shale sandstone,claystone shale,sandstone sandstone,siltstone sand,clay sandstone,sand,clay	
rock density (average)	burddens	f4	n* -1 > 5 > 0.5	-1 -1 ~	data not available data not available metric tons per cu meter metric tons per cu meter	
gas emanation tendency	gas	c4	-1 y* no	-1 yes no	data not available	
gas emanation (quantity)min	methanemin	f4	n* -1 10	-1 -1	data not available data not available cu meter/ton daily coal prod	
gas emanation (quantity)max	methanemax	f4	n* -1 10	-1 -1	data not available data not available cu meter/ton daily coal prod	
gas emanation (quantity)	methane	f4	n* -1 10	-1 -1	data not available data not available cu meter/ton daily coal prod	
spontan. combustion tendency	fire	c4	-1 y* no	-1 yes no	data not available	
water inflow (maximum)	water	i4	n* -1 10	-1 -1	data not available data not available cu meters per year	

has, in addition, a "verbose" option that displays to the user possible answers to each question. The user enters the new data in blocks, corresponding to the various INGRES files (or optionally combines the individual blocks into a whole questionnaire session); answers are verified (possible answers, formats, consistency with previously entered data for the same mine) and then either accepted or rejected by the program. In the latter case, a list of possible answers is given under the non-verbose option. When the user has finished, the data already entered are copied from UNIX into the various INGRES files with the required formats, data definitions, etc.

To conclude this outline of the Coal Mines Data Base, its contents, structure, and use, we would like to state that our main objective in the development of this data base was to achieve maximum ease and simplicity, not only for IIASA users but especially for outside users who may not be familiar with data bases. Although further features could be implemented, the new structure of the data base has demonstrated more ease in access and data retrieval than previous pilot structures (based on only a few extremely big INGRES relations that were difficult to manipulate). However, the simplicity and ease of use are counterbalanced by a longer response time when the system is heavily loaded (at least, on the relatively modest computer facilities at IIASA). We hope, nevertheless, that this type of approach will contribute to increasing the number of data base users without requiring permanent assistance from special data base managers.

3 FACTORS INFLUENCING RESOURCE REQUIREMENTS OF PRINCIPAL COAL-MINING METHODS

3.1 INTRODUCTION AND APPROACH TAKEN IN THE STUDY

Resource inputs to the coal-mining process are influenced by a great number of factors. Some of these factors are managed in the course of design, construction, and operation of a mine, others are given *a priori*, i.e. the natural conditions of the deposit. The natural conditions first of all determine whether the coal of a given deposit can be classified as recoverable reserves (i.e. whether the natural conditions are adequate for the available mining technology and the prevailing economic environment).

Although the resources used by coal mines, as well as the factors influencing these resources, are numerous it is useful to develop a general scheme of the process of resource consumption. Such a scheme could be a starting point for a more universal approach to modeling all the resource requirements of coal mines.

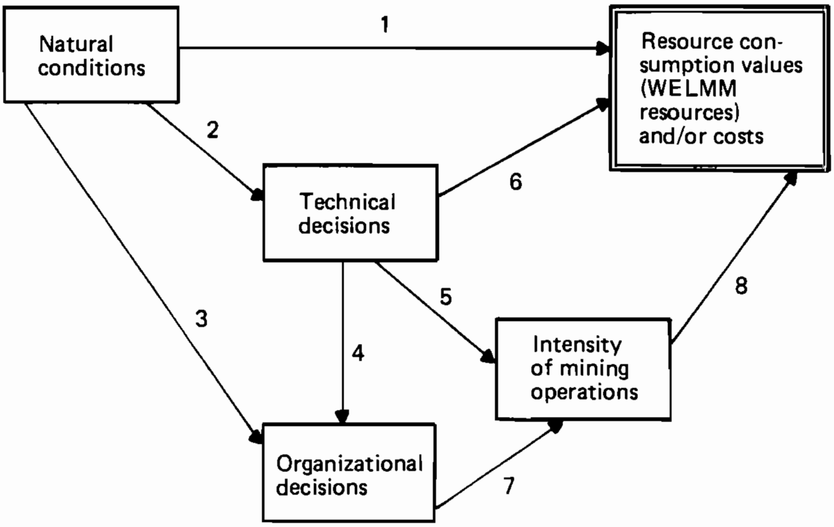

FIGURE 5 Principal interactions between the factors influencing resource consumption in the coal-mining process. ("Intensity of mining operations" here means the output of the whole mining process or the output per unit process.)

Figure 5 shows a general scheme where the resource consumption (and thus also the production costs) of the coal-mining process is given as a function of a set of influencing factors. The main factors to be considered are natural, technical, organizational, and the scale factor, i.e. the intensity of mining operations (measured in tonnes of coal output per mine and/or per unit process, e.g. overburden removal or coal transport).

Natural conditions influence resource consumption directly (arrow 1 in Figure 5) and indirectly by determining technical and organizational decisions at a mine (arrows 2 and 3). Technical and organizational decisions in turn affect resource consumption directly (arrow 6) and indirectly (through their influence upon the intensity of mining operations).

Each of the factors mentioned can of course vary independently within a certain range. In addition, technological progress requires new organizational setups and allows the intensification of mining operations within the same range of natural conditions. The rates of technological progress are rarely the same for different natural conditions. Through technological progress and its resulting influence on organizational decisions and the scale of mining operations, resource requirements can change drastically over time. A good historical example of such changes can be shown for flat coal beds in the Donetsk basin (Donbass) in the USSR. Mechanization possibilities were limited at these beds in the 1930s, but radical progress was made afterwards. In fact, nowadays mechanization at flat beds can be considered as more effective than at steep beds in the same basin. Thus, specific resource consumption figures can change significantly within the same range of natural conditions. However, this is a long-term process. If considered statically, all factors are, in principle, interconnected as represented by Figure 5. Thus, the natural conditions are the prime factors among all the factors under consideration.

One can imagine a number of approaches to modeling the influence of various factors on the consumption of resources. The most suitable approach uses models of the following type:

$$R_i = \frac{1}{\eta} \sum_j \left[r_{ij} V_j \right] + \frac{1}{\eta} \frac{R'_i}{O} \tag{1}$$

where

R_i is the specific consumption (or cost) of resource i, measured per unit of the calorific value of the coal mined;
r_{ij} is the same resource consumption measured per natural unit of work for each mining operation j;
V_j is the volume of work in operation j per tonne of coal mined;
R'_i is the annual consumption of resource i, independent of the quantity of coal produced;
O is the annual coal output of the mine;
η is the calorific value of the coal.

The first term on the right-hand side of eqn. (1) represents the part of the total resource consumption that is proportional to the coal output of the mine. This part is dependent on the size of the individual mining operations and on their intensity of use of resources. R'_i is the fixed part of the resource consumption; its value is not influenced by output variations. The factor η is used to recalculate resource consumption values per unit of the energy content of the coal produced. Models of the type represented by eqn. (1) provide a good tool for structural analysis of the factors influencing resource consumption at mines. (Equation (1) can also be used for a number of minerals other than coal.)

The influence of any factor (natural, technical, or organizational) can be disaggregated into a number of typical components, each of which can be described as a function of the factor. Synthesis of these functions in a form of eqn. (1) gives a structural model of how the factors influence a specific resource consumption value through a set of partial impacts on the following variables.

a. *The number of operations j in the mining process*. Mining in complicated natural conditions requires additional operations. For example, degassing is needed at mines with high methane emanation; special air conditioning is required in deep mines because of higher working temperatures at greater depths; boring and blasting are necessary at opencast mines if the rocks are firm. Additional operations such as loading and conveying coal at faces are characteristic of flat seams only.

b. *The volume of work V_j in operation j per tonne of coal mined.* Unfavorable natural conditions increase the specific amounts of work of a number of mining operations. The resource requirements of these operations per tonne of coal grow proportionally to these amounts. For example, the number of tonne-kilometers of lifting work per tonne of coal (and the resulting electricity consumption) increases with the depth of underground mines; demand for materials for mine supports is higher if rocks are unstable; deep opencast mines produce much more waste rock per tonne of coal output. If the cost of removing 1 m^3 of overburden is considered constant, the total cost of 1 tonne of coal should increase by a factor of 8 when the overburden to coal ratio rises from 1 to 17 m^3/t.

c. *The resource consumption value r_{ij} of resource i per unit of work in operation j.* Specific resource consumption values (i.e. per unit of work) are influenced by a number of natural and technical factors. For example, labor consumption at face operations is higher at thin beds; material and energy consumption per meter of boring increases with the hardness of the rocks; use of equipment increases in the presence of acidic waters.

d. *The annual coal output O of the mine*. The capacity of a mine is highly influenced by a number of natural and technical factors, as is the daily output per face. Increasing the amount of coal produced per mine and/or per face is considered a highly efficient way of reducing specific production costs, since about 30–50% of the annual costs are fixed. The specific cost (i.e. per tonne of coal) is an inverse function of the amount of coal mined out.

e. *The calorific value η of the coal*. This value is dependent on nature, i.e. on the extent of metamorphism of the coal and on the ash content, and ranges from about 8,000 to 33,500 kJ/kg. However, the ash content can be influenced by technical decisions on additional waste admixture (produced in mining operations) or waste removal (in preparation operations).

It is rather difficult to realize in detail the scheme represented by eqn. (1) if one is engaged in an initial, limited analysis of the problem, neither would it be necessary in the present case, as a detailed model of the sub-operations would be required only if one had to deal with the detailed design and project evaluation of a particular mine. However, eqn. (1) is a good basis for developing simpler logical models of the interdependences under consideration.

Thus, the analysis of WELMM resource requirements of the coal-mining process will be based on the following principles. The natural resource (WELMM) requirements will be studied for three mining methods separately: opencast, conventional underground, and hydraulic underground. This is because the impacts of the main (geological) factors on both the mining technology and the WELMM requirements are too different to make these mining methods directly comparable. Geographic regions of different scales (e.g. countries or coal basins) will be considered separately for each mining method: the details of such regions (e.g. available deposits, technological traditions, or economic systems) are often (but not always) so important that mines from the different regions cannot be considered together, or even compared directly.

Resource consumption values will be analyzed as specific values (i.e. per tonne of coal mined out or sold). Estimates per unit of energy produced can be made by dividing resource consumption by the calorific value η.

Analysis of the consumption of each kind of WELMM resource and the economics of coal mining (as presented in Section 4) will begin with a study of the share of the total resources consumed in each main mining operation and the dependences of these shares upon various factors. Later on, the annual and/or specific resource consumption of the mining process as a whole will be studied by regression analysis to determine the dependences of the natural resource requirements on the natural conditions and the capacity of a mine.

3.2 GENERAL CHARACTERISTICS OF COAL-MINING METHODS

Because of the influence of the deposit characteristics on the mining technology and the influence of both of these in turn on the resource requirements, it is necessary to distinguish between two main types of mining method: opencast and underground mining*. We found it useful to distinguish additionally between conventional underground mining (longwall and room-and-pillar mining) and hydraulic mining, because in hydromining both the coal-winning and the coal transport operations are quite different from those employed in conventional underground mining**. This classification is

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*Mining methods that are still in an experimental stage, such as borehole mining or *in situ* underground coal gasification, will not be considered here, the main reason being the absence of reliable data from large-scale commercial applications of these methods.

**Of course, in reality it is sometimes difficult to follow this type of classification, as there are mines that combine elements from both technological systems : hydromines with conventional, mechanical coal winning and hydraulic coal transport, and longwall mines with mechanical–hydraulic coal winning and conventional coal transport by conveyor.

more appropriate for the WELMM type of analysis reported here, and should not be interpreted as the wish of the authors to overemphasize hydromining technology, which, on the basis of its actual application (a few million tonnes of coal produced annually worldwide by hydromines), is by no means comparable in importance with conventional underground mining systems. This situation is not expected to change in the foreseeable future.

An analysis of the history and perspectives of the world coal-mining industry reveals that the most important factors influencing resource consumption in the course of mining can be summarized as follows:

1. depth of coal bedding;
2. thickness of coal seams;
3. tectonic disturbances of deposits;
4. methane emanation;
5. mine output;
6. method of mining.

These factors, and others, will be discussed in more detail for the different mining methods later in this section.

1. *Depth of coal bedding*. This factor, together with other natural factors, influences resource consumption values both directly and indirectly. The combination of depth and thickness of seams (i.e. the overburden to coal ratio) characterizes the range inside which the opencast method can effectively be used. Coal seams extending to greater depths at constant thickness imply an increase in the amount of waste rocks mined per tonne of coal produced. If the overburden to coal ratio exceeds a marginal value (which depends on the calorific value of the coal mined, and is around $10 m^3/t$ for brown coal and up to $30 m^3/t$ for high-quality coal), then underground mining, with higher resource requirements, is usually substituted for opencast mining. If depths increase further, resource consumption increases even more. Direct resource requirements increase with depth because longer shafts and underground workings have to be maintained. As the pressure of surrounding rocks increases, and construction of supports becomes more difficult, the cost of maintenance and repair of the workings becomes higher. As the temperature of surrounding rocks increases with depth, special installations for ventilation, degassing, and air conditioning, and sometimes the total reorganization of the mining system, become necessary. If these measures prove to be ineffective, output per face drastically decreases.

2. *Thickness of coal seams*. The average thickness of the coal seams affects the volumes of work required per tonne of coal mined out. The total cost of driving and maintenance of workings in an underground mine depends on the density of the coal seams in the bearing strata and thus on the area of the deposit, not on the output of the mine. In thin seams, coal output from one square meter of seam is less, which is why the costs of the operations grow (measured per tonne of coal produced).

The same can be said about the specific costs of coal and rock transportation and of land reclamation operations. In addition, face operations at thin seams are associated with uncomfortable working conditions and lower labor productivity. Last, but not least, there is a lack of some modern equipment for working on thin seams.

3. *Tectonic disturbances of deposits*. It is difficult to make an exact quantification of the impacts of tectonic disturbances on resource consumption values. Nevertheless, their considerable effect is obvious. The impacts of tectonic disturbances and their scale can be quite different. The cost of prospecting dramatically increases in disturbed deposits, geological data become less reliable, and therefore mistakes in design and operation of the mine become more likely. High-efficiency equipment is barely applicable in these conditions, and mining operations are less intensive.

4. *Methane emanation*. Methane emanation considerably affects the resource consumption of an underground mine. Mining of gaseous beds consumes much air and energy for ventilation. Cross sections of underground workings have to be made larger, and the cost of heading increases. Gas emanation has an effect on the systems of mining deployed. The coal output per mine and face becomes limited. As an alternative one can arrange special degassing facilities. They are costly but nevertheless very effective because all mining operations can be intensified. In addition, the recovered methane can be used as fuel at the mine or can be delivered to other consumers and, as such, is receiving growing worldwide attention as a potential additional gas resource (Delahaye and Grenon 1983).

5. *Mine output*. The capacity of a mine depends upon a set of factors, including the available coal reserves, bedding conditions, local demand for coal, the equipment used, and sometimes on historical traditions of design practice in the country. Thus, the capacity of a mine can vary substantially for the same value of one of these factors when considered separately from the other factors. All the resource consumption values per tonne of coal produced become lower at mines with a higher output*. In addition, the capacity of a mine tends to increase with technological advances, a good example being the development of high-capacity equipment and resulting giant capacities at some modern opencast mines.

6. *Method of mining*. The three main methods of mining (opencast, traditional underground, and hydraulic underground) have radically different resource consumption values. Specific costs are in practice several times lower at opencast mines than at underground mines (and, according to experience in the USSR, 20–40% lower at hydraulic mines than at traditional underground mines). Such costs are nevertheless hardly comparable because of the different natural conditions in which these mining methods are applied. Theoretically, the specific costs should be roughly similar for each of them if considered near the limit of the fields of their effective application. For instance, opencast mines operating at very great depths have costs comparable with underground mines operating at the same depths; and hydraulic mining becomes particularly advantageous when steep seams have to be mined.

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*Of course, this tendency has its limits, so that a mine has an optimal capacity for every set of influencing conditions.

These three methods of mining have radically different cost structures and different demands for particular resources. In addition, the influencing factors have quite different impacts for each mining method. For all these reasons the three methods will be analyzed separately in this report. Some additional subgroups for different systems of mining and main types of equipment will be treated separately where necessary.

3.3 OPENCAST COAL MINING

The opencast method is considered the most economical of all known mining methods. However, a study of this type of mining must begin with some qualifications. First, opencast and underground mines are usually compared without taking into account the important differences in mining depth. At greater depths the efficiency of opencast mining decreases sharply and becomes lower than the network of underground mining. Beds near the surface, which are usually mined by the opencast method, are often thicker; but such undermetamorphosed seams are of coal of low calorific value. Second, experience in the USSR shows that labor productivity for the best hydraulic underground mines can reach a level comparable with that of opencast mines in the same regions. For these reasons, the results of comparisons of the three main coal-mining methods must be interpreted with great care.

3.3.1 Comparative Advantages and Disadvantages of Opencast Mining

The technological advantages of opencast mining operations compared with underground mining may be summarized as follows:

a. It is possible to use big machines in opencast mines whereas in underground mining the size of equipment is limited by the cross section of the workings.
b. A smaller number of geological factors can adversely influence the production process. For example, there are no problems with high temperatures or gas emanation. Seam thickness, tectonic faults, and the risk of spontaneous combustion do not have as important impacts and can be managed better.
c. No ventilation or air conditioning is required.
d. Working conditions in the open air are more attractive.
e. The rate of development of machinery is higher for opencast mining.
f. For the reasons mentioned above, labor costs per tonne of coal produced are lower.
g. It is possible to construct opencast mines with much higher capacities than those of underground mines.
h. There are generally fewer losses of coal reserves *in situ*.

When compared with underground mining, opencast mining has some disadvantages too:

a. A greater amount of waste rock is mined per tonne of coal produced. (It should be mentioned, however, that overburden operations are carried out under much better conditions, i.e. in the open air with high-capacity equipment.)
b. Overburden hardness has a greater influence on productivity.
c. Climatic conditions have considerable influence on the economics of coal production.
d. Opencast mining operations disturb larger areas of land and have other unfavorable environmental impacts (such as lowering of the groundwater table and noise and dust emissions).
e. Deposits of coal under protected buildings or other facilities are in most cases unavailable, or involve high penalties for land acquisition and subsequent reclamation. (The giant lignite mines in Garsdorf and Hambach in the Federal Republic of Germany provide impressive examples of such costs: before mining operations begin entire villages are moved, and after mining is completed the landscape is remodeled as part of the reclamation process.)
f. The small-scale production of very large equipment for opencast mining leads to long delivery times and to possible bottlenecks.
g. Stringent requirements generally govern the maneuverability of mining equipment.
h. The overburden to coal ratio increases with the depth of mining operations. Consequently, resource requirements and mining costs also increase.

Several factors therefore determine the field of application of opencast mining. First, opencast mining is less economical than underground mining when the overburden to coal ratio exceeds the marginal value (which varies with the calorific value of the coal and economic and local conditions). Second, the level of industrial development and the related high population density in a region determine to an important extent the possibility of mining by the opencast method. If land is occupied by industrial buildings and other protected facilities, or if there are nonrenewable natural objects in the region, the opencast method cannot be used; even if such objects are renewable in principle, the cost of coal production will rise. Third, if there are constraints associated with the availability of the labor force, the opencast method becomes greatly advantageous, for it can be much less labor-intensive than conventional underground mining. Finally, the use of opencast mining ensures maximum output with a short construction period, although the time required for ordering and installing large equipment has an adverse effect. Where it is advantageous to apply opencast mining, geological and climatic conditions must determine the individual choice of the most efficient technology and equipment.

3.3.2 The Influence of Natural Conditions on Opencast Mining

a. *Overburden to coal ratio.* If this ratio increases, then most of the resource requirements (and thus the production costs) also increase, roughly according to the following relation:

$$c = c_c + R_{o:c}c_o \tag{2}$$

where c represents the total mining requirements, including overburden operations, per tonne of coal produced; c_c is the requirements for coal operations per tonne of coal produced; c_o equals the requirements for overburden operations per cubic meter of overburden removed; and $R_{o:c}$ is the overburden to coal ratio, in cubic meters per tonne.

b. *Hardness of overburden.* When hard rocks must be excavated, the cost per cubic meter of overburden stripped is substantially higher than for loose, sedimentary rocks. On the other hand, soft or clayey overburden can create problems for the stability of high-capacity equipment and its operation (for example, some of the supergiant equipment used in opencast mining, such as the bucket-wheel excavators used in brown coal mines in the FRG, having a capacity of 25,000 m^3 per day, weigh around 13,000 t).

c. *Presence of hard stone bands in the seams.* Such bands make opencast mining operations more complicated and reduce economic efficiency.

d. *Presence of other minerals.* These can have both negative and positive influences on coal-mining operations. Although they can hinder the continuity of mining operations, a possible benefit is the mining of these minerals together with coal.

3.3.3 Environmental Impacts of Opencast Mining

The main environmental consequences of opencast mining can be summarized as disturbance of land (although reclamation technologies can help in restoring the disturbed land) and disturbance of natural water flows and/or the water table. Both kinds of disruption in turn influence the production costs. Air pollution (caused by dust) and noise also damage the environment. Operational coal losses in opencast mining are much lower than those incurred through underground methods. Losses consist mainly of coal left as safety pillars and in zones where coal beds are in contact with surrounding rock and interstrata rock. For strip mines in the Eastern United States, for example, mining losses account for about 10% of reserves *in situ*; losses in pillars (under buildings, outcrop, etc.) account for about 7% of the reserves *in situ*. This leads to a total recovery rate of 83% (of course, this rate depends very much on the type of mining technology used).

3.4 CONVENTIONAL UNDERGROUND COAL MINING

The two main systems of underground mining are longwall and room-and-pillar mining. In longwall mining, a plough or drum shearer moves along the coal face (100–300 m long) to cut the coal, which then falls on to a conveyor. Self-advancing hydraulic roof supports provide roof control and protection for the machine operator. Each time the machine passes along the coal face, the roof supports release their pressure and move forward.

In room-and-pillar mining, coal is removed in intersecting tunnels (generally 4–5 m wide). Coal pillars are left to support the roof. Mining operations move forward until as much coal as possible has been removed from the seam. As mining operations move back to the entrance of the mine the coal pillars are often removed ("room-and-pillar with extraction"). There are two types of room-and-pillar mining: the conventional system and a system that employs a continuous mining machine. In conventional room-and-pillar mining the coal seam is cut using a cutting machine. Coal in the section of the seam is shattered by explosives or by compressed air. Loading machines move the coal to a conveyor or to shuttle cars for transportation out of the mine. When the coal has been removed, holes are drilled in the roof and steel expansion bolts are inserted for roof control. In the continuous room-and-pillar system, coal is removed, loaded, and transported by a continuous mining machine, thus resulting in higher productivity.

The shortwall mining system is, to some extent, a combination of the longwall and room-and-pillar systems. A continuous mining machine cuts and loads coal from a pillar about 50–80 m wide while self-advancing roof supports provide protection.

3.4.1 Comparative Advantages and Disadvantages of Conventional Underground Mining

Compared with opencast mining, underground mining permits excavation of thin coal seams at greater depths (seams lower than 400–500 m have up to now always been worked by the underground method). Underground mining also produces fewer unfavorable environmental impacts, i.e. less land disturbance (subsidence can be reduced by complete stowage). Compared with hydraulic underground methods, conventional underground mining has the following advantages: there is no need to use large amounts of water (this is significant only in areas with limited surface- and groundwater resources; water requirements for hydraulic mines with closed-cycle water circulation are also negligible) or to dewater the coal; and there are possibilities for obtaining coarse coal and for selective removal of stone from coal seams (although this cannot be achieved by all schemes of face mechanization).

The economic efficiency of underground mining is usually much lower than that of opencast mining. This is caused partly by the more complicated geological conditions prevailing normally at greater depths. Second, the intensity of production operations is relatively low as a result of the limited applicability of big machinery. Also, mining equipment and related facilities, beside being smaller than in opencast mines, have to be organized *in situ*;

consequently, construction, operation, and maintenance are particularly expensive and resource-consuming. A final characteristic of underground mines is the high expenditure necessary for safety measures.

Of the underground mining technologies the longwall and room-and-pillar systems have different peculiarities. The advantages of the room-and-pillar system over the longwall system are as follows:

a. Coal can be produced during seam opening and driving of development workings.
b. There is a possibility for selective mining and a greater flexibility in responding to changing geological conditions (variation of seam thickness, faults, poor roof conditions, etc.).
c. There are no critical areas, as there are in longwall mining (such as transition longwall drives), or such areas pose no practical problems.
d. The equipment is less complicated and thus more reliable and does not require as highly trained personnel as in longwall mining; moreover, the capital costs are lower.
e. Fewer people are required per production unit.
f. The system does not consume as many metal parts and pieces of equipment as are consumed at mechanized longwall faces (e.g. for hydraulic and other roof support).

The comparative disadvantages of the room-and-pillar system are mainly related to limitations in its applicability. Some of these are listed here:

a. The minimum seam thickness mineable (around 1.5 m) is higher than in longwall mining.
b. Application of room-and-pillar mining is limited by the mining depth, which is not more than 500 m, even under optimal conditions.
c. The operations are not really continuous (or only to a certain extent), as roof control operations are carried out separately*.
d. There are problems associated with rock dust and ventilation as well as with protection of miners from falling stones.
e. Recovery rates are considerably lower than for longwall mining (50–60% if pillars are not extracted, compared with up to 85–95% in longwall mining).
f. The pillars left tend to create unfavorable pressure conditions in over- or underlying seams.

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*On the other hand, the equipment used in longwall systems, though ensuring a truly continuous operation, has the disadvantage of being costly and time-consuming to move to a new working area.

3.4.2 The Influence of Natural Conditions on Underground Mining

The main factors limiting the efficiency of underground mining may be summarized as follows:

a. *Strata temperature*. The average geothermal gradient at a depth of 650 m and lower is 2.8 °C/100 m. Air conditioning is the principal method for cooling air and providing normal working conditions at the coal faces of such mines. However, if mining is carried out below 1,200 m, the strata temperature can rise to 60–70 °C; this implies progressively increasing expenses for cooling.

b. *Rock pressure*. Rock pressure also increases with mining depth. Serious problems occur when weak roofs make the use of supports more complicated, or when the floor of the workings begins to swell.

c. *Gas content of coal seams*. The relationship between gas content and mining depth is not simple and some variation has been observed. At some major coal basins in the USSR, for example, we find the following. As a rule, no increase in gas content is observed at depths exceeding 300–400 m in the Donetsk basin (Donbass). In the Kuznetsk basin (Kuzbass) the highest gas content has been observed in seams that lie in closed anticlines or at major faults. Finally, in the Karaganda basin the most intensive degassing has been recorded at depths of 250–300 m.

Seam degasification has proved to be an efficient measure for controlling the gas content of the mine air, since it improves the intensity of mining operations. Also, the recovered methane constitutes an additional energy source.

d. *Gas outbursts*. Seams prone to sudden outbursts of gas and associated coal outbursts are, for example, now being mined at 130 coal mines in the Donetsk, Kuznetsk, Karaganda, and several other basins in the USSR. The danger of outbursts is expected to grow as mining proceeds to greater depths. The development of reliable technological means for preventing this danger constitutes one of the most complicated mining problems still to be resolved.

e. *Depth of mining operations*. Depth adversely affects the efficiency of mining operations in two ways. First, as mining depth increases, the network of haulage and air workings must be extended, and this leads to increased expenditures. Second, many of the factors discussed above are correlated with depth. For example, in the Donbass in the USSR, a 100 m increase in depth (beyond the 600 m limit) increases expenditures for each tonne of coal output by 5–7%. So far, no estimates have been made for mining at depths exceeding 1,500 m. In the USA the problem of increasing mining depth is less important, owing to the shallowness of most deposits.

f. *Coal hardness*. Coal hardness has an influence upon the quantity of energy consumed in the mining process.

g. *Liability of spontaneous combustion of coal*. In some mining areas up to 10% of coal seams are prone to spontaneous combustion. Preventing fire is still a very complicated and serious problem.

h. *Tectonic faulting of coal seams*. Tectonic faulting is one of the most significant obstacles to the application of efficient modern machinery. Heavily faulted areas are found in the Kuzbass and in some parts of the Karaganda and Donbass coalfields in the USSR, as well as in many other coal basins in Europe.

i. *Seam thickness*. Complete mechanization is not yet possible for seams thinner than 0.6 m, and this limits their exploitation at present. It is not possible to exploit seams thinner than 0.4 m if men are required at the coal face. If the thickness increases in such a way that it is necessary to develop additional slices the efficiency of coal-mining operations decreases sharply. In this respect it is interesting to note the recent development, in the FRG, of hydraulic roof supports and shearer loaders that allow excavation at mechanized faces from very thick seams of up to 5 m in only one slice (Benthaus *et al.* 1980).

j. *Coal quality*. The quality of coal (calorific value, ash content *in situ*, moisture, sulfur, and phosphorus content, volatile matter content, etc.) has a great economic effect, both on coal production (requiring, for instance, coal preparation operations) and on coal utilization and its related environmental impacts. It slightly influences the choice of mining technology, but does not noticeably affect the possibility of mining.

k. *Angle of dip*. Strong dipping of the coal seams mainly limits the possibilities of mechanization at a face.

Other factors, influencing mainly the economics of coal production, include the amount of water pumped per tonne of coal produced, the density of the reserves *in situ*, and the amount of reserves.

3.4.3 Environmental Impacts of Underground Mining

Table 3 shows an overview of the main environmental impacts associated with underground mining. Generally, these impacts are not as significant as those associated with opencast mining, and particularly when compared with the environmental impacts of facilities upstream of the coal energy chain (power plants, liquefaction facilities, etc.). In addition, engineering control measures to limit adverse impacts can be applied at relatively low cost.

TABLE 3 Overview of environmental impacts of underground coal-mining operations.

Process	Environmental impacts	Factors determining extent of impacts	Engineering control measures
Stone winding	Land occupied by spoil heaps	Thickness of seams and stone bands, depth of seams, development scheme	Central spoil heaps for group of mines, reclamation
	Emissions from burning spoil heaps	Existence of pyrite bands, liability of spontaneous combustion of coal	Fire precautions
Pumping of acidic water from mine	Reduction of water quality (mineralization) of sweetwater ponds	Mining depth, hydrology of coal-bearing strata, sweetwater resources in the region	Water treatment
Disturbance of strata integrity	Surface subsidence, temporary land disturbance, additional losses of coal reserves if security pillars are necessary	Seam thickness, dip, mining depth	Land reclamation, security pillars, stowing techniques (in favorable cases, surface subsidence is smooth and no reclamation is necessary)
Energy production for mine	Emissions (fly ash, SO_2, NO_x, etc.), wastes	Coal quality, conversion technology used	Use of high-grade, clean fuels (low-sulfur coal, methane, natural gas); emission control (scrubbers), waste disposal and reclamation

3.5 HYDRAULIC UNDERGROUND COAL MINING

A typical technological chain for hydraulic underground mining consists of hydraulic or mechanical breaking of coal (a distinction can therefore be made between pure and mechanical hydromining), transport of coal by water flow under gravity, pumping of the coal slurry, and hydraulic lifting. The process is continuous and is typically carried out in the following way. The shortwall system is used in hydraulic underground mining and this predetermines a long network of development workings, four to six times longer than the network associated with the longwall system. Hydraulic and mechanical–hydraulic driving methods with roof support predominate in the shortwall system. Several different ways of breaking coal at coal faces may be employed; hydraulic (with hydraulic monitors) and mechanical–hydraulic (with a shearer) are the most efficient methods. Operations at the shortwall face as a rule do not require support and roof control. Gravity-flow hydraulic transport and hydraulic lifting typically constitute the next steps. The slurry lifted out of the mines is then pumped to the preparation/dewatering plant situated at the mine site or at the place of consumption. Dewatering and drying of the coal, cleaning, and return of the water to the hydraulic mine (when distances permit recycling) are carried out next. Other operations (i.e. development work) are similar to those in conventional mines.

The requirements for possible and successful application of hydraulic mining may be summarized as follows:

a. coal seams have to be at least slightly inclined (3–7°) to allow for gravitational flow of the slurry;
b. great seam thickness;
c. shortwall mining with its related extensive driven workings;
d. sufficient solidity of roof and floor;
e. relatively soft coal and relative absence of dirt bands;
f. availability of the required water.

3.5.1 Comparative Advantages and Disadvantages of Hydraulic Mining

The hydraulic method was developed in the USSR, where to date most of the hydromines in the world are located. At present there are six pure hydromines and three mechanical hydromines operating in the USSR. The total annual coal output approaches $10 \cdot 10^6$ t. Hydromining is carried out in the Kuzbass and, to a smaller extent, in the Donbass. It has been tested under a wide range of geological conditions, i.e. in seams of different thicknesses with dips from 3° to very steep inclinations. Because hydraulic mining is a relatively new method, possibilities for a high rate of technological improvement are greater than for traditional underground technologies. As an illustration of this potential, between 1966 and 1977 the average rate of increase in labor productivity in hydraulic mines in the USSR was twice that of conventional mines operating under the same conditions. Hydraulic mining is also used, or has been tested, in Canada (Sparwood mine), the FRG (Hansa mine, but without success), and Japan, as well as in other countries, but nowhere is it as widely used as in the USSR.

The hydraulic method has several technological advantages. In brief, the method is continuous, consists of few operations, and is comparatively simple. More specifically, its advantages are as follows:

a. Hydraulic mining is particularly effective where conditions are difficult, such as disturbed tectonics, inclined seams, methane emanation, and risks of spontaneous combustion. Thus it offers good possibilities for mechanization and high productivity in conditions that are difficult for conventional underground mining (e.g. thick and strongly inclined seams or deep seams).
b. The high degree of mechanization significantly raises labor productivity and thus reduces the labor costs.
c. Because of the high output per face, fewer faces are required to provide a particular mine output; the number of faces can be increased significantly without hiring new staff.
d. Face equipment is light and robust and few metal parts are required; its low cost means that the initial investment is rather small.
e. The equipment permits a substantial amount of maneuverability in the hydraulic coal-breaking process at the face and can be adapted fairly easily to any tectonic changes in seam bedding.
f. The system is very apt for automation, remote control, etc. and for centralizing the hydraulic transport of coal.
g. Safety is improved. The low dust content in the air, the absence of electrical supply systems, and the elimination of blasting reduce the danger of gas and coal dust explosions; the probability of spontaneous fires, especially in seams where there is a risk of spontaneous combustion, is reduced; fewer men working at the face and the absence of trains and machinery at entries and haulage roads lead to less accidents. According to experience gained in the USSR, two to three times fewer injuries have been observed at hydraulic mines than at conventional underground mines*.

Drawbacks inherent to hydraulic technology include high water consumption for industrial needs, high electricity requirements, especially for transporting coal and dewatering slurry, and the need for additional surface areas for wastewater ponds. The method is also characterized by a substantial increase of driven workings, resulting from the application of shortwall mining. Also, the method has limited selectivity in mining and it is impossible to obtain coarse coal (this is important only for some consumers, however). Finally, hydraulic mining necessitates additional operations, such as dewatering of the coal slurry. It also involves increased coal losses (up to 30% or more) caused both by mining and by dewatering of slurry, but the recovery rate is still better than in room-and-pillar mining or in longwall mines operating under similar (difficult) conditions and with a comparable

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*However, as the accident (due to smoking) in the Hansa mine in the FRG has shown, there still exist problems of a psychological nature with respect to the miner's perception of risk.

productivity.

Research and experience suggest that the field of application of hydraulic underground mining is very wide, and can be expanded if the water pressure at the hydraulic monitors is increased (currently ranging from around 100–150 bar to pressures at least 10 times as high). However, the dangers related to such high pressures would have to be managed too.

Further improvements in hydraulic methods in the USSR may be expected in the following areas in the near future: development of self-propelled hydromonitors with remote control and a high degree of autonomy, followed by programmed remote and automatic control of the monitors; wider use of mechanical–hydraulic power loaders in drives; mechanization of roof bolting; transition to remote control, and then to programmed and automatic control of development operations; use of closed-cycle water supply schemes; transport of coal by pipeline over long distances from the mine; automatic control of hydraulic transport and lifting; combining a number of hydraulic mines into centrally controlled systems; and finally, development of methods for combustion of coal in a slurried state without dewatering or drying.

3.5.2 The Influence of Natural Conditions on Hydraulic Mining

In principle, all factors determining the resource requirements and economics of conventional underground mining are, to a greater or smaller extent, also valid for hydraulic mining. However, hydromining is particularly advantageous under conditions that are not favorable for conventional mining techniques, such as steep seams or poor bedding conditions (geological faults, changes in seam thickness and inclination, water inflow, etc.).

If the coal is very hard, mechanical–hydraulic mining (i.e. mechanical coal winning and hydraulic transport) rather than purely hydraulic mining is used, for its application is not limited by coal hardness (if adjoining rocks are of less than average stability, pure hydromining should be applied). However, these factors do not limit the field of application of hydraulic mining technologies in general.

Limiting conditions include a seam dip of less than 3–4° (thus preventing the gravitational flow of slurry), seam floors liable to water soaking and heaving, seams less than 0.5 m thick, and the requirement to produce coarse coal.

3.5.3 Environmental Impacts of Hydraulic Mining

In addition to the environmental impacts of conventional underground mining, discussed in Section 3.4.3, hydromines have the following environmental impacts. The production and dewatering of the coal slurry require large amounts of water and additional land requirements for surface installations. Wastewater produced in the dewatering process has to be treated in wastewater ponds. However, research is currently under way to develop closed water cycles that would significantly reduce the water requirements and the necessity for wastewater treatment.

4 ANALYSIS OF WELMM REQUIREMENTS AND ECONOMICS OF COAL MINES

4.1 OPENCAST MINING

4.1.1 Structural Analysis of Resource Requirements of Mines in Selected Countries

4.1.1.1 Opencast Mines in the USA

Sixty percent of the total coal output of the USA is currently produced by opencast mining (459 million out of a total of 752 million tonnes* in 1982). As seen in Table 4, the regional distributions of current production and of strippable coal reserves are quite different (Averitt 1975, Fluor Utah Inc. 1975, WOCOL 1980b, US Department of Energy 1981). In fact, about 60% of surface production is concentrated in the Appalachian and Illinois basins and the Western Interior region (including Texas) in the Eastern United States, whereas these districts account for only about 40% of the strippable reserve base *in situ*. On the other hand, the Western coal provinces actually account for around 40% of surface-mined coal but possess 60% of the strippable reserve base. This means that the geographic focus of strip-mined coal in the USA will have to move to the Western coal provinces in the long run. This trend has already been quite strong in the last 10 years, with the share of Western strip-mined coal in the total US coal production steadily increasing. The total strippable reserve base of $142 \cdot 10^9$ t should not be regarded as recoverable reserves. The latter are estimated to be 80% of this total with respect to technical recoverability and, according to earlier studies by the US Bureau of Mines (1971), only 50% in view of their technical *and* economic recoverability. However, even if only 50% recoverability is assumed, the recoverable strip reserves are still huge (150 times the amount produced from surface mines in 1982) and will allow the high share of strip-mined coal to be maintained in the medium term**. A major part of any increase in surface mine production capacity will come from the Western regions of the United States because of the favorable geological conditions prevailing and the low sulfur content of the coal. Coal basins in the Western regions are located in thinly populated and somewhat underdeveloped areas. Apart from its lower sulfur content, the coal generally has a lower calorific value (lignite or subbituminous coal) than in the Eastern United States. Geological conditions are excellent: there are numerous seams of great thickness and coal-bearing suites that are almost

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*Tonnes (metric tons, t) are used throughout this report.

**According to the WOCOL (1980b) projections, surface-mined coal output is expected to increase to 800 million tonnes (low case) or even 1,500 million tonnes (high case) by the year 2000.

flat and regular over large areas.

Opencast mines in the USA are not very large in terms of output. The largest do not exceed production capacities in the range of 10–15 million tonnes per year. The average annual output of the 10 largest surface mines in 1982 was around 10 million tonnes, and that of the surface mines within the 50 biggest US coal mines in 1982 was 5.25 million tonnes (*Keystone Coal Industry Manual* 1978, 1979, 1980, 1981, 1982), whereas the average output of all 2,120 surface mines operating in 1982 was only over 200,000 t per year. However, there has been an increase in the average mine output. For instance, the average annual output of the 10 biggest surface mines increased from 3.6 million tonnes in 1969 to 8.8 in 1979 and to around 10 million tonnes in 1982 (*Keystone Coal Industry Manual* 1978, 1979, 1980, 1981, 1982). American opencast mines usually operate under very favorable conditions: the mining depth does not exceed 40–60 m and high-productivity equipment is used for handling overburden and coal as well as for transportation.

TABLE 4 Regional distribution of strippable coal reserves and surface production in the USA.

Region	Eastern	Interior		Western	Total[a]
Basin	Appalachia	Illinois, Western Interior	Texas Lignite	Fort Union, Powder River, Green River, Four Corners	
Total reserve base *in situ* (10^9 t)[b]	104.0	100.5	11.5	208.4	430.5
Strippable reserve base *in situ* (10^9 t)[b]	19.3	24.6	11.5	85.4	141.8
Strippable reserve base as percentage of total reserve base (%)	19	24	100	41	33
Strippable reserve base as percentage of total US strippable reserves (%)	14	17	8	60	–
Total production in 1982 (10^6 t)	373.1	131.3	31.4	215.7	752.3
Strip-mined production in 1982 (10^6 t)	152.2[c]	76.3[c]	31.4	182.2[c]	458.9
Strip-mined production as percentage of total production	41	58	100	84	61

[a] Including Alaska.

[b] *Demonstrated Reserve Base of Coal in the United States on January 1, 1979* (US Department of Energy 1981).

[c] 1981 values; the total strip-mined production in the USA in 1981 was $440.9 \cdot 10^6$ t.

Sources: Averitt (1975), Fluor Utah Inc. (1975), WOCOL (1980b), and US Department of Energy (1981).

As a first step the main data for analysis of surface mines in the United States were taken from published material. The most detailed information was prepared by Fluor Utah Inc. (1977) and Bonner and Moore Associates for use in computer simulation models designed to evaluate the possible costs of large-scale surface coal mining in the United States. Eight hypothetical test cases of coal mining in different regions of the country, under typical geological and local conditions and using representative mining methods, were considered in this study. All test case mines are in areas with great potential for surface mining operations and include the mining systems most commonly used in the USA, representing the best technology currently available.

Our study also included data derived from a US Bureau of Mines study on the estimated capital investment and operating costs of strip mines (Katell *et al.* 1976a) and data on two mines considered by the Bechtel Corporation in their US National Energy Supply model (Stanford Research Institute 1975, Hogle *et al.* 1976, Bechtel Corporation 1977, 1978). The disadvantage of these data is that they do not account for local conditions in detail and that they are sometimes too aggregated. Therefore, compared with estimates taking detailed account of deposit characteristics (e.g. Fluor Utah data) or with real operational data, they are more unreliable and, in general, are underestimated (this particularly applied to the USBM study).

Various surface mine projects in the Western part of the USA are described in Environmental Impact Statements prepared by the Geological Survey of the United States (Department of the Interior). These statements were considered as a third source of data, but after careful analysis it was concluded that they are a somewhat insufficient source of information. First, not all the data necessary for the analysis are included (e.g. no differentiation is made between raw and saleable (clean) coal and, in some cases, even the overburden to coal ratio is not included). Second, some information is not complete (e.g. on equipment lists and energy requirements for the equipment used). Finally, basic data on geology or coal quality are very often inconsistent and/or contradictory within the same report. This sheds an unfortunately not too positive light on the quality of the data on the environmental impacts contained in these reports, on the basis of which decisions about the acceptability of environmental impacts of large-scale energy projects are supposed to be made.

Table 5 summarizes the main geological characteristics of the mines in the US coal basins studied, as well as the mining systems and main characteristics of the mines or groups of mines in these basins. Average seam thicknesses vary from about 1.2 to 21.9m, overburden thicknesses from 5.4 to 67m, and overburden to coal ratios from 1.1 to 15.1 m^3 per tonne of coal recovered. Generally, all mines are located in extremely favorable conditions and, even in the Eastern part of the country, in better conditions than are encountered in most other coal-producing countries.

According to US terminology, the mining systems include the following.

a. *Area stripping with draglines*. After drilling and blasting of overburden, a first dragline is used to remove a portion of the overburden where necessary. A second dragline, operating on a bench created by leveling the spoil from the first machine, is used to remove the remaining overburden and to rehandle a portion of the initial spoil. The overburden is cast to spoil heaps occupying the panel mined previously. The top of the coal seam is then cleaned (by front-end loaders or graders) prior to drilling and blasting. Coal is then loaded by a shovel in the pit bottom and is hauled by a fleet of trucks.

TABLE 5 Main characteristics of surface mines or groups of surface mines[a] in the principal coal basins of the USA considered in the WELMM analysis.

Region	Eastern	Interior		Western				Hypothetical (projected mines)
Basin	Appalachia	Illinois	Texas Gulf	Four Corners	Fort Union	Green River	Powder River	
Mining system	Contour stripping, mountain-top removal	Area stripping with draglines		Area stripping with draglines		Multiple-dipping seam mining	Area stripping with draglines or shovels	Area stripping with shovels
Number of seams mined	1–2	1	1	1–4	1	2	1–4	1
Average seam thickness (m)	~1.2	1.2–1.8	3.1	3.7–7	3.7–7.6	5.8	9.1–21.9	1.8
Depth (m)	16–49	23–?	17	22–30	17–21	41	50–95	21–32
Overburden to coal ratio (m^3/t)	10.5–11	13.9–15.1	3.2	4.1–5.4	2.8–3.2	6.4	1.1–3.5	5–11.6
Heat content of coal (MJ/kg)	29.3–29.6	27.9–28.1	16.3	19.6–20.9	16.5	23.9	18.0–22.1	22.5–31.5
Recovery rate (%)	92	81–92	92	90–92	90–92	92	87–98	90
Lifetime (yr)	30	30	30	25–30	20–30	30	17–40	20
Output of raw coal (10^6 t)	4.6–4.7	3.6[b]–4.9	8.5	6.6–17[b]	8.3[b]–8.4	5.8	2.1[b]–18.1	2.7[b]–6.1[b]
Output of clean coal[c] (10^6 t)	4.6–4.7	[b]–4.9	8.4	6.5–[b]	[b]–8.3	5.7	4.4–17.8	[b]
Number of mines analyzed	2	2	1	2	2	1	12	3

[a] Values in ranges may not always correspond to the same mines.

[b] No coal preparation.

[c] Coal preparation includes crushing and screening.

Source: Coal Mines Data Base, IIASA.

b. *Contour stripping* with draglines*. After drilling and blasting of overburden, a dragline following the contour of a coal outcrop along a gently sloping hillside removes the overburden. Overburden is cast to spoil heaps occupying the previously mined panel. Coal is then loaded by a shovel into trucks.

c. *Area stripping with shovels*. Overburden is removed by electric shovels, which load it into trucks for transport to mined-out pit areas. Coal from the exposed seam is loaded by a shovel and transported by trucks.

d. *Multiple-dipping seam mining*. Overburden is removed by shovels or front-end loaders and a fleet of trucks carries it to waste dump areas. The equipment operates on a series of benches in a hillside pit. Coal is then loaded by front-end loaders into trucks.

e. *Mountain-top removal*. Overburden is removed by shovels or front-end loaders and transported by trucks, all operating on a mountain top or ridge. Coal operations are carried out by a front-end loader in the pit bottom and haulage is by a fleet of trucks.

Further analysis in this section takes into consideration the manpower, energy, and material consumption and the natural resource requirements. In addition, some cost data** will be discussed; naturally, cost information is much more likely to be affected by unpredictable factors than are the physical resource requirements themselves. Data on requirements are mainly considered for the operational period of a mine. Data for the construction period are usually more scarce and were analyzed only when sufficient data were available. All quantities are given in metric units.

Manpower Requirements

Manpower requirements for US opencast mines considered in the analysis are summarized in Table 6. Personnel employed for operation and maintenance range from about 24 to 316 persons per million tonnes of clean coal produced annually (including coal preparation). The average for all US opencast mines recorded in the Coal Mines Data Base is 134 persons per million tonnes produced annually. If we assume 230 working days per person per year, this corresponds to a labor productivity of 32.4 t per man-shift. The manpower requirements of the mines in the CMDB can be considered as quite representative for the coal-mining industry of the USA, where in 1981 the average labor productivity at opencast mines was 27.4 t per man-shift. The highest average labor productivity at US opencast mines was achieved in 1973, with 33.4 t per man-shift.

Operational personnel account for approximately 70% of total manpower requirements, while the remaining 30% are involved in maintenance of equipment. Manpower requirements depend very closely on geological and

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*A special mining system also in use in the USA, as well as in Australia, is auger mining, usually associated with contour strip mining. It is commonly utilized to recover additional tonnages after the stripping ratio has become too great to be economical. Augers extract coal by boring horizontally into the seam; some augers are as much as 2 m in diameter and are drilled over 60 m into the hillside.

**All cost data in this section were originally in different currencies and from different years, and have been converted to US$(1975) values. Appendix D gives the conversion rates used.

TABLE 6 Manpower requirements of US opencast mines[a].

Basin	Powder River		Hypothetical (projected mines)	Fort Union	Texas Gulf	Four Corners	Illinois	Green River	Appalachia, West Virginia	Appalachia, Ohio
Mining system	Area stripping: with draglines	with shovels and trucks		Area stripping with draglines				Multiple-dipping seam mining	Mountain-top removal	Contour stripping with draglines
Overburden to coal ratio (m^3/t)	1.8–3.5	1.1–2.4	5–11.6	2.8–3.2	3.2	4.1–5.4	13.9–15.1	6.4	11.0	10.5
Average	2.6	1.9	8.6	3.0	–	4.8	14.5	–	–	–
Total personnel employed	75^b–392^b	161^b–643	153^b–202^b	234^b–475	508	491–796^b	446–604	1,805	1,457	740
Average	243.5	310.9	183.3^b	354.5	–	643.5	525	–	–	–
Personnel employed per 10^6 t clean coal	23.6–72.1^b	17.7^b–89.7	33.1^b–56.3^b	28.1^b–57.2	60.7	46.8^b–75.3	122.8–123.4	315.0	316.2	158.7
Average	45.4	38.7	44.7^b	85.2		61.1	123.2	–	–	–

[a] Values in ranges may not always correspond to the same mines.

[b] Excluding coal preparation: specific values are expressed per 10^6 t raw coal.

Source: Coal Mines Data Base, IIASA.

TABLE 7 Composition of manpower requirements for different mining and preparation operations in selected US surface mines (persons per 10^6 t clean coal produced annually).

Basin	Powder River	Fort Union	Texas Gulf	Four Corners	Illinois	Green River	Appalachia, West Virginia	Appalachia, Ohio
Mining system	Area stripping with shovels and trucks	Area stripping with draglines				Multiple-dipping seam mining	Mountain-top removal	Contour stripping withdraglines
Overburden to coal ratio (m^3/t)	2.4	3.2	3.2	4.1	15.05	6.4	11.0	10.45
Overburden drilling and blasting	5.4	—	4.4	5.6	11.2	14.8	15.6	15.7
Overburden removal	34.8	13.8	13.9	19.1	45.3	134.8	176.6	43.0
Coal drilling and blasting	0.3	1.3	0.4	0.6	—	1.3	—	—
Coal loading and haulage	5.5	8.5	8.4	10.8	12.3	21.5	19.2	19.1
Coal handling and preparation	22.0	19.9	19.9	23.3	28.2	81.4	59.9	59.3
Land reclamation	0.4	2.6	2.7	1.7	7.7	1.9	1.6	4.6
General and administration	21.2	11.1	11.0	14.1	18.8	57.4	43.4	16.7
Total[a]	89.7	57.2	60.7	75.3	123.4	314.8[b]	316.2	158.7

[a] Totals may not add because of rounding errors.

[b] The total for the operations is 313.1, compared with a total specific manpower requirement of 314.8 given in the original data source (Fluor Utah Inc. 1977, vol. 9, appendices D.3 and D.4).

technological conditions. As the overburden to coal ratio increases, manpower requirements also increase. Table 7 shows the manpower requirements for the various mining and preparation operations in selected mines.

Overburden operations account for approximately 45% of the total manpower requirements in opencast mines. It is this part of the total that is most variable (within the group of mines considered in Table 7 it varies by as much as a factor of 14). The most influential factors relate to the technology deployed for overburden operations (overburden transport by trucks is particularly labor-intensive) and the overburden to coal ratio.

Labor requirements for coal extraction operations constitute only around 10% of total labor requirements. Coal handling and preparation account for about 25%, and administration for about 17%. Crews working on land reclamation are quite small.

Manpower requirements vary considerably between regions and basins. On the one hand, labor productivity in the Western USA is about twice that in the Eastern region, reaching 76 t per man-shift. On the other hand, Western coal does not have such a high calorific value. Therefore, if one considers the labor requirements per tonne of coal equivalent (1 tce = 29.3 MJ or 7 Gcal) the difference is somewhat smaller. For an annual energy production of 10^6 tce clean coal (including coal preparation), 33 to 138 persons (the average being 71.4) are required in the Western coal provinces and 109 to 159 (average 131.4) in the Eastern and Interior regions. Mountain-top removal and multiple-dipping seam mining systems have labor requirements of up to 387 persons per 10^6 tce, but these mining systems, which are deployed in special geological conditions, cannot be compared directly with conventional area-stripping methods.

On the whole, labor requirements connected with opencast mining are very moderate. If the United States wanted to produce 10^9 t of coal per year from Western opencast mines, not more than 80 to 100 thousand people would be required. On a general scale this does not appear extravagant or impossible. However, if the program were to be carried out in the rather thinly populated Western areas considerable capital and material input would be required to create an appropriate infrastructure, to support not only the working population but also the additional population induced to live in these areas. Examples such as the tar sand development in Athabasca, Canada demonstrate the scale and difficulties, as well as the potential sociological problems, created by the rapid increase in population of formerly practically uninhabited areas.

Energy Requirements

Opencast mines consume two main kinds of final energy, namely electricity and diesel fuel. The quantities and relative amounts of these energy types depend on the technologies used for overburden operations and on the overburden to coal ratio. Draglines and conveyors consume electricity, while tractors, front-end loaders, and trucks use only motor fuel.

Electricity consumption is not very high in the opencast mines under consideration; it averages 17.0 kWh/t or 21.9 kWh/tce of clean coal produced (including coal preparation operations). Table 8 shows clearly that energy requirements differ widely between groups of mines, and that there is a

TABLE 8 Electricity requirements of US opencast mines[a].

Basin	Powder River		Fort Union	Texas Gulf	Four Corners	Illinois	Green River	Appalachia, West Virginia	Appalachia, Ohio	Hypothetical (projected mines)
Mining system	Area stripping: with draglines	with shovels	Area stripping with draglines				Multiple-dipping seam mining	Mountain-top removal	Contour stripping with draglines	Area stripping with shovels
Overburden to coal ratio (m^3/t)	1.77–3.5	2.4	2.8–3.2	3.2	4.1	13.9–15.05	6.4	11.0	10.45	9.2–11.6
kWh/t clean coal	9.1–21.3	10.3	13.3–16.3[b]	13.9	17.0	19.4[b]–37.1	8.3	8.6	31.1	20.7[b] – 27.0[b]
kWh/tce	12.1–31.4	15.8	23.7–29.1[b]	24.9	23.8	20.2[b]–39.0	10.2	8.5	31.1	24.8[b]–27.0[b]

[a] Values in ranges may not always correspond to the same mines.

[b] Excluding coal preparation; values are expressed per tonne of raw coal.

Source: Coal Mines Data Base, IIASA.

correlation of electricity requirements with the overburden to coal ratio. As this ratio increases from around 2 to 15 m^3/t, electricity consumption rises proportionately from around 9 to 37 kWh/t clean coal produced. In multiple-dipping seam and mountain-top removal mining, electricity requirements are two to three times lower than for other mining systems, since most of the operations are carried out by diesel-powered equipment.

It is also of interest to consider the relationship between electricity consumption and labor requirements in order to see whether electricity-intensive systems (which generally use larger equipment than diesel-powered systems) use more or less labor. Within the same system of mining (e.g. area stripping with draglines) both electricity and manpower requirements evolve in the same direction because of their common dependence on the overburden to coal ratio. However, if different mining systems are compared, it is not apparent that electricity intensiveness also means labor intensiveness. The relationship between these two variables depends on the stage of development and on the general efficiency of the technological system. Improved technology usually implies the substitution of large-scale, electrically driven machines for labor.

Conversely, systems with small electricity consumption, such as those using diesel-powered tractors or front-end loaders, are more labor-intensive (by as much as a factor of 2). The reason for this is the smaller size of the diesel equipment used for overburden operations compared with electrically powered equipment. Table 9 presents the distribution of electricity consumption by type of mining operation for the main mining technologies used in the USA.

More than half of all the electricity used in opencast mines is consumed in overburden operations. Most of the rest is used for coal preparation. Other operations, including extraction of coal, are mainly based on other forms of energy.

Diesel fuel consumption in opencast mining operations depends on the type of technology used for overburden removal. Considerable volumes of motor fuel are consumed by tractors, front-end loaders, and trucks, whereas draglines do not need motor fuel. For area stripping with draglines, the fuel consumption ranges from 0.3 to 1.8 liters per tonne of coal. More than half of this amount is used for coal loading and hauling, and about 15% is consumed by reclamation equipment. For systems based on tractors and trucks for overburden operations, specific diesel fuel consumption reaches up to 19.5 l/t. Fuel consumption data for two mining systems are shown in Table 10.

Mining systems that have disproportionately high diesel consumption (e.g. systems in which overburden operations are carried out with trucks and other diesel-powered equipment) also have disproportionately high energy consumption. The main reason for this is that diesel engines have an end-use efficiency (ratio of final energy (e.g. diesel or electricity) to useful (i.e. mechanical) energy) that is three times lower than that of electric motors. A second observation is that energy requirements are quite strongly correlated with the overburden to coal ratio, because of the high share of overburden operations in the overall energy requirements. Finally, if one looks at the energy efficiency of the coal-mining process, the overall energy requirements, as presented in Table 11, appear to be rather low: generally, they do

TABLE 9 Distribution of electricity consumption by mining operation in selected US opencast mines (kWh/t clean coal).

Basin	Powder River	Fort Union	Texas Gulf	Four Corners	Illinois	Green River	Appalachia, West Virginia	Appalachia, Ohio
Mining system	Area stripping with shovels and trucks	Area stripping with draglines				Multiple-dipping seam mining	Mountain-top removal	Contour stripping with draglines
Overburden drilling and blasting	0.3	—	0.3	0.4	1.1	0.6	1.1	1.2
Overburden removal	2.1	5.4	5.6	8.5	27.7	—	—	21.8
Coal drilling and blasting	—	0.1	0.1	0.1	—	—	—	—
Coal loading and haulage	0.4	0.4	0.4	0.5	0.8	0.2	—	0.6
Coal handling and preparation	7.5	7.4	7.5	7.5	7.5	7.5	7.5	7.5
General and administration	—	—	—	—	—	—	—	—
Total	10.3	13.3	13.9	17.0	37.1	8.3	8.6	31.1

Source: Fluor Utah Inc. (1977).

TABLE 10 Fuel consumption for two systems of opencast mining in the USA (liters/t clean coal).

Mining and preparation operations	Area stripping with draglines (Texas Gulf)	Mountain-top removal (Appalachia, West Virginia)
Overburden drilling and blasting	0.08	0.04
Overburden removal	0.11	17.49
Coal loading and haulage	0.64	1.51
Coal handling and preparation	0.08	0.08
Reclamation	0.19	0.15
General and administration	0.08	0.23
Total[a]	1.17	19.49

[a] Totals may not add because of rounding errors.

Source: Fluor Utah Inc. (1977).

TABLE 11 Energy requirements of US surface mining systems.

Mining system	Overburden to coal ratio (m^3/t)	Total final energy[a] requirements (kWh equivalent per tonne of clean coal)	(Final) Energy requirements as percentage of heat content of coal produced(%)	Primary energy[b] requirements as percentage of heat content of coal produced (%)
Area stripping with draglines or shovels	2–5 (3.0)[c]	19.0–50.5 (28.3)[c]	0.31–0.95 (0.53)[c]	0.82–2.16 (1.41)[c]
	10–15 (14.5)[c]	31.8–57.0 (44.4)[c]	0.41–0.74 (0.57)[c]	1.15–2.11 (2.04)[c]
Contour stripping with draglines	10.45	61.1	0.75	2.0
Mountain-top removal	11.0	215.6	2.62	5.37
Multiple-dipping seam mining	6.4	161.4	2.44	5.04

[a] For diesel fuel a thermal equivalence of 1 liter = 38.5 MJ = 10.7 kWh equivalent was used.

[b] It is assumed that diesel fuel and electricity are produced from coal with conversion efficiencies of 50 and 30%, respectively.

[c] Average for the mines analyzed.

Source: Coal Mines Data Base, IIASA.

not exceed 57 kWh equivalent per tonne of coal produced, that is, the energy consumed represents less than 1% of the energy produced (the comparison is made on a thermal equivalent basis). If one assumes that the required energy is produced entirely from coal, with average conversion efficiencies of 30% for electricity generation and 50% for synthetic diesel fuel, the energy requirements of the coal-mining process would still not exceed 2% of the energy produced. Even in the worst case – that of mountain-top removal – the final energy required represents 2.5% of the energy produced. If the total energy requirement were produced from coal, the primary energy requirements represent slightly more than 5% of the energy content of the mined coal. This demonstrates that, even under the most unfavorable conditions, the energy balance of the coal-mining process is extremely positive.

Material Requirements

A great variety of materials are needed for coal mining, some of the most important being explosives, tires, and spare parts for equipment. The large number of different items explains why very few data on physical quantities are available. Therefore, material requirements could be considered for this report only in terms of cost. The costs presented exclude those of fuel, electricity, and other services, which are dealt with in physical quantities in the framework of the WELMM analysis. Material costs vary considerably within the different systems of mining, as shown in Table 12, and typically range from around 0.9 to 2.2US$(1975) per tonne of clean coal produced (i.e. including coal preparation). For multiple-dipping seam mining and mountain-top removal mining, material costs are considerably higher. Tires and explosives account for around one-third of the total material costs, the remainder being mainly costs of spare parts. Material requirements also depend on the overburden to coal ratio because of the high share of overburden operations in the total material expenses (see Table 13). For area and contour stripping, overburden operations (drilling, blasting, and removal) account for around 50–70% of the total material expenses*. For multiple-dipping seam and mountain-top removal mining, overburden operations account for 80 and 86%, respectively, of the total material costs.

Water Requirements

In surface mines most water is used by water trucks for road haulage maintenance and dust control. The water consumption is not very significant, being generally only around $0.1\,m^3$ per tonne of coal produced. However, in some cases overburden operations can drastically disturb underground water flows.

Extreme examples such as the giant lignite mines in the Federal Republic of Germany illustrate this: in order to carry out mining operations at depths of up to 400 m, the lowering of the groundwater table requires the pumping of 12 tonnes of water per tonne of coal mined. Another example is provided in the case of brown coal mining in the German Democratic Republic, where the national average is 6 tonnes of water pumped out per tonne of

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*All costs in this section have been converted to US$(1975) values. Appendix D gives the conversion rates used.

TABLE 12 Costs of materials[a] for different mining systems in the USA ($(1975)/t clean coal).

Mining system	Total cost	Tires	Explosives
Area stripping with draglines	0.35[b]–2.27 (1.05 average)	0.07–0.1 (0.08 average) (8%)	0.06–0.72 (0.28 average) (27%)
Area stripping with shovels and trucks	0.55[b]–1.32 (0.86 average)	0.05[b]–0.212 (0.11 average) (13%)	0.23–0.31 (0.26 average) (30%)
Contour stripping with draglines	2.21	0.14(6%)	0.59(27%)
Multiple-dipping seam mining	3.84	0.67(17%)	0.41(11%)
Mountain-top removal	5.59	0.95(17%)	0.98(18%)

[a] Costs exclude those for fuel, electricity, and other services, which are dealt with in terms of physical quantities in this report.

[b] Figures probably underestimated by a factor of 2 by original data source (Katell *et al.* 1976a).

Source: Coal Mines Data Base, IIASA.

TABLE 13 Distribution of material costs[a] for selected surface mining technologies in the USA ($(1975)/t clean coal).

	Area stripping with:		Contour stripping with draglines	Multiple-dipping seam mining	Mountain-top removal
	draglines	shovels and trucks			
Overburden to coal ratio (m^3/t)	3.2	2.4	10.45	6.4	11.0
Overburden drilling and blasting	0.19	0.21	0.66	0.45	1.03
Overburden removal	0.21	0.71	0.83	2.58	3.78
Coal drilling and blasting	~0	0.06	0	0.01	0
Coal loading and haulage	0.17	0.11	0.35	0.36	0.35
Coal handling and preparation	0.18	0.19	0.27	0.31	0.28
Land reclamation	0.03	0.01	0.06	0.01	0.02
General and administration	0.02	0.04	0.03	0.11	0.09
Total cost of materials[b]	0.86	1.32	2.21	3.84	5.59

[a] Excluding fuel, electricity, and other service costs.

[b] Totals may not add because of rounding errors.

Source: Fluor Utah Inc. (1977).

coal produced. This totals to nearly $2 \cdot 10^9$ t of water pumped out annually, or approximately 20% of the total available water resources of the country.

However, the amount and extent of such impacts depend on local specific hydrological characteristics and, since there is considerable variation between individual mining areas, they cannot be compared.

Land Requirements

The most serious environmental impact of opencast mining is undoubtedly the temporary destruction of the land surface. The area of the land disturbed is larger than simply the horizontal projection of the area of the coal seam mined. The factors determining the amount of land disturbed are well known and can be estimated using formal engineering methods. On the one hand, land disturbance increases in proportion to the depth at which mining operations are carried out. In addition, the type of overburden determines the slope of the highwall and thus also the land requirements. On the other hand, seam thickness, coal density, and the dip of the seams are negatively correlated with the area disturbed. The system of opencast mining and the characteristics of the equipment used do not have a great influence on the area initially disturbed.

For the US surface mines in the Coal Mines Data Base, total land disturbance amounts to about 50 km^2 per year for a total coal production of about 180 million tonnes per year, or about 0.28 km^2 per million tonnes of coal produced. The annual land disturbance per tonne of coal mined for the various US coal basins is presented in Table 14.

TABLE 14 Land disturbance by surface mines[a] in the USA.

Region/Basin	Land disturbance		Average seam thickness (m)
	(m^2/t)	(m^2/tce)	
Eastern:			
Appalachia	0.68[b](0.58–0.78)	0.68[b](0.58–0.78)	1.2[b](1.17–1.22)
Hypothetical	0.46	0.43	1.8
Interior:			
Illinois	~0.70	0.73[b](0.73–0.74)	1.5[b](1.22–1.8)
Texas Gulf	0.30	0.55	3.0
Western:			
Four Corners	0.22[b](0.22–0.23)	0.33	6.1[b](3.66–7.0)
Fort Union	0.18[b](0.11–0.25)	0.32[b](0.2–0.45)	5.6[b](3.66–7.62)
Green River	0.26	0.32	5.8
Powder River	0.22[b](0.03–1.44)	0.31[b](0.04–1.94)	n.a. (up to 21.9)
Hypothetical	0.46	0.60	1.8

[a] Values presented in ranges may not always correspond to the same mines.

[b] Weighted average.

Source: Coal Mines Data Base, IIASA.

American surface mines generally operate at very shallow depths. As shown in Table 14, the large thicknesses of the seams mined in the Western United States result in moderate land disturbance compared with mines in the Interior or Eastern coal-mining provinces. For example, a mine in the Powder River basin that exploits a coal seam around 15 m thick causes a land disturbance as low as 7 ha ($7 \cdot 10^4 m^2$) per million tonnes of coal mined. The thinner coal seams prevailing in the Eastern part of the USA result in land disturbances about three times as high as in the Western region. If one considers, however, that the coal mined in the Western USA is of subbituminous rank and therefore of lower calorific value than the coal mined in the Eastern part of the country, the land disturbances per tonne of coal equivalent in Eastern coal mines are twice as high as those in the Western part of the USA.

All the land disturbed during mining operations can and should be reclaimed. New opencast mining projects in the United States now include obligatory land reclamation; a carefully planned set of operations must be worked out to restore the land to at least its original quality. In this context, other positive aspects of land reclamation should be noted, such as upgrading of soil and improved land management.

Operating and Production Costs

Table 15 presents typical direct operating costs and their distribution by mining operation for selected surface mining technologies. For conventional area-stripping methods, direct operating costs* vary from 3.4 to 7.63 $(1975)/t clean coal produced. As the overburden to coal ratio increases, the share of overburden operations in the total operating costs rises to 45%. Hence, the overburden to coal ratio has a strong influence on the operating costs. Mining technologies that are used to exploit coal in a more complicated geological bedding have, of course, much higher operating costs, reaching more than 18 $(1975)/t clean coal produced. In this case, overburden operations can account for over 70% of the total operating costs. Direct operating costs typically constitute about 80% of the total production costs (including depreciation and interest), except for multiple-dipping seam and mountain-top removal mining, for which the share is about 90%. Total production costs range, therefore, from 4.43 to 9.96 $(1975)/t clean coal for conventional area-stripping methods, and can reach 17.71 and 20.97 $(1975)/t clean coal for multiple-dipping seam and mountain-top removal mining, respectively.

Table 16 presents a more detailed breakdown of production costs for selected surface mining technologies in the USA. Expenses for manpower and materials each represent typically about 30% of the total production costs. For multiple-dipping seam and mountain-top removal mining, manpower expenses can reach 38% and material expenses 35% of the total production costs. The rest of the production costs are made up by miscellaneous expenses, equipment costs, depreciation (typically around 15% of the total production costs), and interests (ranging from 4 to around 10% of the total).

Whereas discussion of the WELMM requirements and costs has thus far concentrated on the operational requirements, those for the initial mine construction period should also be mentioned. These data are, of course, not relevant for the planning and analysis of operating mines but are important

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*All costs have been converted to US$(1975) values. Appendix D gives the conversion rates used.

TABLE 15 Distribution of direct operating costs[a] for selected surface mining technologies in the USA (\$(1975)/t clean coal).

Mining system	Area stripping with draglines		Area stripping with shovels and trucks	Contour stripping	Multiple-dipping seam mining	Mountain-top removal
Basin	Fort Union	Illinois	Powder River	Appalachia, Ohio	Green River	Appalachia, West Virginia
Overburden to coal ratio (m^3/t)	3.2	15.05	2.4	10.45	6.4	11.0
Overburden drilling and blasting	–	1.04	0.32	1.05	0.77	1.35
Overburden removal	0.64	2.37	1.89	2.24	8.49	11.99
Coal drilling and blasting	0.08	–	0.06	–	0.08	–
Coal loading and haulage	0.52	0.68	0.29	0.8	0.88	0.82
Coal handling and preparation	0.61	0.77	0.65	1.37	1.79	1.38
Land reclamation	0.12	0.37	0.02	0.25	0.08	0.11
General and administration	0.28	0.48	0.5	0.44	1.33	1.04
Other, miscellaneous costs	1.16	1.92	1.2	2.04	1.81	1.85
Total direct operating costs[b]	3.40	7.63	4.93	8.2	15.22	18.54

[a] Including costs of equipment (repair, replacement), materials, services, and manpower. Specific values are calculated from annual costs of steady state year (first year of full production) (source: Fluor Utah Inc. 1977).

[b] Totals may not add because of rounding errors.

TABLE 16 Specific total production costs for selected surface mining technologies in the USA ($(1975)/t clean coal).

Mining system	Area stripping with draglines		Area stripping with shovels and trucks	Contour stripping	Multiple-dipping seam mining	Mountain-top removal
Basin	Fort Union	Illinois	Powder River	Appalachia, Ohio	Green River	Appalachia, West Virginia
Overburden to coal ratio (m^3/t)	3.2	15.05	2.4	10.45	6.4	11.0
Expenses for:						
Manpower	1.19	2.60	1.93	3.17	6.67	7.0
Materials and services	0.97	2.95	1.79	2.88	5.15	7.36
Others	1.16	1.92	1.20	2.04	1.81	1.85
Equipment and depreciation	0.68	1.40	1.00	1.53	3.12	4.04
Interests	0.43	1.09	0.44	0.65	0.94	0.73
Total production costs[a]	4.43	9.96	6.34	10.27	17.71	20.97

[a] Totals may not add because of rounding errors.

Source: Fluor Utah Inc. (1977).

in considering the long-term perspectives of coal mining, especially for identifying possible bottlenecks in the availability of certain critical resources, such as manpower or equipment, for the increase and/or replacement of existing mine capacities. To date, however, it has not been possible to gather sufficient information on natural resource (WELMM) requirements for the construction period. The general availability of information on mining in the USA makes data collection on this topic difficult. At best, information on manpower requirements and some equipment is available, but data in the Coal Mines Data Base to date are too sketchy to allow a detailed discussion of construction resource requirements. However, the importance of this problem has been considered and is, among other things, reflected in the greater number of parameters for the construction period of a mine as well as in the introduction of a special equipment file (including detailed equipment identification, manufacturer's name, capacity, and working weight) in the CMDB. It is hoped that in future US studies (e.g. the obligatory Environmental Impact Statements) more attention will be devoted to studying resource requirements for the construction of new mines. In view of the lack of data this report will concentrate on the construction investments for US surface mines only.

Investment Costs

Total investment costs* for US opencast mines in the Coal Mines Data Base range from 4.7 to 31 \$(1975) per tonne of raw coal produced annually (excluding the investments for coal preparation facilities). When the costs of coal preparation facilities are included, total investment costs range from 16.4 to 34.6 \$(1975) per tonne of saleable coal (considering only those mines for which original data, including coal preparation data, were available). The estimates as presented in studies by the US Bureau of Mines (Katell *et al.* 1976a) and the Bechtel Corporation (Stanford Research Institute 1975, Hogle *et al.* 1976, Bechtel Corporation 1978) are generally significantly lower than the estimates from other references for mines under similar conditions. The main reason for this underestimation of investment costs is that, in the studies mentioned, detailed local deposit characteristics were not taken into account and the estimates therefore represent "minimum" values.

In order to minimize biases stemming from comparisons of investment values based on different financial assumptions, only the direct construction investments, including premining and infrastructure expenses, were compared for the structural analysis. Typically, about 80% of the total direct construction investment is spent on equipment and on facilities for coal handling and preparation (breaking and sizing, blending, and stockpiling). An additional 13% is spent on establishing the appropriate infrastructure (roads, and water and electricity supply systems) and buildings; the remaining 7% is used for premining expenses (exploration drilling, engineering fees, Environmental Impact Statements, etc.). A typical breakdown of direct construction investments is presented in Table 17 for a surface mine in the Texas Gulf coal basin.

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*All costs have been converted to US\$(1975) values. Appendix D gives the conversion rates used.

TABLE 17 Typical distribution of total and direct construction investments for a surface mine in the Texas Gulf basin.

Mining operations	Investment ($(1975)/t clean coal)	Percentage of total direct investment (%)	Percentage of total investment (%)
Overburden operations	2.64	18.8	15.8
Coal loading and hauling	0.94	6.7	5.7
Coal handling and preparation	7.36	52.5	44.1
Land reclamation	0.35	2.5	2.1
Premining and construction of facilities	2.74	19.5	16.4
Total direct investment	14.03	100	84.1
Total interests	2.66	–	15.9
Total investment	16.69	–	100.0

Source: Fluor Utah Inc. (1977).

Investments for overburden equipment are closely connected with the amount of waste rock removed. In fact, the specific value of such investments (i.e. per tonne of annual coal output) changes in nearly direct proportion to the overburden to coal ratio.

The amount and cost of equipment for mining and preparation of the coal, in contrast, are independent of the volume of overburden removed. The cost of this equipment depends partly on the characteristics of the mined coal, such as its density and quality, and, more importantly, on the type of technology used for these operations. For a given technology, specific investments for particular items of coal-mining equipment are practically constant for all mines, whereas they differ considerably for different types of technologies. For instance, the costs of equipment for coal mining and preparation range from 8.4 to 9.5$(1975) per tonne of clean coal production capacity when area stripping with draglines is employed, but these costs can be nearly twice as high for other technologies used in the USA, such as contour stripping, mountain-top removal, or multiple-dipping seam mining. Land reclamation equipment costs are influenced by the geometric parameters of the mine, but in total these costs are not high: not more than 0.1–1.0$(1975)/t clean coal. The remainder of the direct construction investments for buildings and related facilities, infrastructure, and premining is fairly constant for all mines, the typical range being 23–31 · $10^6$$(1975) per mine. Table 18 presents more detail and summarizes the discussion on investment costs for selected surface mines in the USA.

TABLE 18 Distribution of construction investments for selected US surface mines.

Mining system	Area stripping with draglines				Area stripping with shovels and trucks		Contour stripping	Multiple-dipping seam mining	Mountain-top removal
Overburden to coal ratio (m^3/t)	1.8	3.2	4.1	15.0	2.4	9.2	10.45	6.4	11.0
1. Construction investments ($(1975) per tonne capacity)									
a. Equipment:									
Overburden operations	n.a.	2.6	4.0	13.4	2.3	8.1	10.8	5.6	8.0
Coal mining	n.a.	1.0	1.3	1.2	0.3	1.45	3.15	3.1	2.9
Reclamation	n.a.	0.3	0.2	1.0	0.5	0.4	0.7	0.1	0.2
Total equipment	4.8	3.9	5.5	15.6	3.1	9.95	14 65	8.8	11.1
b. Coal preparation	none	7.4	7.8	8.3	7.6	none	10.85	12.2	10.9
c. Buildings and infrastructure	n.a.	1.8	2.3	3.1	2.1	0.7	3.2	3.3	2.7
d. Premining	n.a.	0.9	1.1	1.7	1.0	3.1	1.8	1.3	1.7
Total direct construction investment	8.0[a]	14.0	16.7	28.7	13.8	13.75[a]	30.5	25.6	26.4
2. Investment in overburden equipment ($(1975) per m^3 overburden removed)	n.a.	0.81	0.98	0.89	0.96	0.88	1.03	0.87	0.73
3. Investments for infrastructure and premining costs (10^6 $(1975) per mine)	n.a.	26.8	26.4	27.1	26.3	16.4[a]	27.2	31.2	23.1
4. Investments in land reclamation ($(1975) per km^2 land disturbed per year)	n.a.	1.16	1.03	1.43	0.76	0.93	0.86	0.55	0.43

[a] Per tonne of raw coal (i.e. excluding coal preparation).

Source: Coal Mines Data Base, IIASA.

4.1.1.2 Opencast Mines in the USSR

Approximately 275 million tonnes* of coal were produced in 1981 by surface mines in the USSR. Around half of this quantity was brown coal. The share of surface-mined coal in the total coal production of the country has been steadily increasing, from 20% in 1960 to over 27% in 1970, and is currently nearly 40%, and will continue to increase in the future.

The demonstrated strippable coal reserves *in situ* amount to about 40% of the total coal reserves, as shown by Table 19. For brown coal, strippable reserves represent as much as 70% of the total reserves. Most of the reserves are situated in the Asian part of the country; it is also here that vast, almost unexplored coal occurrences are known to exist (e.g. the Lena, Tunguska, Taimyr, and Yakut basins), although the difficult climatic conditions (winter temperatures below minus 60°C, and permafrost) are very likely to limit the application of surface mining technologies in the near future. The most important regions (i.e. those with high percentages of reserves) are the Kansk–Achinsk and Kuznetsk basins and the Ekibastuz deposit. The foremost of these is the Kansk–Achinsk basin in Western Siberia, which accounts for 70% of the total strippable coal reserves *in situ*. Geological conditions are extremely favorable: the main seam is 50 m thick or more, and the overburden to coal ratio usually does not exceed $3.5\,m^3/t$. Coal strata are undisturbed, with flat bedding underlying soft rocks. Hydrological and climatic conditions (continental) are more complicated. Large-scale development of this coal basin started quite recently and the long-term development prospects are impressive: in principle, the maximum production for this basin could reach 10^9t per year.

The Kuznetsk basin, or Kuzbass, contains an estimated $9.2 \cdot 10^9$t of demonstrated strippable hard coal reserves. The coal is bituminous and of high quality, unlike the lignite in the Kansk–Achinsk basin. However, a major share of these reserves is located in highly disturbed, steep bedding seams. There are also some other large deposits (e.g. the Erunakovkoye deposit) containing a large number of thick and relatively undisturbed coal seams. The climate is continental and, in the southern part, less severe. Mines in operation are smaller than they are in the Kansk–Achinsk basin. The average overburden to coal ratio and resulting production economics are less favorable.

The Ekibastuz deposit in Kazakhstan is one of the most important in the USSR. Bituminous (hard) coal reserves ($7.4 \cdot 10^9$t) are highly concentrated and very large mines are in operation. The coal seam thickness sometimes exceeds 100 m. Currently the overburden to coal ratio is no higher than 3.5 m^3/t.

The mining technologies applied differ from those employed in the USA. Coal-mining and stripping operations are carried out in all mines and basins in the USSR by excavators, about two-thirds of which are power shovels and nearly one-third walking draglines. Although the number of bucket-wheel excavators is small, they were used in the mining of 31% of the coal produced by the opencast method in 1975.

About two-thirds of coal produced is transported by pit railway, one-third by truck, and 10% by conveyors and other modes. In stripping operations 35%

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*Tonnes (metric tons,t) are used throughout this report.

TABLE 19 Demonstrated strippable coal reserves *in situ* in the USSR (10^9 t).

Region/Basin	Hard coal	Brown coal	Total
European USSR, including Urals	–	2.2	2.2
Kazakhstan, including Ekibastuz and Karaganda basins	7.8	7.3	15.1
Kuznetsk basin (Kuzbass)	9.2	1.3	10.5
Kansk–Achinsk	–	119.6	119.6
Minusinsk	3.8	–	3.8
Tunguska and others in Krasnoyarsk area	0.7	–	0.7
Eastern Siberia, including Lena, Taimyr, and Yakut basins	5.0	4.7	9.7
Far East	0.1	3.5	3.6
Total strippable reserves[a]	27.2	139.2	166.2
Total coal reserves	220.0	200.0	420.0
Total coal resources	5,182.5	3,287.0	8,669.5

[a] The totals include smaller deposits not accounted for in the regional breakdown.
Sources: Kuznetsov *et al.* (1971) and Astakhov (1977a).

of the overburden is transported by rail and 21% by truck, and 37% is dumped directly.

Four opencast mines of the USSR are recorded in the Coal Mines Data Base. Since all of them are still in the project/development phase, the data cannot be considered absolutely accurate, although they are fairly reliable estimates. A wide range of geological conditions and resulting mine technologies and capacities characterize the mines, which are located in the different coal regions/basins, including the Kansk–Achinsk, the Ekibastuz, and the Kuznetsk (flat and steep bedding seams). Because of the different geological conditions (Table 20), the quantitative data describing each mine cannot be averaged or compared directly and should therefore be discussed separately. The mines all have very large capacities of up to 60 million tonnes per year – considerably higher than US mines. In addition, the overburden to coal ratio does not exceed 3.3 m^3/t, i.e. the operating conditions are better than in most of the US mines. In general, the Kansk–Achinsk and Ekibastuz mines cannot be compared with US mines because of technological differences, such as the use of bucket-wheel excavators and belt conveyors. In addition to the four mines included in the CMDB, supplementary data on operating mines, based on statistics of the various coal-mining enterprises, have been considered.

Manpower Requirements

Manpower requirements estimated for the four mines are presented in Table 21. Coal operations do not require more than 16% of the total manpower. The share of overburden operations is higher: up to 27% when high-capacity bucket-wheel excavators are used and up to one-third of the total manpower requirements when shovels and trucks/conveyors are used for

TABLE 20 Main characteristics of four opencast mines of the USSR that are recorded in the Coal Mines Data Base.

	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mines	
			Flat bedding	Steep bedding
Number of workable seams	1	3	n.a.	10
Average seam thickness (m)	55	43	1.5–2	3.3
Overburden to coal ratio (m^3/t)	1.6	1.5	3.25	2.2
Tectonic conditions	Very good	Very good	Regular bedding	Highly faulted
Relief of the surface	Flat	Flat	Hilly	Flat
System of mining (and equipment)	Combined stripping (bucket-wheel excavators and conveyors)	Stripping and transport scheme (bucket-wheel excavators, shovels and conveyors/locomotives)	Cyclic–continuous stripping (shovels and trucks/conveyors)	Cyclic–continuous stripping (shovels and trucks/conveyors)
Calorific value of coal (MJ/kg)	15.7	16.3	24.8	26.4
Mine output (10^6 t raw coal per year)	60	30	30	20

stripping operations. The remaining manpower requirements are for numerous auxiliary operations (infrastructure, repairs, etc.) and are mainly dependent on the mining technology used, not on the deposit geology.

TABLE 21 Manpower requirements of four opencast mines in the USSR (persons per 10^6 t raw coal per year).

Mining operation	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mines	
			Flat bedding	Steep bedding
At coal benches	1.3	4.2	16.9	n.a.
At overburden benches	3.7	3.9	15.2	n.a.
Coal transportation	3.9	4.8	9.0	n.a.
Overburden transportation	2.3	11.1	29.0	n.a.
At dumps	2.8	2.1	8.2	n.a.
Land reclamation	0.4	–	8.9	n.a.
Energy supply systems	9.7	2.6	5.4	n.a.
Water drainage	3.1	0.4	2.4	n.a.
Repairs	8.2	12.4	43.7	n.a.
Other operations	6.1	8.6	9.3	n.a.
Subtotal[a]	41.5	50.3	148.0	91.5
General and administration	5.5	12.5	12.0	15.0
Total mine personnel	47.0	62.8	160.0	106.5
Total manpower requirements per 10^6 tce produced annually	87.7	112.7	188.9	118.3

[a] Totals may not add because of rounding errors.
Source: Astakhov (1977b).

Energy Requirements

Energy requirements are summarized in Table 22. In general, these are lower than for US mines, for two reasons: the overburden to coal ratios are lower, and the mines are larger and use giant equipment (e.g. bucket-wheel excavators). Also, the energy requirements for the mines using conveyors and/or locomotives for overburden and coal transport are considerably lower than for mines that use trucks. If steeply dipping or faulted seams are mined, the total energy requirements are comparable to those of mines in the USA that are worked under similar conditions. However, even in this case the net direct energy balance is extremely positive: if it is assumed that all ancillary energy requirements are produced from coal, the total direct energy requirements do not exceed 6% of the energy produced, i.e. one tonne of coal produced and converted to electricity and diesel is sufficient to satisfy the energy requirements to produce 17 tonnes of coal.

Material Requirements

Material requirements estimated for the mines are presented in Table 23. The structure of these expenses depends on the system of mining and transportation used. If trucks are used, tires account for a considerable share of these expenses; if conveyors are used, conveyor belts also constitute

TABLE 22 Energy requirements per tonne of raw coal produced for four opencast mines in the USSR.

Energy requirements	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mines	
			Flat bedding	Steep bedding
Electricity consumption (kWh/t)	17.3	8.7	6.1	29.5
Motor/diesel fuel consumption (l/t)	0.17	0.15	4.2	4.33
Other energy requirements (e.g. coal autoconsumption) (tce/100 t)	0.72	0	0	27.0
Total final energy requirements (kWh equiv./t)[a]	25.0	10.3	51.0	295.6
Total primary energy requirements:				
in tce/t[b]	0.008	0.004	0.014	0.051
as percentage of energy produced (%)	1.5	0.7	1.7	5.7

[a] Thermal equivalence: 1 kWh = 3,600 kJ.

[b] It is assumed that electricity and motor fuel are produced from coal with conversion efficiencies of 30% and 50%, respectively.

Sources: Astakhov (1977b) and Coal Mines Data Base, IIASA.

a major expense. Spare parts and repair materials are important items too. The cost of explosives and blasting agents is rather high at mines where overburden drilling and blasting are required. In addition, the specific material costs also depend to a large extent on the type of mining system used, especially when highly faulted or steep seams are mined: the total material cost can be up to a factor of 2 higher than for mines using the same technology but exploiting flat seams with regular bedding.

TABLE 23 Costs of materials for four opencast mines in the USSR (roubles(1975) per tonne of raw coal produced)[a].

Type of requirement	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mines	
			Flat bedding	Steep bedding
Explosives	0.03	0.02	0.12	0.27
Blasting agents	0.01	0.01	0.03	0.05
Drill rods	–	–	0.03	0.01
Sleepers	–	0.01	0.02	–
Tires	–	–	0.02	0.18
Spares and repair materials	0.06	0.05	0.11	0.22
Lubricants and cleaning materials	0.01	0.02	0.08	0.11
Conveyor belting	0.04	–	–	0.02
Other materials	0.01	0.01	0.06	0.09
Total	0.16	0.12	0.47	0.95

[a] All costs have been normalized to common base-year (1975) values (see Appendix D). It is not possible to present a definitive conversion factor for nonconvertible currencies. The exchange rate proposed and used in this study is 1 US $ = 0.7 rouble or 1 R = 1.43 US $(1975), which roughly corresponds to the official exchange rate.

Source: Astakhov (1977b).

Environmental Impacts

Environmental impacts are summarized in Table 24 for the four USSR mines being considered. Land requirements and waste rock (overburden) produced are considerably less than for US mines, owing to lower overburden to coal ratios and larger seam thicknesses (up to 55m average thickness). Unlike US mines, those in the USSR do not always carry out land reclamation in the course of mining operations. In the Kuzbass mines recultivation is planned for 20–40 years after the start of mining operations. For the Ekibastuz mine the time lag is about 10 years. Only for the Kansk–Achinsk mine is it planned to recultivate the disturbed area immediately after mining operations.

TABLE 24 Selected environmental impacts of four opencast mines in the USSR.

Type of impact	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mines	
			Flat bedding	Steep bedding
Waste rocks mined and disposed of (tonnes per tonne of raw coal produced annually)	4.17	2.7	9.1	5.37
Water inflow (liters per tonne of raw coal produced annually)	106.6	4.9	204.4	n.a.
Water consumption (liters per tonne of raw coal produced annually)	7.0	1.1	5.5	n.a.
Land disturbed (m^2 per tonne of raw coal produced annually)	0.018	0.014	0.049	0.056
Land recultivation measures	Simultaneous	After 10 yr	After 20–40 yr	After 20 yr

Sources: Astakhov (1977b) and Coal Mines Data Base, IIASA.

Production Costs

Production costs for opencast mines in the USSR are four to six times lower than for conventional underground mines. Overburden operations usually account for a large share of total operational expenses. In the Kansk–Achinsk basin, production costs generally do not exceed 2 roubles (1975), or about 3US$(1975), per tonne of raw coal produced. Table 25 presents the distribution of operating costs for a mine working in the Kansk–Achinsk basin with an annual output of 8 million tonnes of raw coal. The overburden to coal ratio is about 1.5 m^3/t; coal and overburden are transported by rail. Of the total operating costs, manpower accounts for only 20%; 13% of the expenses go on materials, and 6% on power and energy; 20% are accounted for by depreciation.

Resource Requirements for Construction

Resource requirements for construction of the four opencast mines studied are summarized in Table 26. The total construction period ranges from seven to eight years. Mines in the Kansk–Achinsk and Ekibastuz basins start producing coal in the first year of construction, whereas in the Kuzbass

TABLE 25 Distribution of operating costs for a typical mine working in the Kansk–Achinsk basin.

Mining operations	Percentage of total operational cost (%)
Overburden operations	
Drilling and blasting	3.2
Overburden removal	13.2
Transportation	12.7
Dumping	12.0
Subtotal	41.1
Coal operations	
Drilling and blasting	–
Coal removal	7.6
Transportation	12.9
Subtotal	20.5
Auxiliary operations	38.4
Total	100.0

Source: Kamenetzky (1974).

TABLE 26 Resource requirements for the construction of four opencast mines in the USSR.

Resource requirements	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mines	
			Flat bedding	Steep bedding
Planned annual mine capacity (10^6 t raw coal)	60.0	30.0	30.0	20.0
Evolution of annual mine capacity (10^6 t raw coal)	8/12/40/56/60	8/15/26/30	6/18/30	>1/12/20
Time after mine construction start-up (yr)	1/2/3/5/6	1/2/3/4	3/6/9	5/8/10
Total construction period (yr)	7	7	8	8
Total leased mine area:				
(km^2)	50.0	30.6	72.0	57.0
(m^2/t annual capacity)	0.83	1.02	2.4	2.8
Material requirements for construction (per 10^3 t annual capacity):				
Wood (m^3)	4.0	4.3	n.a.	0.3
Field metals (t)	3.5	1.2	n.a.	>0.9
Concrete, cement (m^3)	11.0	8.5	n.a.	4.3
Reinforced (ferro-)concrete (m^3)	10.0	10.8	n.a.	0.8
Sand, gravel (m^3)	–	46.7	n.a.	56.9

Source: Astakhov (1977b).

mines the time lag between construction start-up and first production ranges between three and five years. Full production is reached in these mines 10 years after the start of mine construction. The material requirements are primarily for surface installations and buildings as well as for road construction. Another important requirement is the material (primarily metals) contained in the equipment. Table 27 shows the weight of equipment as well as the distribution of the total equipment weight per main equipment item for two projected mines.

TABLE 27 Weight of equipment installed in two opencast mines in the USSR (tonnes per 10^3 t raw coal per year).

Items of equipment	Kansk–Achinsk mine	Kuzbass mine (steep bedding)
Excavators	0.70	0.55
Dozers	0.04	0.03
Dump trucks	–	0.28
Coal haulers	–	0.45
Conveyors	0.72	0.30
Drilling equipment	0.01	0.03
Hydraulic mining equipment (incl. pipes)	–	0.68
Transloaders	0.22	–
Stackers	0.29	–
Other	>0.16	>0.09
Total	>2.14	>2.41

Source: Astakhov (1977b).

Construction Investments

Construction investments are of course closely related to the type of mining and transportation equipment used at a particular mine. More than half of the total direct construction investment is spent on equipment and the installation of equipment. The distribution of direct construction investments for each type of mining operation (Table 28) shows that overburden operations account for nearly half of the total construction investment. The remainder is equally divided between coal extraction and auxiliary operations, including infrastructure. For mining methods in which the overburden is dumped directly (i.e. without transport – through a stacker, for example) the share of equipment investment in the total construction investment is considerably lower. The distribution of direct construction investments for the mines under consideration is presented in Table 29. In addition to the direct construction investments, considerable capital is necessary to develop the appropriate infrastructure (transportation, housing for workers, etc.), especially as the most profitable deposits are in rather deserted, undeveloped areas with a rough climate. These infrastructure investments can amount to up to 100 million roubles per mine.

TABLE 28 Distribution of direct construction investments for selected opencast mines in the USSR (as percentage of total construction investment).

Mining operations	Haranovsky mine	Safronovsky mine	Nazarovsky mine	Irsha–Borodinsky mine
Overburden operations				
Drilling and blasting	0.4	0.9	–	0.1
Overburden removal	10.3	44.6	29.2	18.3
Transportation	32.2	–	11.2	19.6
Dumping	6.7	–	4.3	6.6
Subtotal	49.6	45.5	44.7	44.6
Coal operations				
Drilling and blasting	–	0.3	0.1	–
Coal removal	10.4	11.3	10.3	14.8
Transportation	19.7	12.8	6.9	14.3
Subtotal	30.1	24.4	17.3	29.1
Auxiliary operations				
Drainage	2.6	1.7	7.1	7.1
Laboratory and quality control	0.2	–	0.1	0.1
Repairs	0.5	9.6	1.6	0.9
Other operations and services	9.7	4.7	20.8	8.9
Infrastructure	7.3	14.1	8.4	9.3
Total	100.0	100.0	100.0	100.0

Source: Kamenetzky (1974).

TABLE 29 Distribution of direct construction investments for three opencast mines in the USSR (as percentage of total construction investment).

Items of investment	Kansk–Achinsk mine	Ekibastuz mine	Kuzbass mine (steep bedding)
Site preparation and prestripping	4.4	9.9	4.2
Equipment	41.4	33.7	36.9
Equipment assembly	6.0	6.2	6.5
Building and installation	6.1	32.1	42.3
Other	42.1	18.1	10.1
Total direct investment	100.0	100.0	100.0
Total direct investment in roubles (1975) per tonne of raw coal production capacity installed	9.2	8.1	8.4

Source: Coal Mines Data Base, IIASA.

4.1.1.3 Opencast Mines in Other Countries: Examples from Austria and Australia

Although the main starting point of the WELMM analysis of coal mining was to take into consideration mines in the USA and the USSR, data on mines in other countries also became available in the course of the study, and were included in the data base. Examples of mines presented in this section are not as detailed and exhaustive as the data for the USA and USSR, but were considered worth including in the report.

The Oberdorf opencast mine, Austria. The Oberdorf mine* is in the Voitsberg–Köflach coal basin in Southeast Austria. The Tertiary basin is divided into several partial synclines, of which the Oberdorf syncline, with its 32 million tonnes of recoverable reserves, accounts for about 80% of the remaining reserves in the entire basin. The geology of the deposit is characteristically Alpine and the mine deposit extends over about 2 km^2. The coal formation has a mild to moderate inclination with thicknesses of up to 40 m. Rocks are covered with sands and clays. The lignite has an average moisture content of 35% and an average ash content of 21%, while the calorific value varies between 8,290 and 12,480 kJ/kg raw coal. The coal will mostly be used in a coal-fired power plant a few kilometers away.

The projected annual output of raw coal is 1.25 million tonnes. The construction of the mine will require about five years, including prestripping operations. The average overburden to coal ratio is 4.5 m^3 per tonne of coal produced.

The manpower requirements estimated for the construction period of the mine are 876 man-years per million tonnes of annual mine capacity, including 292 manual–technical and 452 manual–nontechnical man-years. Foremen and engineers account for 32 man-years per million tonnes of annual capacity. Prestripping involves around 12 million cubic meters of overburden, which is dumped into old open pits a few kilometers away. Investment during the construction period will amount to 700 million AS(1978), i.e. about 560 AS(1978) or 26.42 US$(1975)** per tonne of raw coal capacity. Of this, land acquisition and prestripping will account for 281 million AS(1978); equipment, mine facilities, and infrastructure will cost 419 million AS(1978). The main equipment items include two bucket-wheel excavators (SRs 400), each with a capacity of 3,500 m^3 per hour. Overburden and coal transport is carried out exclusively by conveyors. The total weight of equipment to be installed is 6,250 t (about 5 t per 10^3 t production capacity).

Table 30 summarizes the operational WELMM requirements for the Oberdorf mine. Manpower requirements of 254.4 man-years per million tonnes of coal produced are distributed as follows: 156 manual–technical and 64.8 manual–nontechnical man-years; foremen and engineers account for 12 man-years. An additional 21.6 man-years are required from other companies, mainly for the maintenance of equipment. Labor productivity at the mine is estimated at 11.3 t per man-shift.

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*Data are based on Kuckenberger (1979), a questionnaire provided by the mining company, and field trips to the area.

**Appendix D gives the conversion rate used.

Environmental impacts can be summarized as follows. The water inflow of 0.25 m^3 per tonne of coal produced is not very important. The surface area mined out will be reclaimed. The total area reclaimed will be even higher than the area mined out, since the overburden from premining activities is disposed of in old opencast mines in the area, which are consequently also reclaimed.

TABLE 30 Summary of operational WELMM requirements for the Oberdorf mine, Austria.

	Annual requirements	Requirements per tonne of coal produced
Water inflow (m^3)	$0.31 \cdot 10^6$	0.25
Electricity (kWh)	$26.7 \cdot 10^6$	21.3
Motor fuel (l)	$0.67 \cdot 10^6$	0.5
Coal (tce)	168.7	$1.35 \cdot 10^{-4}$
Land area disturbed (m^2)	71,250	0.06
Solid waste produced (t)	$2.5 \cdot 10^6$	2.03
Total personnel employed:	318	–
Foremen	27	–
Engineers	5	–
Workers	276	–
Others	10	–

Source: Coal Mines Data Base, IIASA.

The Bowen basin mine, Australia. About 55% of the 1980 total coal production of Australia was from opencast mines ($49.7 \cdot 10^6$ t raw coal or $40.5 \cdot 10^6$ t saleable coal) (Joint Coal Board 1980). The basins with the most important reserves for opencast mining are the Bowen and Galilee basins in Queensland and the Gippsland brown coal basin in the state of Victoria. The mine under consideration is projected for a field in the Bowen basin in Eastern Queensland.

The characteristics of the mine are considered typical of a number of mines to be constructed in Eastern Australia. Coal resources of the field amount to 270 million tonnes, including 208 million tonnes of technically and economically recoverable reserves. One out of four seams is to be mined with a thickness of 33 m and a depth of 9–54 m. The overburden to coal ratio is 1.3 m^3 per tonne of coal produced. Coal mined is of a bituminous, noncoking grade with a sulfur content of 0.3% and an average calorific value of 27.6 MJ/kg raw coal.

The annual mine capacity is projected to be 5 million tonnes. The area-stripping method will be used, with 31 m^3 draglines and 12 m^3 Bucyrus Erie coal shovels. Coal and overburden are to be drilled and blasted prior to mining. Total mine personnel employed will be 260; the manpower requirements are distributed as follows: manual–technical 34.8, manual–nontechnical 6.6, nonmanual–technical 5.6, and nonmanual–nontechnical 5 man-years per million tonnes of coal produced. Total manpower requirements are 52 manyears per million tonnes produced, including 3.2 man-years in the preparation plant.

Overburden produced averages around 3t per tonne of coal; around 0.47 kg ANFO explosives for overburden blasting are required per tonne of coal produced. The estimated ammonium nitrate consumption for coal blasting is around 0.23 kg/t. Environmental impacts of mining include a water inflow of 0.14 m^3/t coal produced. About 0.08 m^3 of this amount is used in the mine itself mainly for dust control. The land area disturbed over the lifetime of the mine will be around 12 km^2. All the disturbed mine area will be recultivated (graded and revegetated); part of the area lying under the natural drainage level will become a lake.

4.1.2 Statistical Analysis of Factors Influencing Natural Resource Requirements and Economics of Opencast Mining

For the statistical analysis of the computerized data, two software packages* were implemented that allow interactive, direct analysis of the data stored in the CMDB. The more important program is for stepwise multiple linear regression; the second one is for polynomial regression. Specific values of the resource requirements or costs per unit of output (normally per tonne of saleable coal) have been used for the dependent variables throughout the analyses.

Some comment should be made on the number of mines taken into account for the individual analyses. In general, the policy was to include as many observations as possible for each regression analysis. For the analysis of the natural resource requirements, the presence or absence of supporting data determined the number of observations in each individual regression analysis. Because of this the number of observations varies. Furthermore, some of the relationships studied (though not all of them) were different for the different technologies used in various countries. This is an additional explanation of why the number of data points taken into consideration for the various equations is different, but in each case it was motivated by concrete logical (and technological) considerations.

Finally, an analysis of the various influencing parameters to be taken into account revealed that the mine output variable is in fact not independent of the variables describing the deposit mined (seam thickness and depth or, in their aggregation, the overburden to coal ratio). In fact, this has already been discussed in Section 3: the natural conditions of the deposit determine technical and organizational decisions at a mine, which in turn influence the intensity of mining operations (i.e. the output per production unit or per mine), and thus are an additional indirect influence on the resource requirements (as was illustrated in Figure 5).

Mines operating under favorable deposit conditions (i.e. an overburden to coal ratio of less than 3 m^3/t) are usually also the mines that have higher than average capacities. This type of relationship, based on the data sample available for analysis, is represented by the following equation (standard errors *s* are shown in italics):

$$\begin{array}{llll} & \ln O_{\mathrm{R}} = 2.599 & - \; 0.137 R_{\mathrm{o:c}} & \quad (3) \\ s & \quad\; \mathit{(0.932)} & \quad \mathit{(0.039)} & \end{array}$$

$n = 34$

$R_{R\mathrm{o:c}} = 0.52$

$R^2_{R\mathrm{o:c}} = 0.27$

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*BMDP Biomedical Computer Program, P-series, 1977, University of California.

where*

O_R	is the annual mine output (10^6 t raw (run-of-mine) coal per year);
$R_{o:c}$	is the overburden to coal ratio (m^3/t);
$R(R^2)_{index}$	are the (squared) multiple correlation coefficients after the introduction of the variable(s) specified by the index into the regression equation;
n	is the number of observations;
s	is the standard error of the estimate and of the regression coefficients.

This relationship, in its nonlinear form (function f_1), is presented graphically in Figure 6. For this type of analysis all available opencast mines, independent of their location or mining technology, have been taken into account. For comparison, Figure 6 shows the relationship obtained by analyzing only mines operating under similar economic systems and with similar (generally quite favorable) types of deposits, i.e. mines in Australia and the USA (function f_2)**. Of course, any given mine capacity is not only influenced by deposit characteristics but depends also on such factors as available reserves and demand for coal. Still, because of the nonlinearity of the relationship between mine output and overburden to coal ratio found for the available data sample, it is not sufficient to include simply the mine output variable in a particular regression equation (as would be the case if Figure 6 showed a linear relationship). Instead, the deviation of the observed mine size shown in the nonlinear relationship in Figure 6 (i.e. the residuals from regression equation (3)) will also be considered to test whether it has a significant influence or offers an improvement on the values predicted from the linear regression functions presented subsequently.

Operational Requirements

An analysis of the influence of mine size and overburden to coal ratio on the *specific total manpower requirements*, excluding coal preparation (persons employed per 10^6 t raw coal produced annually), has first to consider the results of the previous structural analysis. Because of the particular deposit characteristics and the resulting mining technology, mountain-top removal and multiple-dipping seam mining show disproportionately high labor requirements. Therefore, these two particular mining methods were excluded from the subsequent analysis.

Another observation on specific manpower requirements is that a wide range in the data can be observed, even when the influence of the overburden to coal ratio (for instance) has been taken into account. The reason for this

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*Variable definitions, once presented, will not be repeated in the following equations and figures. They are summarized in Appendix B.1. The minimum/maximum values of these variables are presented in Appendix B.2.

**The overburden to coal ratio as the influencing variable passed the 90% significance test, but the overall fit of the regression function is not as good as that of eqn. (3), with correlation coefficients of 0.45 (0.21 squared) and $|t| = 2.55$ ($n = 27$) compared with $|t| = 3.51$ ($n = 34$) in eqn. (3).

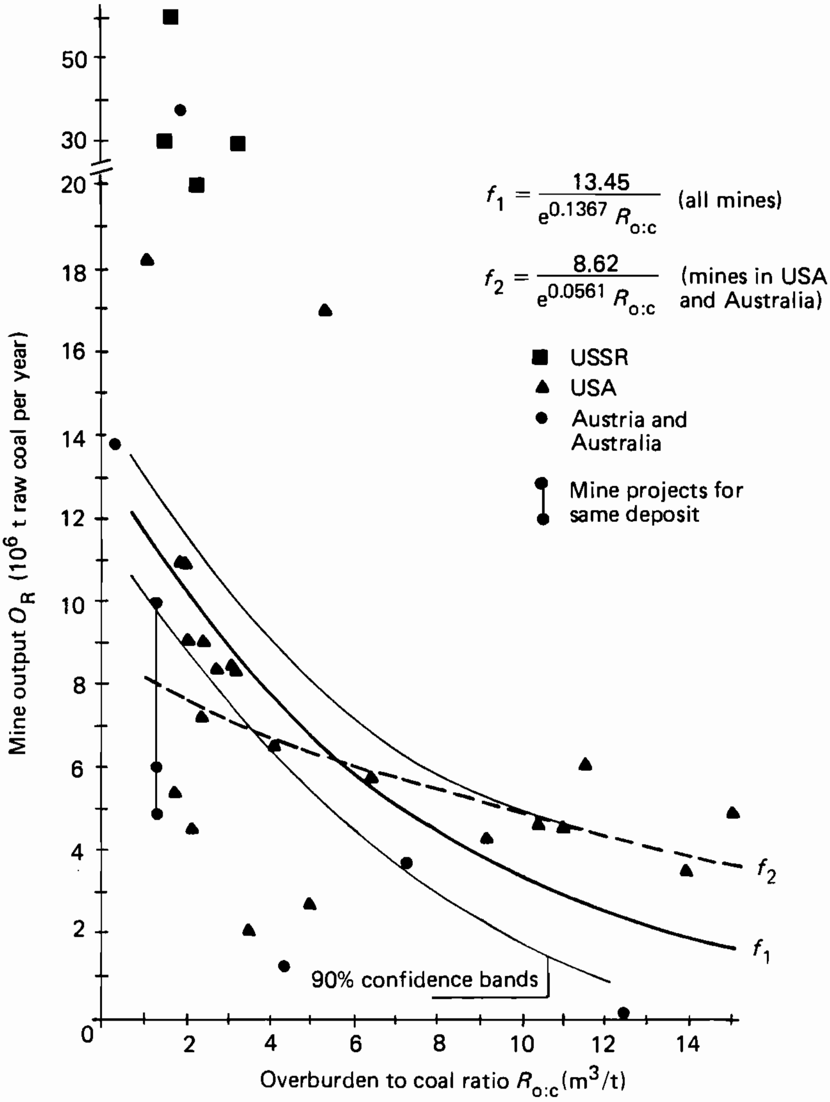

FIGURE 6 Relationship between the overburden to coal ratio and mine output in the data sample available for analysis.
Source: Coal Mines Data Base, IIASA.

The confidence bands represent a probability of 0.9 that the true mean value of y_k *for any* x_k *considered lies within the indicated limits around the predicted value* $\hat{y}_k$. *This applies to all confidence bands in subsequent figures.*

is that the data base contains information on mines with very different technologies (e.g. area stripping with shovels and coal transport by trucks, and mining with bucket-wheel excavators and coal transport by conveyors) as well as on mines in different countries, with different requirements for (social) infrastructure, different economic systems, and consequently different employment policies. (In an extreme case, for example, disproportionately high labor requirements can be explained by a specific policy of the mining company to employ as many miners as possible from other mines that have been closed down in the same area as the newly opened mine.)

Yet, in considering the high share of manpower requirements for overburden operations, the overburden to coal ratio still has a significant* influence on the specific manpower requirements, whereas the mine output does not show a significant influence. If we consider the above-mentioned nonlinear relationship between mine output and overburden to coal ratio (including the residuals** from eqn. (3) in the linear regression model for the specific manpower requirements), the mine output (or, better, any deviations of the observed output from that expected from eqn. (3)) still does not have a significant effect on the specific manpower requirements. However, in the available data base, mines with giant capacities (where one could expect important economies of scale with respect to labor requirements) are represented by just a few examples and practically all of them are located in the USSR; therefore, because of differences in economic systems and employment policies, comparisons with mines in other countries can hardly be made.

In an analysis of mines with similar mining technologies and economic environments (i.e. only mines from the USA and Australia), and which do not have such significant differences in mine output, the influence of the overburden to coal ratio is even more distinct. Again, the influence of mine size (as well as the residual mine size from the relationship in Figure 6) on the specific manpower requirements does not appear significant. Figure 7 presents the result of this analysis for opencast mines in the USA and Australia (for all systems of technology, but excluding mountain-top removal and multiple-dipping seam mining).

In summary, one can conclude that because of the high share of the total specific manpower requirements that is claimed by overburden operations, it is the geology of the mined deposit, as reflected in the overburden to

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*Throughout Section 4.1.2, as well as Section 4.2.2, in addition to an analysis of the improvement of R^2 by introducing an additional variable into the equation and an analysis of the standard error of the regression coefficients, significance tests for the individual independent variables have been performed. The tests are made at a 90% significance level to see whether a particular regression coefficient equals zero. If this hypothesis cannot be rejected the variable is considered as insignificant. Of course, this applies only to those data analyzed that are contained in the CMDB. In reality, or in considering alternative data sets or disaggregation of the available data into different subsets (e.g. systems of technology), the variable could well show a significant influence on a particular dependent variable studied.

**Because of the nonlinearity of eqn. (3) it is necessary to include the residuals in a separate regression. If the relationship in Figure 6 were linear, it is a feature inherent in the linear regression model that any transformation of the mine size variable, i.e. through consideration of its dependence upon the overburden to coal ratio, would not improve the overall fit or the predicted values of a particular linear regression function in comparison with the regression model where simply the mine size variable is considered.

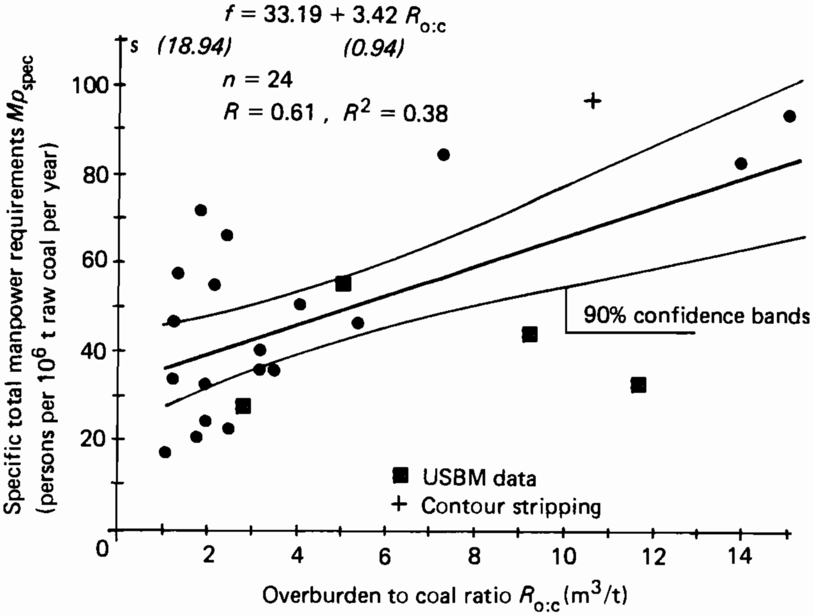

FIGURE 7 The influence of the overburden to coal ratio on the specific manpower requirements for opencast mines (excluding coal preparation operations) in the USA and Australia (excluding mountain-top removal and multiple-dipping seam mining). Source: Coal Mines Data Base, IIASA.

coal ratio, that exercises a strong influence on the specific manpower requirements. This applies equally when comparing mines from different countries with different economic systems and employment policies. Within the available data sample no significant influence of the mine size on the specific manpower requirements was found.

However, at present there are too few data available (especially on mines with very high output, where one could expect important economies of scale) to permit definitive conclusions with respect to the manpower requirements.

For the analysis of the *specific energy requirements*, all energy requirements were first aggregated to the total final energy requirements expressed in kWh equivalent (thermal equivalence)*. In addition, in order to obtain a better comparison, an average value of 8.25 kWh equivalent per tonne of coal produced was added for those mines where available data on energy requirements excluded coal preparation. This value was estimated** from US references (e.g. Fluor Utah Inc. 1977). The total energy requirements (including coal preparation operations) vary greatly; for the opencast mines included in

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*1 kWh = 3,600 kJ, 1 l diesel fuel = 10.7 kWh equivalent.

**On the basis of the available data, no influence of the throughput of the preparation facility on the specific energy requirements was found.

the data base, they range from 18.5 to 60.5 kWh equivalent per tonne of raw* coal. At mines exploiting multiple and deeply dipping seams, as well as for mountain-top removal mining, the values are considerably higher – up to 213.5 kWh equivalent per tonne of saleable coal. However, the requirements of these particular mining methods (resulting from special (unfavorable) deposit characteristics) cannot be compared with those of conventional opencast mining methods.

As discussed in Section 4.1.1 on structural analysis, electrically and diesel-powered equipment have different end-use efficiencies (i.e. electric motors convert final energy into mechanical energy more efficiently – by a factor of 3 – than diesel-powered motors). Therefore, as well as the overburden to coal ratio and the mine size ratio, the percentage of electricity consumption in the total final energy requirements was taken as an additional variable to explain the total energy consumption. For the mines analyzed, electricity accounts for between 16 and 91% of the total final energy requirements. For multiple-dipping seam and mountain-top removal mining, which use diesel power almost exclusively, the fraction of electricity requirements is only about 4–5%. Equation (4) presents the result of the regression analysis of the specific energy requirements as a function of mine size (represented by the size ratio**), overburden to coal ratio, and the percentage of electricity in the total final energy requirements:

$$\begin{array}{lllll} & En_{\mathrm{spec}} = 49.04 & - \; 0.38E_{\%} & + \; 1.65R_{\mathrm{o:c}} & - \; 2.55R_{\mathrm{R}} \\ s & \mathit{(11.23)} & \mathit{(0.14)} & \mathit{(0.69)} & \mathit{(2.01)} \end{array} \qquad (4)$$

$$n = 15$$

$$R_{E\%} = 0.59, \quad R_{E\%,R\mathrm{o:c}} = 0.71, \quad R_{E\%,R\mathrm{o:c},R_{\mathrm{R}}} = 0.76$$

$$R^2_{E\%} = 0.34, \quad R^2_{E\%,R\mathrm{o:c}} = 0.51, \quad R^2_{E\%,R\mathrm{o:c},R_{\mathrm{R}}} = 0.57$$

where

En_{spec} is the specific total energy requirements, in kWh equivalent per tonne of raw coal produced (including coal preparation);
R_{R} is the size ratio $1/O_{\mathrm{R}}$;
$E_{\%}$ is the fraction of electricity in the total energy requirements (%).

Because of the difference in end-use efficiency between electrically and diesel-powered equipment, it is no surprise that the percentage of electricity in the total energy requirements has the strongest influence on the specific energy requirements, followed by the overburden to coal ratio. The first variable characterizes the type of mining technology (and the resulting type of equipment) used, the second represents the influence of the deposit

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*To be consistent with our discussion of the relationship between the mine output and the overburden to coal ratio as presented in eqn. (3) and Figure 6, the specific values are expressed per tonne of raw (run-of-mine) coal.

**The size ratio is introduced to convert the relationship between the specific resource requirements and the mine output to a linear form.

characteristics on the energy consumption. From eqn. (4), and from significance tests performed, it appears that the output of the mine (represented by the size ratio) has an insignificant effect on the specific energy consumption. This applies equally if we take the nonlinear relationship between the mine output and the overburden to coal ratio and consider the residual mine output from eqn. (3) instead. Moreover, the negative value of the regression coefficient for the size ratio R_{R} would imply that there is a negative economy of scale[*]: that is, the bigger the mine (and the smaller R_{R}) the higher the specific energy consumption. However, in view of the limited data available, it would be premature to draw a definitive conclusion. We therefore reformulate eqn. (4), excluding the size ratio:

$$\begin{array}{lllll} & En_{\mathrm{spec}} = & 44.91 & -\ 0.31E_{\%} & +\ 1.34R_{\mathrm{o:c}} \\ s & & \mathit{(11.51)} & \mathit{(0.13)} & \mathit{(0.66)} \end{array} \qquad (5)$$

$n = 15$

R, R^2 values same as for eqn. (4)

If one makes further analyses of only those mines using electrically powered equipment for overburden removal and coal mining, and excludes those where these operations are (partly) carried out by diesel-powered equipment, the results are as presented in Figure 8 (n=12[**]). As expected, the percentage of electricity no longer has a significant impact on the specific energy requirements. The analysis, unbiased from the point of view of different end-use efficiencies of electricity and diesel fuel, shows the strong influence of the overburden to coal ratio on the total energy requirements, due to the high share of the total energy consumed in overburden operations.

Therefore, in looking at mines with similar technologies (i.e. overburden operations carried out by electrically powered equipment) one can conclude that only the overburden to coal ratio has a significant influence. In summary, the choice (if this is not determined by deposit characteristics, as is the case for mountain-top removal mining, for instance) between diesel- and electrically powered equipment at a mine influences the total energy requirements significantly. If diesel equipment is used, the total energy requirements are significantly higher owing to its lower end-use efficiency. Since a high share of the energy requirements is for overburden operations, the energy requirements depend strongly on the overburden to coal ratio. Based on the currently available data, the output of a mine does not appear to have a significant influence on the specific total energy consumption. However, in order to draw a definitive conclusion one would still require more detailed data for given mining technologies with a wider range of mine capacities.

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[*] The same result is obtained when the residual mine output is considered as variable.

[**] As stated at the beginning of this section, one should not be confused by the varying number of observations. Compared with eqn. (5), five mines have been excluded from the analysis for the equation describing Figure 8. However, as the percentage of electricity in the final energy requirements was no longer significant, thus permitting the omission of this variable, two additional observations from the CMDB – where only the total energy requirements and no separate data on electricity and diesel fuel requirements were available – could be included in the analysis. For the equation represented by Figure 8, n therefore equals 12.

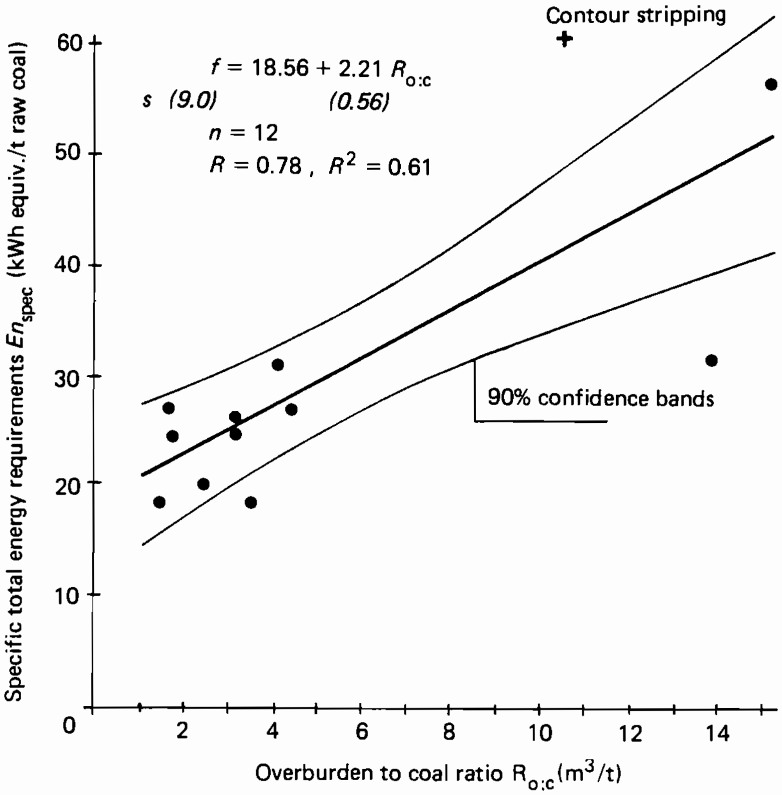

FIGURE 8 Relationship between the overburden to coal ratio and total energy consumption (including coal preparation operations) for mines using electrically powered equipment for overburden and coal-mining operations (USA, USSR, and Austria).
Source: Coal Mines Data Base, IIASA.

Because of the normally high share of electricity in the total energy requirements, a further analysis was made of the *specific electricity requirements*. As additional data from operating mines in the USSR were available, mines in the USA and USSR were treated separately. For a better comparability with the data of the USSR, the specific electricity requirements for the mines of the USA stored in the CMDB were recalculated, excluding the energy requirements for coal preparation, and are expressed per tonne of raw coal produced. For the analysis of the opencast mines in the USA mountain-top removal and multiple-dipping seam mining were again excluded. In addition, as in the analysis of the total energy requirements, only those mines where overburden and coal-mining operations are carried out by electrical equipment were taken into account. The result of this analysis of the dependence of the specific electricity requirements on the overburden to coal ratio is presented in Figure 9.

As in the case of the total energy requirements, one can observe the strong influence of the overburden to coal ratio on the specific electricity requirements, whereas the output of the mine (i.e. the size ratio or the resid-

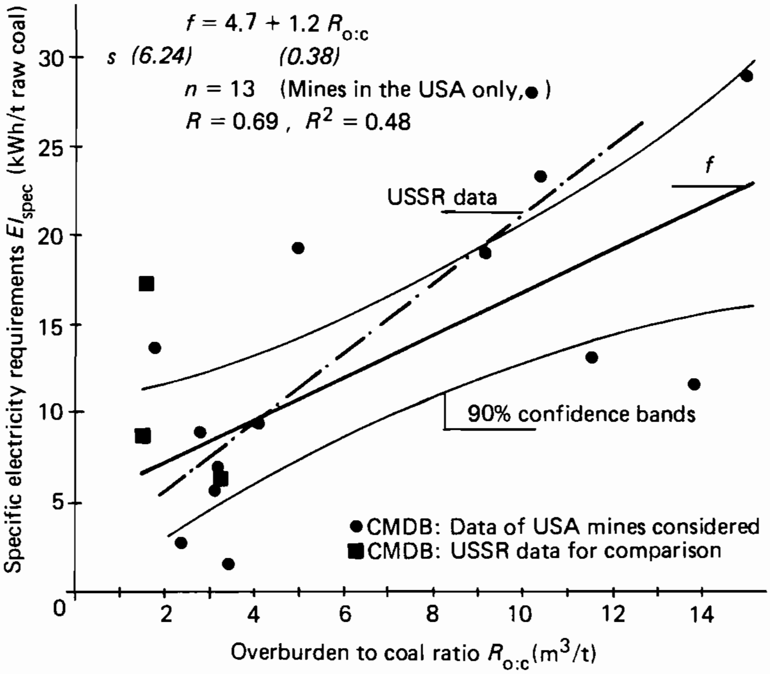

FIGURE 9 Specific electricity requirements (excluding coal preparation) as a function of the overburden to coal ratio for mines in the USA (excluding mountain-top removal and multiple-dipping seam mining) (full line), compared with the same type of relationship obtained from an analysis of all operating opencast mines in the USSR (broken line).
Sources: Coal Mines Data Base, IIASA and Academy of Sciences of the USSR (1979).

ual mine output from eqn.(3)) appears to have no significant influence. As the overburden to coal ratio rises from 1.8 to 15 m^3/t, the specific electricity requirements rise by nearly a factor of 4. These results are further confirmed if compared with the same relationship based on the analysis of all operating opencast mines in the USSR, which almost exclusively use electrically powered overburden equipment. The data for opencast mines in the USSR that are contained in the CMDB are plotted for comparison in Figure 9. The specific electricity requirements at opencast mines in the USSR appear to be influenced more strongly than US mines by the overburden to coal ratio. Since most of the function obtained from analysis of all operating opencast mines in the USSR is within the confidence bands of the function f for the US opencast mines in the CMDB, this demonstrates that the influence of the overburden to coal ratio on the specific electricity requirements is not affected a great deal by differences in the mining technology used in the two countries.

A quite different picture is obtained if one analyzes the *specific motor fuel consumption*. The overburden to coal ratio and the mine output have no significant influence on the specific consumption, which tends to have a fixed value. Its variance is chiefly determined by whether diesel is (partly) also used in overburden operations or mainly only for coal transport, land reclamation, and other equipment.

The ***specific material costs*** data stored in the CMDB for opencast mines in the USA are presented in Figure 10. As discussed in Section 4.1.1 on structural analysis of resource requirements, the share of the total material expenses consumed by overburden operations is very high: from 50 to 70%. One would therefore expect a strong dependence on the overburden to coal ratio. However, as seen in Figure 10, the estimated specific costs of materials have quite a wide range. Mountain-top removal and multiple-dipping seam mining have much higher material requirements than other mining systems. Even within the same group of mining systems (area stripping with draglines or with shovels and trucks, and contour stripping) the differences between estimated data are rather high. In particular, the values derived from studies by the US Bureau of Mines and the National Energy Supply planning model of the Bechtel Corporation are apparently underestimated, especially for mines with high overburden to coal ratios. Even if one includes in these estimates the material expenses of coal preparation facilities (ranging in the available data between 0.19 and 0.3 US$(1975)*/t saleable coal produced) the data still appear to be underestimated. One reason is that these estimates did not specifically take into account the detailed deposit characteristics; a second reason is that the estimates are basically revised versions of much older estimates, which have been adjusted to new base-year dollars. This demonstrates again that estimates based on physical requirements and their subsequent translation into costs, though always based on the original physical units, are much more reliable and do not tend to become outdated as quickly as estimates based on purely economic data. In analyzing the remaining estimates for their dependence on the overburden to coal ratio (the output of the mine appears to have no significant influence), a best fit was achieved by using a nonlinear regression function, as shown in Figure 10. However, the lack of data and the uncertainties associated with cost data in general imply that it would be premature to draw definitive conclusions at the present time. Consequently, the regression function suggested in Figure 10 is for information only, and is not recommended for use in a particular model.

A similar picture, with respect to the influence of the overburden to coal ratio on the specific costs of materials, is shown in Figure 11 for opencast mining in the USSR. The relationship, which is nonlinear (Academy of Sciences of the USSR 1979), is based on an analysis of all operating opencast mines in the USSR (1975 data). However, when compared with the US data (Figure 10) based on a conversion rate of 1 US$ = 0.7 rouble (1975), the specific costs for opencast mines in the USSR are considerably lower. The difference can be explained partly by the fact that the data for the US opencast mines include coal preparation expenses and are expressed per tonne of saleable coal, whereas the relationship from the Academy of Sciences of the USSR (1979) refers to the material costs per tonne of raw (run-of-mine) coal. Two other explanations for the difference lie in the difficulty of comparing

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*All costs have been adjusted to common base-year (1975) values. Appendix D gives the conversion rates used.

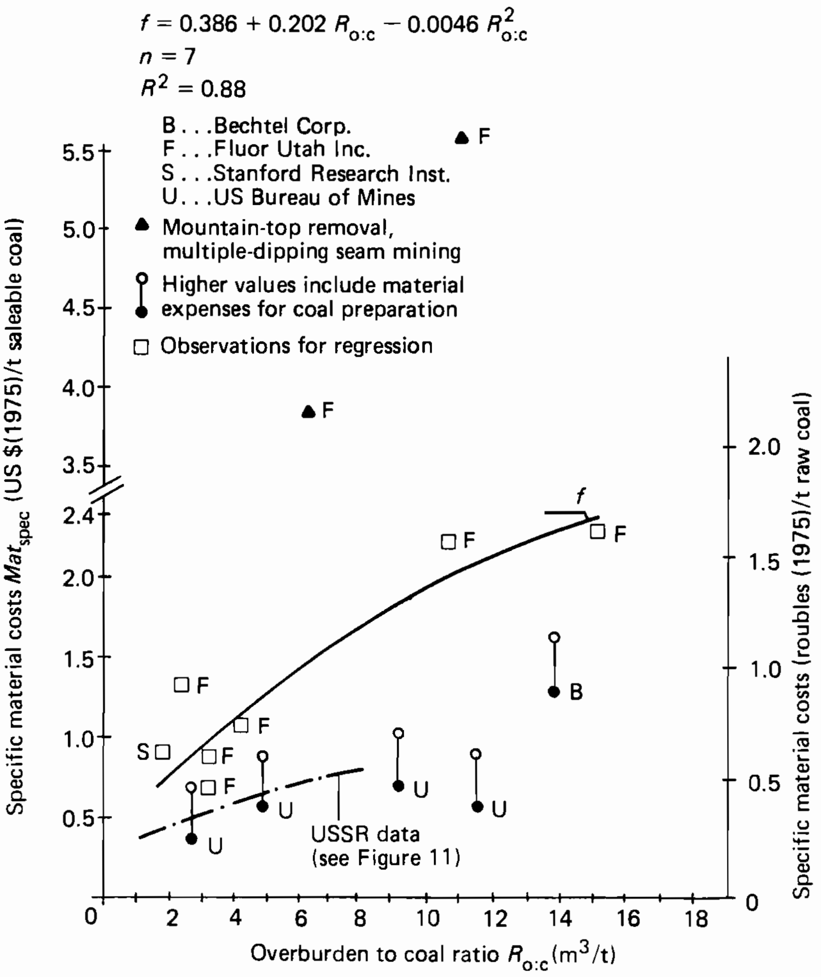

FIGURE 10 Specific costs of materials (including coal preparation): comparison of various estimates for US opencast mines, and comparison with the same type of relationship for opencast mines in the USSR.
Sources: Coal Mines Data Base, IIASA and Academy of Sciences of the USSR (1979).

cost data of currencies that are not freely convertible in general, and in possible differences in the definition of material costs in the two countries.

The analysis of the *environmental impacts* concentrated on the land requirements for opencast mining. The land area disturbed per unit of coal output depends on the thickness of the seam(s) mined and also, to a lesser extent, on the depth, since the greater the slope of the pit the greater the land requirements. On the other hand, the particular mining system and the size of the mine have practically no influence on the specific land requirements. This was confirmed by all the analyses carried out. In the first analysis the overburden to coal ratio (i.e. the combination of seam thickness

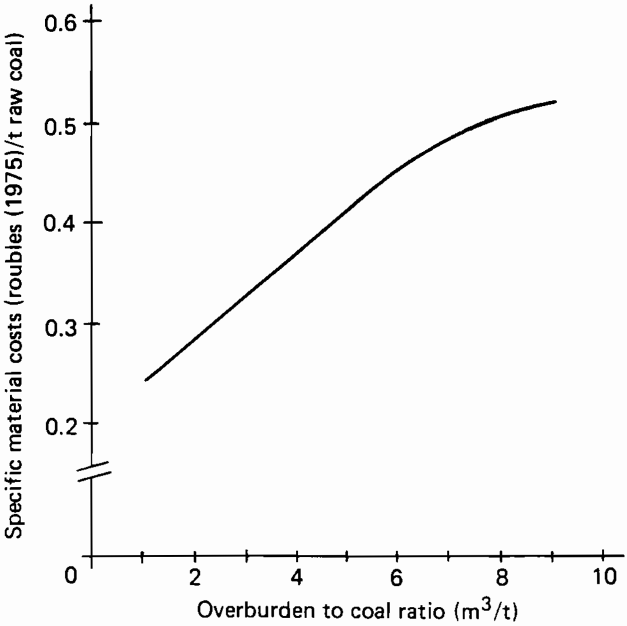

FIGURE 11 Relationship between the overburden to coal ratio and the specific costs of materials, based on an analysis of operating opencast mines in the USSR. Source: Academy of Sciences of the USSR (1979).

and mining depth or overburden thickness) was taken as the variable determining the specific land requirements (expressed in m^2 per tonne of saleable coal produced). The result of this analysis is presented in Figure 12. In analyzing whether the choice of a particular mining system could explain the residuals from the regression function in Figure 12, no influence of the mining system on variations in the specific land requirements was found.

The next analysis consisted of considering the specific land requirements as a function of the average (or total) seam thickness, as well as of the thickness of the overburden mined. Equations (6) and (7) present the results for the average and the total seam thickness, respectively.

$$
\begin{array}{llll}
 & 1/L_{\mathrm{spec}} = 4.00 & + \; 1.06S_{\mathrm{avg}} & - \; 0.19Th_{\mathrm{ov}} \\
s & \quad (3.10) & \quad (0.06) & \quad (0.04)
\end{array}
\qquad (6)
$$

$n = 14$

$R_{S\mathrm{avg}} = 0.94, \; R_{S\mathrm{avg},Th\mathrm{ov}} = 0.98$

$R^2_{S\mathrm{avg}} = 0.89, \; R^2_{S\mathrm{avg},Th\mathrm{ov}} = 0.96$

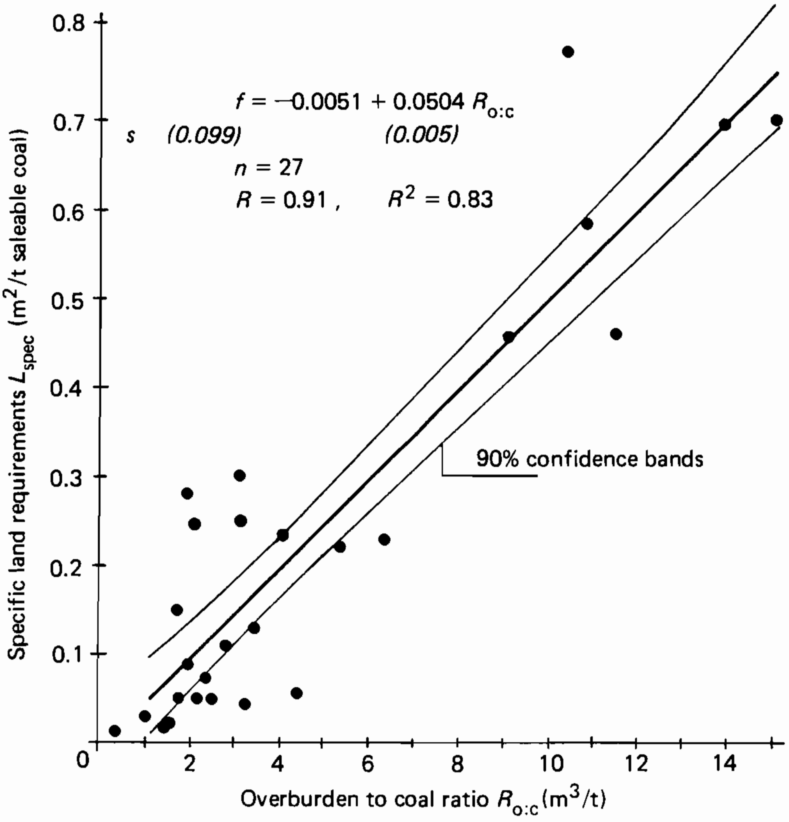

FIGURE 12 The influence of the overburden to coal ratio on the specific land requirements of opencast mining (all systems of technology).
Source: Coal Mines Data Base, IIASA.

$$\begin{array}{llll} & 1/L_{\text{spec}} = -\ 2.38 & +\ 1.22S_{\text{tot}} & -\ 0.096\,Th_{\text{ov}} \\ s & (10.75) & (0.18) & (0.11) \end{array} \qquad (7)$$

$n = 18$

$R_{S\text{tot}} = 0.89,\ R_{S\text{tot},Th\text{ov}} = 0.89$

$R^2_{S\text{tot}} = 0.79,\ R^2_{S\text{tot},Th\text{ov}} = 0.80$

where

L_{spec} is the specific land requirements (m^2/t saleable coal);
S_{avg} is the average seam thickness mined (m);

S_{tot} is the total seam thickness mined (m);
Th_{ov} is the overburden thickness (m).

As the relationship between the specific land requirements and the seam thickness is hyperbolic, the reciprocal value (i.e. tonnes of saleable coal produced per square meter of land disturbed) was taken as a dependent variable to fit into the linear regression model. In both equations the influence of overburden thickness on the specific land requirements is rather small. In the case of eqn. (7) the regression coefficient for the overburden thickness did not even pass the 90% significance test (see also the standard error and correlation coefficients in eqn. (7)). We can therefore conclude that the specific land requirements can be predicted quite accurately from the average or total seam thickness alone, with the regression equation for the average thickness showing a better result. Figure 13 presents the results from eqns. (6) and (7) by considering* only the influence of the average/total seam thickness on the specific land requirements, and in the hyperbolic form of the relationship, derived from the original linear regression model. Both equations show a best fit with the observed data when only one seam is mined (circular data plots in Figure 13). If more seams are mined, and the difference between the average and the total seam thickness becomes larger, the observations are no longer fitted as accurately by the given regression models.

In this respect, is is interesting to note that the land requirement data presented in a number of Environmental Impact Statements, published in the USA, tend to be especially unreliable. The land requirements of two mine projects, in particular, differ by more than a factor of 10 from the land requirements of other mines exploiting similar deposits and using basically the same mining technology. As we refer in this case to two independent publications, it does not seem likely that the difference can be attributed to a simple printing error, but rather it is another confirmation of remarks made earlier in this report about the large number of inconsistencies and apparently wrong data that these Environmental Impact Statements contain.

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*Different data samples are available for the analysis of land requirements, depending on the (combination of) parameters chosen. This is reflected in the varying number of observations and different minimum/maximum values applying to the figures and equations that deal with land requirements (for instance, when comparing f_1 from Figure 13 with eqn. (6), and f_2 with eqn. (7)).

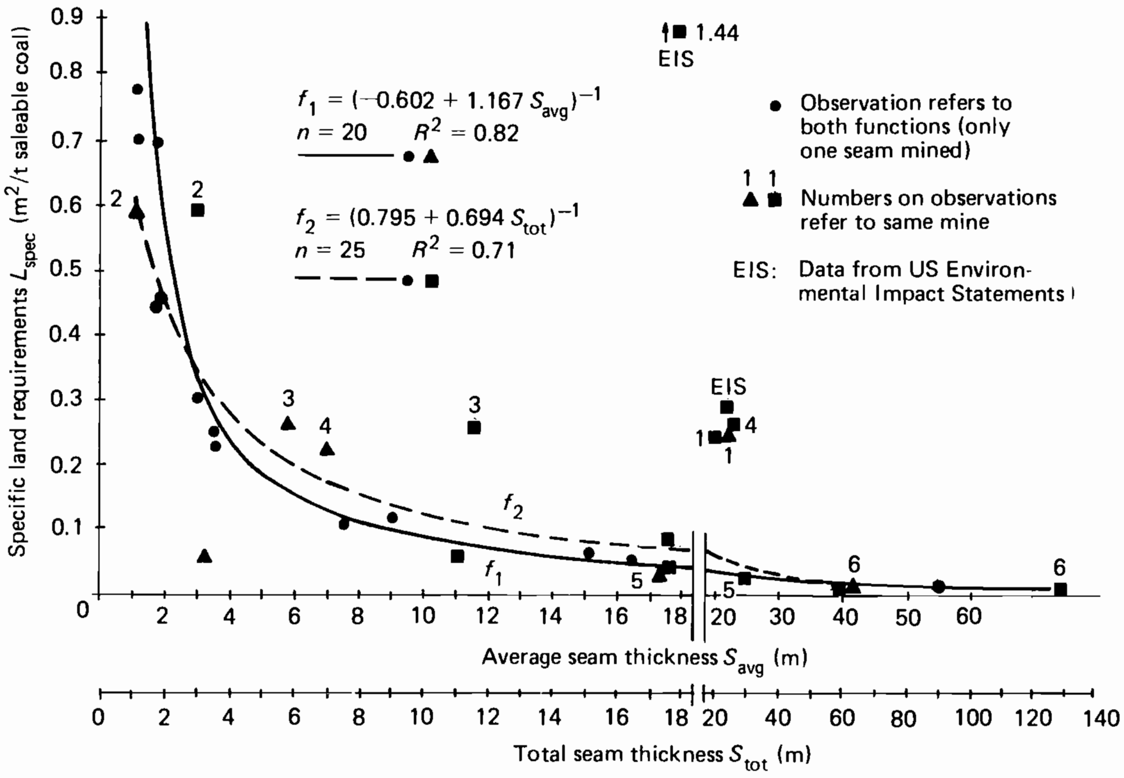

FIGURE 13 Relationship between the average/total seam thickness mined and the specific land requirements (all systems of technology).
Source: Coal Mines Data Base, IIASA.

Construction Requirements

In the analyses discussed thus far, only the operational requirements of the coal-mining process were dealt with. Unfortunately, too few data were available for a similar analysis of the construction requirements, which therefore could be considered only in terms of cost. However, there are difficulties in comparing and interpreting the cost data since the data base includes data from countries with different economic systems as well as data from a variety of references, in which the way the original estimates were derived is by no means consistent. Some studies (e.g. those mentioned earlier, by the US Bureau of Mines and the Bechtel Corporation) are based on adjusting older estimates by the same (or other) authors, the resulting data tending to be particularly unreliable. Original data from different countries and/or different reference years were deflated and converted to US$(1975) prior to analysis, according to the table in Appendix D.

To avoid biases in comparing construction cost data that include costs for coal preparation facilities with those that do not, all cost data apply to coal mining alone and are expressed per tonne of raw coal produced. Whenever a data breakdown was not available from the original data source, the cost of the coal preparation facilities was estimated from other mines (in the CMDB) located in the same basin and then used to recalculate the construction cost data, excluding the cost of coal preparation.

First, the *specific total construction costs* were analyzed. These costs include the direct construction costs as well as infrastructure expenses and indirect costs (e.g. interests). The total construction costs (excluding coal preparation) of the coal mines in the CMDB vary from 4.7 to 31 US$(1975)/t raw coal annual capacity. It is of course very difficult to compare these cost data between mines of different countries with different economic systems, simply because the definitions of the constituents of these costs (interests, infrastructure expenses including social expenses, etc.) are very different. Consequently, only data from mines in the USA were considered in the analysis. However, a wide range in the data can still be observed. This is caused by different assumptions on interest rates and required infrastructure expenses underlying the individual data estimates. However, the results of the analysis as presented in Figure 14 confirm the assumption that the specific total construction costs are strongly influenced by the geology of the mined deposit, as reflected in the overburden to coal ratio*. No influence of the mine capacity on the specific construction costs was found for the range of capacities of the US coal mines considered (from 2.7 to 8.5 $\cdot$ 10^6 t raw coal per year). The estimates derived from the studies by the US Bureau of Mines and the Bechtel Corporation are marked separately in Figure 14 and one can clearly see that the USBM data tend to be underestimated.

In the next step the *specific direct construction investments* were considered (i.e. investments for equipment plus investments for surface facilities (excluding coal preparation), such as offices and washrooms). Despite the problems of converting the original data into US$(1975) values, the direct

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*The same statement can be made for the total construction investments of mines located in other countries (including the USSR).

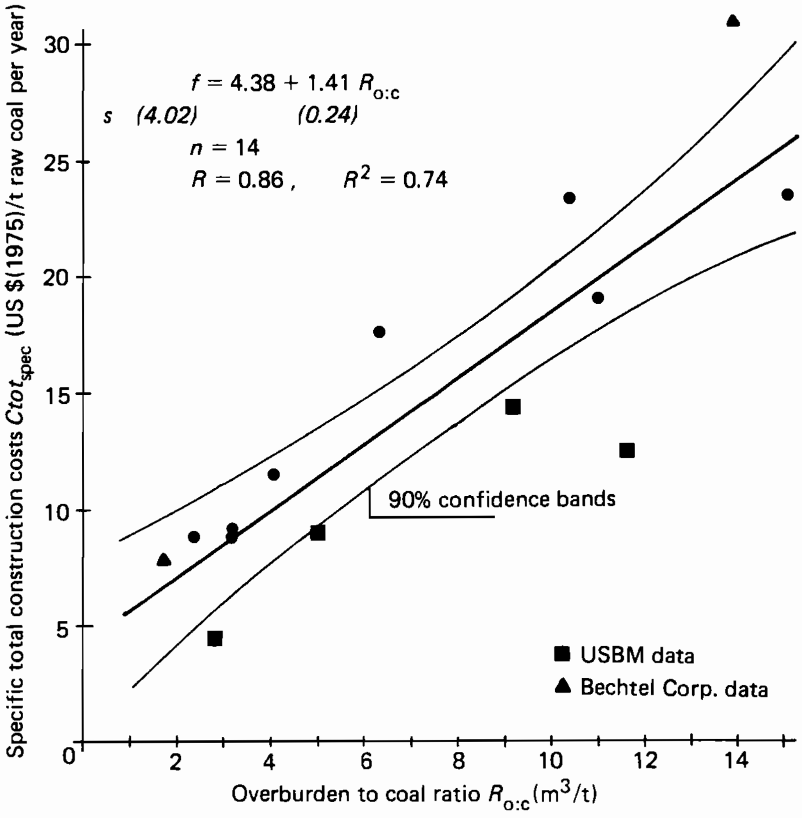

FIGURE 14 The influence of the overburden to coal ratio on the specific total construction costs (excluding coal preparation) for surface mines in the USA (all systems of technology).
Source: Coal Mines Data Base, IIASA.

construction investments of different mines in individual countries appear comparable. As shown in eqn. (8), the overburden to coal ratio and the size ratio determine the specific direct construction costs.

$$\underset{s\quad(5.28)}{Cdir_{\mathrm{spec}}} = 2.64 + \underset{(0.27)}{0.87R_{\mathrm{o:c}}} + \underset{(6.81)}{14.51R_{\mathrm{R}}} \qquad (8)$$

$n = 21$

$R_{R\mathrm{o:c}} = 0.61, \quad R_{R\mathrm{o:c},R_{\mathrm{R}}} = 0.71$

$R^2_{R\mathrm{o:c}} = 0.37, \quad R^2_{R\mathrm{o:c},R_{\mathrm{R}}} = 0.50$

where

$Cdir_{\mathrm{spec}}$ is the specific direct investment costs (excluding coal preparation) (US $(1975)/t raw coal per year).

The positive value of the regression coefficient for the size ratio R_{R} means an economy of scale: as the mine capacity increases (and the size ratio decreases) the increase in specific direct investment costs is lower than for mines with smaller capacities. However, this result is mainly due to the data from the supergiant opencast mines in the USSR, which are affected by the general problem of comparing currencies that are not freely convertible with other currencies. If one makes a separate analysis of the US mines alone, or considers the residual mine output from the nonlinear relationship between mine size and overburden to coal ratio (Figure 6), the mine size appears to have no significant influence on the specific direct construction investments. However, in view of the relatively small and inhomogeneous data sample it would be premature to draw definitive conclusions about the effects of economies of scale with respect to the specific construction investments. For a better evaluation, one would require more data for mines over a wider range of capacities, and for which investment data would have to be more easily comparable.

Still, one can conclude that it is mainly the overburden to coal ratio that determines the specific direct investment costs. Figure 15 shows the results for eqn. (8) rewritten in terms of the influence of the overburden to coal ratio alone.

Looking at the *specific investment costs of equipment*, one would expect an even closer dependence upon the overburden to coal ratio than for the specific direct investment costs, because of the high share of the total equipment expenses given to overburden equipment, as discussed in Section 4.1.1 on structural analysis. The result of the analysis confirms this assumption, that the overburden to coal ratio determines, to a very large extent, the specific cost of equipment to be installed during the construction of a mine. Figure 16 shows the result of this analysis. Compared with the analysis of the specific direct investment costs as presented in Figure 15, the fit of the observed data for the specific equipment cost to the regression line is much better (in terms of a higher R^2 as well as narrower confidence bands). Furthermore, the specific equipment cost does not appear to be influenced by the size of the mine or a particular mining technology, at least not in the data sample analyzed.

The analyses of investment costs have shown that a comparison of opencast mines based on economic data introduces additional biases: different assumptions underlying the individual original estimates, the necessity of converting economic data to base-year values, and finally the difficulty of comparing economic data between different countries and/or different economic systems. All this tends to make the data on individual mines less comparable and the results of the analyses less reliable compared with data and analyses based on engineering-type information as reflected in physical (WELMM-type) indicators.

Yet, similarly to the other analyses performed, the economic analyses show that investment costs are to a very large extent determined by the geology of the mined deposit, as reflected in the overburden to coal ratio. On the

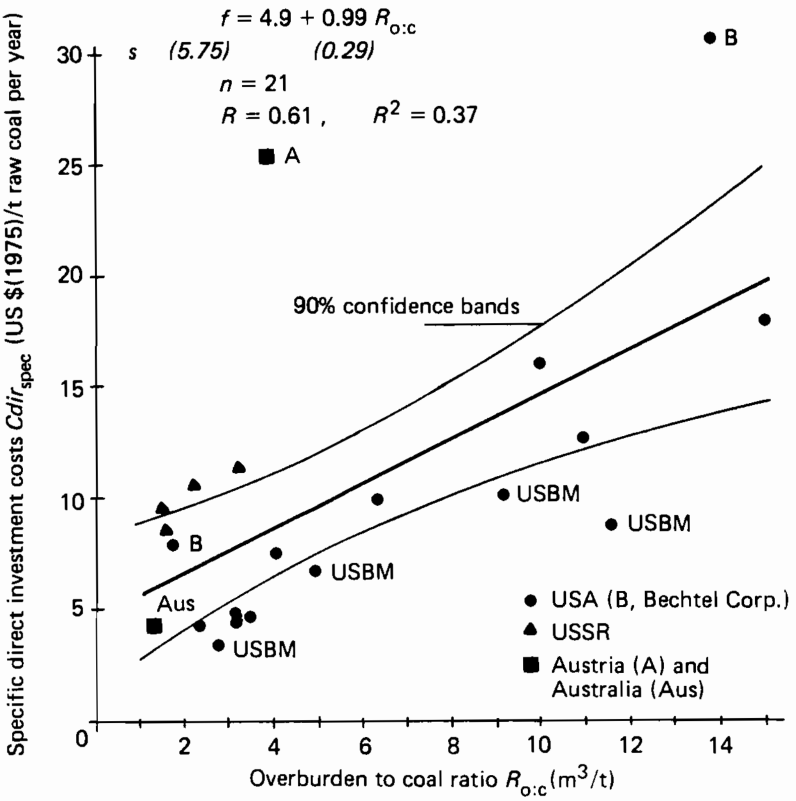

FIGURE 15 The influence of the overburden to coal ratio on the specific direct investment costs (excluding coal preparation) for opencast mines (all systems of technology).
Source: Coal Mines Data Base, IIASA.

basis of the available data sample no significant economies of scale with respect to investment costs could be found. Data on large-capacity mines are presently available for the USSR only, but even in this case there are too few examples to allow a more careful evaluation of the effects of economies of scale on construction investment costs.

In concluding this section on the statistical analysis of factors influencing natural resource requirements of opencast mining, it should be emphasized that in interpreting the results and/or applying them in a particular model one has to bear in mind the relatively small and inhomogeneous data base available for analysis, as well as the fact that the coal-mining process was dealt with as a whole (i.e. not by first analyzing the subprocesses, such as overburden removal, coal winning, and coal transport, and then aggregating these into a single mining process). However, the information required for this type of analysis is generally only available at the level of the

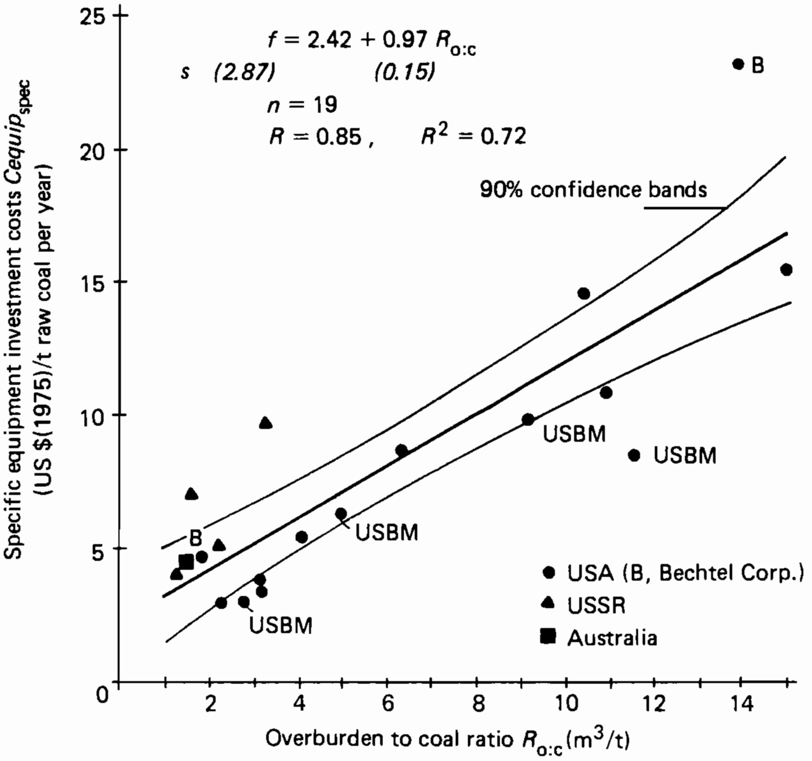

FIGURE 16 The influence of the overburden to coal ratio on the specific equipment investment costs (excluding coal preparation) for opencast mines (all systems of technology).
Source: Coal Mines Data Base, IIASA.

mine deposit or as a result of detailed engineering studies for a particular mine. Therefore, if one is interested in studying the long-term effects of resource depletion, considering the available coal reserves or even part of the coal resources of a given basin or country, very little information is available – normally only depth, seam thickness (i.e. the overburden to coal ratio), and coal quality. Therefore, the somewhat simplified and crude representation of mining operations as a single process and consideration of only some main influencing factors (i.e. the overburden to coal ratio and mine size) appears to be a legitimate approach. In view of these precautions, the results* of the analyses can be considered as satisfactory, even though they include an inevitable degree of uncertainty and inaccuracy. The relationships and

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*With respect to applications of these results, the authors would like to emphasize again that the relationships ought to be considered only within the intervals considered in the analyses (summarized in Appendix B.2). A linear type of model does not necessarily imply that the particular relationship considered is linear *in general* but rather that the relationship is approximated *within the interval considered* by a linear model.

interdependences discussed in the structural analysis, Section 4.1.1, and which are expected to be found also in the empirical data contained in the CMDB, are confirmed in the statistical analyses and could be *quantified*. The results achieved in this first step of the study ought to be improved and confirmed using larger, more homogeneous data samples. The authors consider a continuation of this type of approach not only a valuable but also a necessary direction of future studies, which this report is intended to encourage.

4.2 CONVENTIONAL UNDERGROUND MINING

4.2.1 Structural Analysis of Resource Requirements of Mines in Selected Countries

4.2.1.1 Underground Mines in the USA

Around 40% (or about 293 million tonnes per year) of the total annual coal output (1982) of the USA is produced from underground mines. The major industrial base of US underground mining is situated in the Eastern region (Appalachia and Illinois basins). Only a small part of the total US coal resources has been depleted up to now. Past cumulative production and loss in mining account for only 9.7% of the total coal reserve base *in situ* (Averitt 1975, US Department of Energy 1981). The reserve base for underground mining in the Eastern United States alone, based on a minimum seam thickness of 0.7 m and depths not exceeding 300 m, is still estimated at $153 \cdot 10^9$ t (US Bureau of Mines 1974). The total reserve base for underground mining in the USA is estimated to amount to $289 \cdot 10^9$ t. Even assuming that only 50% of the reserve base may be recoverable, it would still allow the current underground mining production level to continue for 490 years. In addition, it is well recognized that knowledge of coal resources at depths of up to 1000 m (the mining depth at a number of mines in Europe and the USSR) is still insufficient to permit a realistic evaluation of the ultimate potential of underground mining in the USA (e.g. Averitt 1975, US Department of Energy 1981).

The huge reserves available in the USA are located in extremely favorable geological conditions, in contrast to those prevailing in most basins in Europe or the USSR. In the USA, coal seams deeper than 600 m had not been exploited until now. Mining depths exceeding 300 m are rare, which explains why there has been little interest in resources located at greater depths. The bedding of the coal seams exploited in the USA is usually very regular and flat. As a rule, only one seam is exploited in a mine. Such favorable conditions permit the application of room-and-pillar mining and the use of flexible continuous mining equipment (accounting for about two-thirds of underground-mined coal). Longwall mining is employed in the USA on a small scale (less than 10% of underground coal production). The following analysis of resource requirements of underground mines in the USA was based on a number of studies published between 1974 and 1978 (Katell and Hemingway 1974a, b, Stanford Research Institute 1975, Hogle *et al.* 1976, Katell *et al.* 1976b, Bechtel Corporation 1977, 1978). All the data have been estimated for a number of hypothetical underground coal mines in a capacity range from 0.93 to 4.5 million tonnes per year.

Characteristics of these mines may be summarized as follows. One slightly inclined seam of bituminous coal 1.2–1.8 m thick is exploited in each mine, and mining depths are extremely small. The room-and-pillar system is used, and main headings are equipped with conveyors. Each loading unit consists of a continuous miner, a loading machine, two shuttle cars, and a roof bolter. The shuttle cars dump coal into a ratio feeder at the tailpiece of the unit belt conveyor. A manpower unit consists of 10 persons and a foreman. Continuous miner sections produce around 310 tonnes of coal per unit per shift, with about 60% recovery.

The construction period of a mine is assumed to be about 3 years, the development period 1–2 years; the lifetime of a mine is about 20–30 years, with 220–250 days of annual operation. The geological conditions taken into account and the technological parameters are supposed to be typical of a great number of mines of the USA.

Manpower Requirements

Personnel requirements compiled for mines in the USA generally do not include a great number of auxiliary personnel of supporting companies. Therefore, manpower estimates tend to be incomplete. Nevertheless, labor requirements at underground mines are very low compared with mines in other countries. Table 31 presents the estimated manpower requirements for a number of hypothetical mines. These requirements are probably underestimated and alternative data are therefore presented in Table 32.

Simple mining schemes, centralized surface facilities, the virtual absence of waste rock operations, and no roof supports at the faces are the main reasons for the low manpower requirements of the room-and-pillar system. If it is assumed that there are 220 working days per year, the manpower requirements, as shown in Table 31, result in a labor productivity of 16.6–20.8 t per man-shift. Even in considering an alternative estimate from Table 32 of 7.4 t per man-shift, or the average productivity at underground mines in the USA (1982) of 9.6 t per man-shift, a higher labor productivity can be observed in US room-and-pillar mines than in mines in many other countries. However, it should again be stressed that this high productivity is, first and foremost, a result of excellent bedding conditions as well as of the large reserves, which permit the application of room-and-pillar mining.

Electricity Requirements

Electricity requirements for US underground mines range between 13.0 and 21.1 kWh/t raw coal produced. These requirements are relatively low, since the main sources of electricity consumption, such as the equipment for ventilation and for lifting water and coal, do not use large amounts of energy, because of the relatively small depths of the mines and good geological conditions. Table 33 presents the electricity requirements for each main type of equipment. Face equipment (mining and loading) consumes between 50 and 60% of the total electricity requirements. Electricity, and thus energy, requirements are extremely low, especially when compared with the energy produced by the coal-mining process (a similar situation to that already discussed for opencast mines).

TABLE 31 Estimated manpower requirements of hypothetical US underground mines.

Seam thickness	1.2 m			1.8 m			
Annual mine capacity (10^6 t raw coal)	0.93	1.87	2.8	0.96	1.85	2.9	4.5
Manpower requirements (persons per 10^6 t raw coal per year):							
Underground	214	207	207.9	200	193	187.6	191.3
Surface	11.8	8	6.4	11.5	8.1	6.2	6
Supervision	47.3	31.5	26.4	44.8	30.3	24.5	24.2
Total manpower	273.1	246.5	240.7	256.3	231.4	218.3	221.5
Labor productivity (total mine) (tonnes per man-shift)[a]	16.6	18.4	18.9	17.7	19.6	20.8	20.5

[a] Assuming 220 working days per year.

Sources: Katell and Hemingway (1974a) and Katell *et al.* (1976b).

TABLE 32 Alternative estimated manpower requirements (including coal preparation) for a room-and-pillar mine in the USA with a coal output of 1.8 million tonnes per year.

Type of personnel	Manpower requirements (persons per 10^6 t raw coal per year)
Nonmanual, technical	111.9
Nonmanual, nontechnical	146.8
Manual, technical, with critical skills	299.6
Other	53.1
Total personnel	611.4
Labor productivity (total mine, including coal preparation) (tonnes per man-shift)[a]	7.435

[a] Assuming 220 working days per year.

Source: Bechtel Corporation (1978).

TABLE 33 Estimated electricity consumption of different types of equipment for two US underground mines (kWh/t raw coal).

Equipment	Seam thickness: 1.2 m Annual capacity: 2.8 million tonnes (raw coal)	Seam thickness: 1.8 m Annual capacity: 0.96 million tonnes (raw coal)
Continuous miners	2.9	7.2
Loading machines	2.1	1.9
Shuttle cars	2.6	3.2
Roof bolters	0.8	0.7
Belt conveyors	1.3	2.2
Fans	1.2	2.5
Other	3.2	3.4
Total	14.1	21.1

Source: Katell *et al.* (1976b).

Material Requirements

Table 34 presents some estimated data on the material requirements considered as representative of room-and-pillar mines in the USA. In terms of physical quantities, rock dust (66.5 t), roof bolts (468.6), and lumber (around 160 kg) are the most important material requirements per 10^3 t of raw coal produced. Roof bolts account for 74%, rock dust for 9%, and lubricants and hydraulic fluids for about 7% of the total cost of materials, which is 1.58 \$(1975)* per tonne of raw coal produced. The material requirements can of course vary significantly between individual mines, depending on the geology of the deposit.

Water Requirements

Water consumption for coal production is extremely low in US underground mines, i.e. about 35 liters per tonne of coal produced. The water consumed is for controlling dust and cooling equipment. Water inflow into a mine can be of significance, especially for electricity consumption, but the inflow depends very much on local hydrological conditions, which cannot be compared from one mine to another.

Land Requirements

The total surface area leased to produce one million tonnes of coal per year over a 20-year lifetime of a mine varies from 14.5 to 21.7 km^2, depending on whether a coal bed of 1.2 or 1.8 m thickness is exploited. The land requirements also depend on whether more than one seam is exploited and on the dip of the coal bed. Generally, the impact on the surface area undermined (e.g. through subsidence) is smaller at room-and-pillar mines in the USA than at longwall mines in other countries, because of the coal pillars left underground. However, this advantage implies considerable loss of the *in situ* coal reserves (up to 50%).

Production Costs

The estimated cost of coal production varies from 8.95 to 10.15 \$(1975) per tonne of raw coal produced, according to the US Bureau of Mines (Katell *et al.* 1976b). If the mine capacity grows from 0.96 to 4.5 million tonnes per year, the specific cost declines by as much as 1.15 \$(1975)/t or 11.4%. The scaling factor therefore appears somewhat insignificant if one considers the range of capacities mentioned above. Typical distributions of production costs are presented in Table 35 for mines exploiting a coal bed 1.8 m thick with capacities of 0.96 and 4.5 million tonnes per year. Wages, payroll overhead, and union fees comprise 53% of total production costs; equipment supplies and materials account for 20–23%, energy for around 4%, and depreciation for 9–11%. Estimated production costs have shown an annual escalation of 10% over the period from August 1974 to March 1977 (Bechtel Corporation 1977). More recent production cost estimates for a typical room-and-pillar mine having an annual output of 1.8 million tonnes of clean coal (i.e. including coal preparation) amount to around 30 \$(1978) per tonne of clean coal produced (Bechtel Corporation 1978).

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*All costs have been converted to 1975 values. Appendix D gives the conversion rates used.

TABLE 34 Material requirements of a room-and-pillar mine in the USA producing 1.8 million tonnes of clean coal per year.

Material	Requirements per 10^3 t clean coal produced	
	Amount	US $(1975)
Lumber and wood products	0.35 m^3(~160 kg)	32.5
Explosives and blasting materials	10.0 kg	18.5
Diesel fuel	104.3 liters	9.1
Gasoline	14.0 liters	2.4
Lubricants and hydraulic oil	–	120.4
Fertilizers	6 kg	0.5
Tires	–	12.0
Roof bolts	468.6	1,278.8
Rock dust	66.5 t	160.0
Concrete and cement products	–	62.6
Brattice cloth	6.7 m	18.0
Miscellaneous	–	9.8
Total[a]	–	1,724.2

[a] Total does not add because of rounding errors.

Sources: Stanford Research Institute (1975) and Hogle *et al.* (1976).

TABLE 35 Estimated production costs (US $(1975)/t raw coal) for two hypothetical US underground mines exploiting a coal seam 1.8 m thick.

	Mine output: $0.96 \cdot 10^6$ t/yr		Mine output: $4.5 \cdot 10^6$ t/yr	
1. *Direct costs*				
a. Labor	2.41	(30%)	2.24	(28.8%)
b. Supervision	0.64		0.34	
c. Equipment supplies				
Spare parts	0.7	(10.8%)	0.7	(12.4%)
Ventilation	0.2		0.21	
Bits and cables	0.2		0.2	
d. Materials				
Lubricants and hydraulic oil	0.28	(9.3%)	0.28	(10.4%)
Roof bolts and timber	0.34		0.34	
Rock dust	0.15		0.14	
Miscellaneous	0.17		0.17	
e. Power and water	0.42	(4.1%)	0.35	(3.9%)
f. Payroll overhead	1.22	(12%)	1.03	(11.5%)
g. Union welfare	1.15	(11.3%)	1.13	(12.6%)
2. *Indirect costs* (15% of a to d)	0.76	(7.5%)	0.69	(7.7%)
3. *Fixed costs*				
Taxes and insurance	0.37	(14.9%)	0.32	(12.6%)
Depreciation	1.14		0.81	
Total	10.15	(100%)	8.95	(100%)

Source: Katell *et al.* (1976b).

4.2.1.2 Underground Mines in the USSR

At present, a major share of the coal mined in the USSR is produced by underground mining. In 1981, around 430 million tonnes of coal were produced from underground mines, corresponding to 61% of the national coal output. Underground mining is employed mostly in the Donetsk, Kuznetsk, Karaganda, Moscow, and Pechora basins.

In 1975, the average depth of underground mining was 409 m, i.e. much greater than in the USA. In the Donbass, the average mining depth was 545 m, in the Kuzbass 252 m, and in the Karaganda basin 372 m. The average mining depth is increasing steadily: for instance, between 1975 and 1977 the average depth increased to 566 m in the Donbass and to 398 m in the Karaganda basin. Seventy percent of all faces exploit flat seams (0–25°), 10% of faces exploit inclined seams (25–35°), and the rest work steep seams (over 35°). About 72% of the coal produced is brought to the surface via vertical shafts, 25% via slopes, and only 3% through adits (Astakhov 1977b). Longwall mining is used almost exclusively in the USSR, in many cases with the preliminary drivage of entries to the border of the panel.

Most of the coal is mined mechanically, mainly by narrow-web shearers. Caving and smooth lowering methods are used almost exclusively for roof control. Fifty-four percent of coal from seams with a dip of up to 35° is obtained from completely mechanized faces equipped with narrow-web shearers (sometimes also with coal ploughs), armored face conveyors, and hydraulic roof supports. A continuous scheme of operation is typical at such faces. Locomotives are normally used for underground transport; 20% of all the coal is transported by belt conveyors.

Longwall mining proved the most effective mining method for the geological conditions in the basins of the USSR. Significant progress has been made during the last two decades in the complete mechanization of face operations and in the concentration of coal mining at high-output, productive faces. A number of attempts to use room-and-pillar mining equipment have failed because of the great depths and the geological conditions, which vary over a wide range for different coal basins, as shown in Table 36.

TABLE 36 Characteristics of geological conditions of three coal basins in the USSR.

	Donetsk basin	Karaganda basin	Pechora basin
Number of exploited coal beds	1–6	3–5	2–6
Average thickness of coal beds (m)	0.7–1.55	1.45–3.10	2.0–3.0
Maximum depth of mining operations (m)	415–1,050	370–600	175–350

Source: Astakhov (1977a).

The technological parameters of underground mines, in their turn, are highly influenced by these geological conditions, as well as by the organizational structure of mining operations. Consequently, one can observe a similarly wide range of variation in technological parameters. Current average data for the USSR as a whole, as well as for all mines of the major coal basins, are presented in Table 37.

The general evolution of these parameters is influenced positively by technical progress, but negatively by the worsening of geological conditions,

TABLE 37 Average technological parameters for underground mines in the main coal basins of the USSR.

Parameter	Average for USSR coal industry	Donetsk basin	Kuznetsk basin	Karaganda basin
Annual mine output				
(10^3 t)	893	855	1,334	1,654
(10^{12} kJ)	18.0	20.9	35.2	34.8
Average number of coal faces in operation at a mine	5.6	6.4	7.2	5.7
Daily output per face (for a working day) (t)	454	393	481	876
Annual number of working days	312	317	313	286
Daily number of machine-shifts		Predominantly 3		
Length of drivage per 10^3 t coal produced (m)	14.5	14.3	20.7	10.2
Length of workings maintained per 10^3 t annual output (m)	57.2	68.2	45.1	43.3
Tonnage of stone wound per 10^3 t coal produced	209	294	112	132

Source: Astakhov (1977b).

which will become more and more complex at greater depths. For a long time the average rate of increase in the depth of mining in the Donbass was from 14 to 17 m/yr. One can assume that this increase would counterbalance a great share of the impacts of improvements in mining technology. The impacts and economics of underground coal mining in the USSR will, on the whole, depend very much on the rate of substitution of coal mined in the Donbass by coal produced under better conditions, such as in the Kuzbass. This substitution is considered a necessity in the long run, though the rate of substitution is constrained by a variety of problems, including those of an institutional nature.

All these factors were taken into account in the estimation of technological parameters for new coal mines. Most of these parameters, shown in Table 38, are assumed to be more favorable than those of mines in operation now. However, the mines currently in operation will inevitably have to be reconstructed every 15–20 years. The characteristics of these reconstructed mines will not differ in principle from new mines that are planned now.

TABLE 38 Estimated technological parameters for new mines in the USSR.

Parameter	Donetsk basin	Kuznetsk basin	Karaganda basin	Others
Annual mine output (10^3 t)	1,800–4,000	1,200–1,800	1,800–4,000	450–4,500
Number of faces operating per mine	5–23	2–4	7–10	1–8
Daily output per face (t)	550–1,400	1,350–1,500	600–1,800	330–1,875
Annual number of working days	260–300	300	300	260–300
Daily number of machine-shifts	3	3	3	3
Length of mine workings maintained (m/10^3 t annual capacity)	10–34	15–27	15–26	8–26
Specific volume of drivages for mine construction (m^3/t annual capacity)	150–440	125–135	130–200	67–275
Electromotive power installed (kW/10^3 t annual capacity)	19.2	7.8	13.4	8.6

Source: Astakhov (1977b).

Manpower Requirements

The average labor requirements per 10^3t of (raw) coal production in the USSR were around 410 man-shifts in the late 1970s. This corresponds to a labor productivity of 2.44 t per man-shift. About 76–89% of the total labor requirements are for laborers, the rest are for engineers, managers, and administrative personnel. Between 74 and 86% of the total number of laborers work underground, and face workers represent typically around 30% (up to 50%) of this number. It is difficult to compare labor requirements with those of other countries (e.g. the USA), not only because of the differences in technology and geology but also because the data on labor requirements in the USSR include a great number of additional personnel engaged in indirect activities such as equipment repair or social services (kindergartens, hostels, etc.). The specific manpower requirements vary by a factor of more than 3 between mines in various basins in the USSR, being primarily the result of the different geological conditions prevailing. Tables 39 and 40 show the main geological/technological characteristics and the distribution of specific manpower requirements for each type of operation in a number of mines operating in the USSR for which data (from 1977) are stored in the CMDB. The data presented in Table 40 correspond to an underground productivity ranging from 2.7 to 6.6 t per man-shift in the Donbass and up to 8.3 t per man-shift in the Kuzbass. Total mine personnel productivity ranges from 1.7–4.3 t per man-shift in the Donbass to up to 5.6 t per man-shift in the Pechora basin. The total number of people employed per million tonnes of coal produced (in 1977) ranges from 690 to 2,392.

TABLE 39 Geological and technological characteristics of selected operating underground mines in the USSR.

	Donetsk basin						Karaganda basin				Pechora basin	Kuznetsk basin	
	Hypothetical	Abakumov	Krasnoarmeyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakhstanskaya	Gorbachov	Intinskaya	Karagaylinskaya	Inskaya No. 1
Geological characteristics													
Number of seams mined	1	3	2	4	2	2	3	4	5	4	2	2	6
Average seam thickness (m)	1.2	1.2	1.5	1.15	1.33	1.4	3.1	2.6	2.15	2.3	3.0	3.2	2.6
Dip of seams (deg)	Flat	7–9	8–9	10	9–13	19	8–18	7–9	8–18	8–9	15–18	Flat	Flat
Maximum mining depth (m)	1,070	800	986	414	760	833	370	560	476	450	174	175	200
Gas emanation (m^3/t)	n.a.	–	21.7	–	2.57	–	n.a.	38.3	11.0	22	0.7	n.a.	n.a.
Water inflow (m^3/t)	1.5	1.9	0.6	3.9	0.9	1.5	0.2	0.7	0.3	0.5	1.3	n.a.	n.a.
Calorific value of coal (MJ/kg)	21.4	34.1	34.3	32.2	33.8	33.8	35.0	27.2–35.2	35.2	34.3	30.4	33.2–35.4	32.5–33.9

	Donetsk Basin						Karaganda basin				Pechora basin	Kuznetsk basin	
	Hypothetical	Abakumov	Krasnoarmeyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakhstanskaya	Gorbachov	Intinskaya	Karagaylinskaya	Inskaya No. 1
Technological characteristics													
Annual raw coal production (10^6 t)	1.8	1.53	2.44	1.29	1.95	1.56	3.05	3.22	2.46	2.53	1.54	1.56	1.47
Average number of production faces	n.a.	8.1	9.5	6.7	4.8	3.8	9.7	7.4	10.5	7.8	2.5	n.a.	n.a.
Average production face length (m)	n.a.	1,761	1,907	974	753	840	813	1,183	1,106	1,128	347	n.a.	n.a.
Average number of faces under development	n.a.	n.a.	7.6	15	10	8	13.6	7	10	16	7.6	n.a.	n.a.
Length of development workings (m/10^3 t coal produced)	n.a.	13.0	5.4	12.9	5.4	6.6	8.9	3.8	8.4	9.2	5.6	n.a.	n.a.

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

TABLE 40 Distribution of manpower requirements (excluding coal preparation) for operating underground mines in the USSR in 1977 (man-shifts per 10^3 t raw coal).

	Donetsk basin						Karaganda basin				Pechora basin	Kuznetsk basin	
	Hypothetical	Abakumov	Krasnoarmeyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakhstanskaya	Gorbachov	Intinskaya	Karagaylinskaya	Inskaya No. 1
Coal mining at faces	n.a.	133.5	112.5	102.1	49.9	69.9	44.7	52.6	68.6	56.6	18.2	85.0	89.1
Driving of development workings	n.a.	58.4	52.4	76.0	45.9	45.6	35.5	26.3	41.6	35.3	33.3	n.a.	n.a.
Underground transport	n.a.	98.8	57.8	56.7	25.6	35.5	18.8	15.3	21.3	13.0	15.0	18.9	11.4
Maintenance of workings	n.a.	50.0	12.1	39.9	5.9	20.1	15.9	25.6	9.5	19.2	12.6	n.a.	n.a.
Other underground operations	n.a.	32.2	46.3	30.1	25.1	25.0	24.8	26.2	29.0	38.5	44.0	11.1	21.0
Total underground	n.a.	372.9	281.1	304.8	152.4	196.1	139.7	146.0	170.0	162.6	123.1	119.8	129.1
Surface operations	n.a.	74.2	83.1	71.0	40.4	51.7	31.1	21.7	34.4	45.0	36.4	37.7	44.4
Total production	n.a.	447.1	364.2	375.8	192.8	247.8	170.8	168.7	204.4	207.6	159.5	157.5	173.5
Engineers, foremen	n.a.	46.8	47.4	39.9	23.5	29.7	22.6	19.6	24.6	26.7	15.5	25.7	20.9
General, administrative, social	n.a.	79.4	58.7	76.9	16.2	25.9	19.8	12.1	11.9	18.7	4.2	5.1	3.2
Total mine personnel	n.a.	573.3	470.3	492.6	232.5	303.4	213.2	199.4	240.9	253.0	179.2	188.3	197.2
Total mine personnel (persons per 10^6 t raw coal)	991	2,392	1,905	2,086	1,046	1,349	885	860	1,033	1,131	895	788	690

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

Energy Requirements

The electricity requirements for a number of operating mines, as presented in Table 41, range from 10.7 to 76.1 kWh per tonne of raw coal produced. Expressed in kilowatt-hours per tonne of coal equivalent produced, the electricity requirements range from 10.3 to 104.5 kWh/tce, or between 0.4 and 4.3% of the energy produced, for a conversion efficiency from coal to electricity of 30%. The main electricity-consuming operations are the lifting of coal and stone, ventilation, and water pumping. Therefore, it is the mining depth that has the greatest effect on the quantity of electricity consumed, along with the degree of mechanization.

Fuel consumption at underground mines does not exceed 1% of the calorific value of the coal produced. It is mainly for heating air and water.

Material Requirements

The material requirements of the underground coal-mining process are relatively low, as only auxiliary materials are used. Nevertheless, a list of the materials consumed by the coal industry would include more than 2,000 items, excluding spare parts. Material requirements are also drastically changing in the course of technical advances with respect to both quantity and quality. Some geological factors, such as mining depth and seam thickness, also influence these requirements. Table 41 includes data on the material costs for a number of producing mines in the USSR with a wide range of geological and technological conditions, resulting in material costs ranging from 0.61 to 2.18 roubles (1977)* per tonne of raw coal produced.

The shares of some important items in the total cost of materials consumed may be summarized as follows (Kravchenko 1979): timber, 21–40%; explosives, 1–5%; spare parts, 7–19%; steel and ferroconcrete supports, 8–14%; steel supports, 1–14%; chains, etc., 3–11%; ventilation tubes, 3–4%; cables, 3–5%; workers' overalls, 8–10%; and other materials, 19–25%.

In terms of physical units, the most important materials are timber and metals for roof support. About 25 m^3 of timber and 1 t of rolled metals are consumed per 10^3 t of coal mined. The above-listed distribution of material costs and the requirements are representative of underground mines in the Donetsk basin exploiting flat or inclined coal seams (Kravchenko 1979).

Detailed data on the material requirements and costs of selected operating mines in the USSR are presented in Table 42.

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*Because of the difficulty of comparing cost estimates in currencies that are not freely convertible, cost data of USSR mines presented in this section have not been converted to the common US$(1975) values normally used throughout this report. Appendix D gives the proposed conversion rates.

TABLE 41 Energy requirements and material costs for operation of underground coal mines (excluding coal preparation) in the USSR.

	Donetsk basin						Karaganda basin				Pechora basin	Kuznetsk basin	
	Hypothetical	Abakumov	Krasnoarmeyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakhstanskaya	Gorbachov	Intinskaya	Karagaylinskaya	Inskaya No. 1
Electricity requirements (kWh/t raw coal)	76.1	29.8	57.7	29.7	19.5	21.3	17.5	28.3	14.4	29.9	10.7	23.3	29.9
Fuel requirements (tce/t raw coal)	0.003	0.005	0.009	0.001	0.001	0.002	0.003	0.002	0.003	0.002	0.006	0.012	0.012
Material costs (roubles (1977)/t raw coal)[a]	2.08[b]	2.18	1.35	1.38	0.91	1.28	0.86	1.01	1.27	1.08	0.88	0.61[c]	1.25[c]

[a] It is not possible to present a definitive conversion factor for currencies that are not freely convertible. In Appendix D an exchange rate of 1 US \$ = 0.7 rouble for 1975 is proposed. This corresponds roughly to the official exchange rate. In assuming 5% escalation per year, the conversion factor proposed is 1 rouble (1977) = 1.29 US \$(1975) or 1 US \$(1975) = 0.77 rouble (1977).

[b] Original data: 1.89 roubles (1975).

[c] Original data: 0.58 and 1.19 roubles (1976), respectively.

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

TABLE 42 Material requirements and costs[a] (per 10^3 t raw coal produced) for selected operating underground mines (excluding coal preparation) in the USSR.

	Timber		Explosives		Metal or ferro-concrete supports		Spare parts	Other materials	Total
	m^3	Roubles (1977)	kg	Roubles (1977)	Number	Roubles (1977)	Roubles (1977)	Roubles (1977)	Roubles (1977)
Donetsk basin									
Abakumov	30.2	857.7	58	26.7	6.4	204.8	162	929.2	2,180.4
Rossiya	13.6	450.3	152	50.2	3	84.5	120	676.3	1,381.3
50-Letiya Oktyabrya	5.6	210.0	136	50.3	n.a.	200.0	110	230.5	800.8
Karaganda basin									
Lenin	13.2	321.0	4.4	3.0	4.1	82.0	84	367.0	857.0
Kostenko	6.2	200.1	8.2	2.9	2.5	92.0	140	571.2	1,006.2
Kazakhstanskaya	13.6	408.0	58	23.2	n.a.	n.a.	90	753.6	1,274.8
Pechora basin									
Intinskaya	8.1	206.2	19	7.6	n.a.	80.0	130	455.2	879.0

[a] The conversion rate proposed is 1 rouble(1977) = 1.29 US \$(1975) (see first footnote to Table 41).

Sources: Academy of Sciences of the USSR (1979) and Coal Mines Data Base, IIASA.

Environmental Impacts

Land requirements and the impacts of mining activities on the area undermined are of a completely different character for underground mining compared with opencast mining. Land requirements are much higher than for opencast mines, because of the thinner coal seams mined. Table 43 presents data on land requirements for operating mines of major coal basins in the USSR. The total area leased for mining activities during the lifetime of a mine ranges from 4 to 32 m^2 per tonne of annual mine capacity. The surface area occupied by buildings, facilities, and waste rock piles usually lies within a range from around 0.1 to 1.2 m^2 per tonne of annual coal output. The actual surface areas undermined per tonne of raw coal produced are within a wide range, from 0.14 to 0.83 m^2, being highly influenced by the total thickness and the dip of the coal seams. However, the impacts of underground mining activities on the surface area are much less severe than for opencast mining activities. In many cases there are no surface impacts at all. In the other cases, where surface areas are affected (through subsidence), one cannot ignore these negative impacts, though they are less dramatic than those of opencast mining activities. The surface area affected by coal-mining operations is much smaller than the total area undermined. The scale of impacts, as well as the necessity and type of surface reclamation activities, depends on a number of factors, i.e. mining depth, thickness of coal seams, hardness of upper rock strata, and, finally, on the methods of roof control.

Removal of water and waste rock. The amounts of water and waste rock that have to be transported to the surface for disposal are important characteristics of a mine, imposed by the prevailing hydrology and geology at the individual mine. These amounts, in turn, greatly determine other resource requirements (and the economics of production) at a mine.

TABLE 43 Land requirements of underground mines in the USSR.

	Donetsk basin						Karaganda basin				Pechora basin
	Hypothetical	Abakumov	Krasnoarmeyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakhstanskaya	Gorbachov	Intinskaya
Area leased (m^2/t annual capacity (raw coal))	17	32	28	29	18.3	3.8	6.9	4.2	8.5	10.4	16.3
Area occupied by buildings (m^2/t annual capacity (raw coal))	0.07	0.7	1.2	0.9	0.5	0.9	0.5	0.7	0.2	0.6	0.4
Area undermined (m^2/t raw coal produced)	0.23	0.49	n.a.	0.83	0.47	0.16	0.32	0.57	0.24	0.61	0.14
Area disturbed (m^2/t raw coal produced)	0	0	0	0.83	0	0	0.32	n.a.	0.24	0	0

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

Water problems in underground mining are usually related to the disturbance of natural underground water flows and to the pumping of acidic mine water to the surface. Water withdrawn from some mines is less than 0.5 m^3/t raw coal produced, but in other mines it can reach 5–10 m^3 (or tonnes) per tonne of coal – for example, in the Podmoskovny (Moscow) coal basin. The pumped mine water, if of sufficient quality, constitutes a potential water supply for industrial or human needs. Acidic water is estimated to be no more than 7–10%, on average, of the total mine water pumped from mines of the USSR at present, but this share will increase as mining activities go to greater depths. Data from 1977 on water and waste rocks removed from a number of underground mines in the USSR are presented in Table 44.

Coal recovery factor. Coal left in safety pillars to prevent damage to buildings and other objects on the mine surface typically constitutes about 6% of the total workable coal reserves in the USSR, and is practically lost forever. This loss can only be slightly decreased in the future, since a substantial number of such pillars are required because the mine surface is occupied by industrial and civil buildings. In less densely populated areas the need for such pillars is less mandatory. Additional pillars are required for the protection of the mine workings. These pillars are typically responsible for the loss of about 9% of the total workable coal reserves. In principle, it is possible to reduce some of these losses if pillars are partially extracted after they are no longer required to protect mine workings (the total maintenance period of mine workings ranges from a few months to many years). Finally, there are additional operational losses of workable coal reserves related to seam thickness, tectonics, and other factors.

The total amount of coal recovered from the workable reserves varies from 60 to 86% for the USSR mines analyzed (i.e. coal losses are between 14 and 40%). In most mines the recovery rate is over 75%, significantly higher than the recovery rate of up to 60% achieved in room-and-pillar mines (e.g. in the USA).

Production Costs

The structure and level of production costs for underground mines are drastically different from those typical of opencast mines, because of geological and technical differences. At underground mines, coal is mined from rather thin seams, thus limiting the possibilities for using large face equipment. Furthermore, a large number of auxiliary operations are required to provide normal working conditions underground.

A rough comparison of the two mining methods for the USSR leads to the conclusion that the total production costs per tonne of coal at underground mines in the Donbass are five times higher than the average production costs at opencast mines. The main factors determining this difference can be described as follows. The ratio of the volume of excavated rocks to the coal output is 25 times lower for underground mines in the Donbass, but expenses per cubic meter of excavated rock are 20 times higher; thus the total cost of waste rock removal per tonne of coal produced is slightly lower for underground mines. However, coal face operations are much more expensive in underground mining. Finally, the most important factor that should be considered is the great number of auxiliary operations necessary for

TABLE 44 Water and waste rock removed at selected underground mines in the USSR.

	Donetsk basin						Karaganda basin				Pechora basin
	Hypo-thetical	Abakumov	Krasnoar-meyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakh-stanskaya	Gorbachov	Intinskaya
Water withdrawn (m^3/t raw coal)	1.53	2.02	0.72	4.03	0.99	2.18	0.55	0.68	0.39	0.62	1.37
Waste rock disposed of at surface (tonnes per tonne of raw coal)	0.39	0.32	0.16	0.47	n.a.	0.22	0.06	0.10	0.11	0.11	0.02

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

underground coal mining: transportation, haulage, ventilation, etc. The cost of these operations is an order of magnitude higher than for the opencast mining method.

It should be stressed that the comparisons made above are not based on considerations of similar bedding conditions for both technologies*. In fact the conditions are *very* different, which explains the fundamental structural differences of the two mining methods.

Table 45 shows the structure of production costs at selected operating underground mines in the USSR. The most important element is labor: underground coal mining is one of the most labor-intensive industrial activities. Thirty years ago labor costs accounted for two-thirds to three-quarters of the total production costs at underground mines in the USSR. Progress in technology and engineering has reduced labor requirements by substitution with equipment and materials. Nevertheless, labor costs currently still account for a little less than half of the total costs of coal mining and, including social expenses, account for about 50% of the total production costs.

Resource Requirements and Investment Costs for Construction

Data on *resource requirements* during the construction of a new mine are, of course, more difficult to obtain than similar figures for the operation period. Table 46 summarizes the resource requirements during the construction period for two planned underground mines in the Donetsk basin. The resource requirements during and for the construction process may be summarized as follows. About one man-shift is required per tonne of projected annual coal output. About half of the labor requirements are for miners and one-third for construction workers; the rest are for assembly workers. The order of magnitude of the materials consumed per 10^3 t of installed mine capacity is as follows: 80 m^3 of concrete and 35 m^3 of cement, 30–50 t of metals (excluding equipment), 30–50 m^3 of wood, and 160–300 m^3 of sand, gravel, and other construction materials. The material consumption is of course neither distributed uniformly in time (peak annual requirements are given in Table 46) nor distributed equally between the surface facilities and mine workings constructed.

Table 47 presents the results of a detailed data analysis of the distribution of materials included in the various installations (or funds) of a modern mine in the Donbass. The mine produces coal from three seams with an annual capacity of 750,000 t of raw coal. Access is through vertical shafts to a mining depth ranging from 530 to 690 m. Compared with the data presented in Table 46, the material requirements are more complete since they include not only construction materials but also the materials constituting the equipment (approximately 3.5 t/10^3 t installed annual capacity). However, one can observe a wide range in these material requirements for the construction of underground mines. The factors influencing this variation will be summarized in the subsequent discussions on the investment costs of underground mines in the USSR.

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*A more detailed discussion of production costs of underground and opencast mines in the USSR is presented by Astakhov and Onufriyev (1978).

TABLE 45 A breakdown of production costs for operating underground mines in the USSR (roubles (1977) per tonne of raw coal produced)[a].

	Donetsk basin					Karaganda basin				Pechora basin	Kuznetsk basin	
	Abakumov	Krasnoarmeyskaya Cap.	Rossiya	50-Letiya Oktyabrya	Gukovskaya	Lenin	Kostenko	Kazakhstanskaya	Gorbachov	Intinskaya	Karagaylinskaya[b]	Inskaya No. 1[b]
Materials	2.18	1.35	1.38	0.8	1.28	0.86	1.01	1.27	1.08	0.88	0.61	1.25
Electricity and fuels	0.64	0.97	0.45	0.37	0.53	0.43	0.6	0.38	0.56	0.29	0.29	0.72
Wages and salaries	7.1	5.52	6.37	3.2	4.4	3.06	3.13	3.41	3.71	4.52	2.87	2.87
Social funds	0.67	0.49	0.59	0.3	0.42	0.29	0.29	0.31	0.35	0.41	0.26	0.26
Other	0.81	1.07	0.92	1.17	1.18	0.96	0.89	0.64	1.24	0.5	0.51	1.39
Depreciation	3.04	4.92	3.35	1.97	2.77	2.21	2.47	2.9	2.57	1.32	1.59	1.24
Total production cost	14.44	14.32	13.06	7.81	10.58	7.81	8.39	8.91	9.51	7.92	6.13	7.73

[a] The conversion rate proposed is 1 rouble (1977) = 1.29 US $(1975) (see first footnote to Table 41).

[b] Original 1976 roubles escalated by 5% per year to 1977 roubles.

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

TABLE 46 Construction resource requirements and investment costs for two new underground mines in the Donbass, USSR.

	Zhdanovskaya Cap.		Hypothetical
	Total requirements during construction period (7 yr)	Peak annual requirements	Total requirements during construction period (80 months)
Manpower			
Average number of persons employed	–	1,970	n.a.
Number of man-shifts (10^3) including:	3,140.8	591.1	2,100
Miners	1,611.5	385.1	n.a.
Construction workers	1,156.1	257.6	n.a.
Equipment assembly workers	373.2	160.0	n.a.
Energy			
Steam (for heating and hot water) (t/hr)	–	13.8	n.a.
Materials			
Prefabricated concrete and ferroconcrete structures (10^3 m^3)	123.6	23.8	n.a.
Metal structures (10^3 t)	76.1	14.7	25.4
Concrete (10^3 m^3)	290.6	57.2	n.a.
Cement (10^3 t)	124.0	24	61.0
Wood (10^3 m^3)	117.0	22	94.5
Sand, gravel, etc. (10^3 m^3)	1,080.9	213.7	285.4
Metals (steel) for rails, pipes, etc. (10^3 t)	23.0	4.4	57.8
Water			
Water consumed (10^6 m^3)	0.86	0.13	n.a.
Land			
Land affected by construction (km^2)	0.23	–	n.a.
Investment costs			
Total (10^6 roubles (1977)) including:	130	n.a.	73
Shaft and mine workings	51.4	11.71	47
Surface facilities	36.9	7.42	7
Equipment and assembly	n.a.	n.a.	14
Other	n.a.	n.a.	5
Construction process			
Earth and spoil moved (10^6 m^3)	5.2	1.0	n.a.
Buildings and surface facilities (10^6 m^3)	0.4	–	0.1
Volume of mine workings driven (10^6 m^3)	0.55	n.a.	0.65
Characteristics of mine			
Annual projected raw coal output (10^6 t)	3.6		1.8
Number of seams to be mined	2		1
Average seam thickness (m)	0.6–1.3		1.2
Mining depth (m)	415		1,070
Number of production faces	5		n.a.

Sources: Astakhov (1977b), Academy of Sciences of the USSR (1979), and Coal Mines Data Base, IIASA.

TABLE 47 Materials in buildings, surface facilities, mine workings, and equipment at the Novopavlovskaya mine in the Donbass, USSR.

Material	Buildings	Surface facilities	Shafts	Underground workings	Equipment	Total
Concrete and ferroconcrete (10^3 m^3)	5.6	1.8	3.2	12	–	22.6
Bricks (10^6)	0.82	0.38	–	–	–	1.2
Sand, gravel, stone (10^3 m^3)	22.5	12.2	6.2	10.8	–	51.7
Asphalt, bitumen (t)	20.0	400.0	–	–	–	420.0
Wood, timber (10^3 m^3)	18.6	5.9	–	–	–	24.5
Rails (t)	–	156	344	741	–	1,241
Iron and steel used in small metal parts and sheets (t)	36	538	5.2	22.8	–	602
Iron and steel:						
in equipment (t)	–	–	–	–	2,596	2,596
in roof supports (t)	–	–	442	1,298	–	1,740
Pipes:						
Iron (t)	–	305	–	36	–	341
Steel (t)	30	64	62	130	–	286
Cement/ceramic (t)	4.5	–	–	–	–	4.5
Nonferrous metals (t):	0.7	6.7	9.2	19.7	–	36.3
Cables (t)	0.7	5.9	9.2	10.9	–	26.7
Wires (t)	–	0.8	–	8.8	–	9.6

Source: Academy of Sciences of the USSR (1979).

The specific *direct investment cost* for the construction period of a mine in the Donbass, built under conditions typical of those in the 1960s, has been estimated by Ivanov and Yevdokimov (1973) in the following terms:

$$i = 23.6 - 14.8/M + 29.8H/M \qquad (9)$$

where the specific investment cost i (roubles per tonne of annual installed mine capacity) is a function of the size of the mine, M (the annual mine capacity in 10^6 t), and the mining depth H (km). Evolution of the geological conditions and growing capital intensiveness have both contributed to considerably higher actual figures than would be calculated using (9).

A very widely used index in Soviet statistics is the specific cost of industrial buildings, related facilities, capital workings, and equipment. This index*, referred to as "industrial basic funds," can be considered as being somewhat analogous to specific direct investment costs in the USA. Data characterizing 1977 costs are presented in Table 48 for selected underground mines in operation in the USSR.

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*"Industrial basic funds" represent the book value of industrial buildings, facilities, and equipment in an industrial plant as they appear in the plant's balance sheets for purposes of amortization. The basic funds are often subdivided into "active basic funds" (equipment) and "passive basic funds" (buildings and facilities).

TABLE 48 Specific costs of industrial buildings, facilities, and equipment[a] at selected underground mines in the USSR (roubles (1977) per tonne of raw coal annual capacity).

	Donetsk basin			Karaganda basin		Pechora basin
	Abakumov	Krasnoarmeyskaya Cap.	50-Letiya Oktyabrya	Kostenko	Kazakhstanskaya	Intinskaya
Capital workings	21.2	41.9	7.8	13.6	17.9	4.9
including:						
Shafts	4.3	4.9	2.5	4.1	1.7	1.1
Buildings and facilities	6.0	5.3	2.4	3.6	2.7	3.2
Total equipment	11.1	12.3	5.6	6.1	4.4	3.5
including:						
Mechanical supports	1.9	1.6	0.9	0.6	0.5	0.6
Mining combines	0.5	0.7	0.1	0.4	0.3	0.2
Conveyors	2.8	1.6	1.9	2.4	0.8	0.8
Locomotives	–	–	–	0.2	–	–
Trolleys	0.4	0.4	0.2	0.1	0.1	0.2
Hoisting gear	0.9	0.9	0.6	0.6	0.5	0.3
Other	4.6	7.1	1.9	1.8	2.2	1.4
Total	38.3	59.5	15.8	23.3	25.0	11.6

[a] "Industrial basic funds."

Source: Academy of Sciences of the USSR (1979).

A statistical analysis performed on mines in the Donbass in 1969 gives some insight into the factors influencing the index mentioned (Astakhov and Moskvin 1969). The specific cost of buildings, facilities, capital workings, and equipment decreases by 2.5% if the seam thickness increases by 10%. It grows by 15% if the weight of a cubic meter of coal grows by 10%. As gas emissions increase by 10%, this direct investment cost index increases by 0.8%.

Alymov *et al.* (1972) suggest that this specific cost index for mines in operation in the Donbass can be described by

$$i = \frac{81.45\, H^{0.247}\, L^{0.357}\, e^{0.119}\, c^{0.143}}{p^{0.234}\, l^{0.259}\, v^{0.437}\, n^{0.215}\, a^{0.50}\, j^{0.163}} \tag{10}$$

where

i is the capital intensity (roubles (1970/71) per tonne of annual mine capacity);
H is the mining depth (m);
L is the total length of the main workings (m/10^3 t annual coal output);
e is the energy consumption per man-hour (kWh);
c is the ratio of waste rock to coal output (%);
p is the productivity of a coal bed (t/m^2);
l is the average length of a face (m);
v is the average rate of face advance (m/month);
n is the number of operating faces per 100 t daily coal output;
a is the share of the equipment cost in the total investment cost (i.e. the basic funds) (%);
j is the ratio of actual to projected mine output (%).

Equation (10) was prepared by the authors at the beginning of the 1970s. Again one can observe that this type of economic index, or any equation used to calculate it, is more quickly outdated by economic trends (i.e. the actual figures are considerably higher), even in a centrally planned economy, than are the physical indicators on which the economic calculations are based.

4.2.1.3 Underground Mines in Other Countries: Examples from France, Austria, and Australia

The WELMM study on resource requirements for coal mining was expanded to cover a number of underground mines in coal regions of the world other than the USA and USSR. Unfortunately, the choice of mines was determined not so much by the actual (or future) potential of coal mining in particular basins but rather by the availability of detailed WELMM data. However, the examples to be discussed in this section provide a first basis for understanding natural resource requirements and problems of coal-mining activities (even if they cannot be considered as "representative") in basins in Europe and Australia. Input data were prepared according to the same methodological approach as was used in the previous parts of Section 4. The data analyzed describe the French Lorraine basin; two Austrian mines working in typical, small Alpine lignite deposits; and an underground mine in the Sydney basin in Australia, a basin with considerable coal reserves and of importance for the world coal market.

The Lorraine basin, France. The Lorraine basin* is located at the French–German border in the French Moselle *département*, and forms a prolongation of the German Saar basin. The geology of the basin is quite complex, with tectonic faulting, methane emanation, extremely high water inflow, and relatively thin coal seams. The succession of flexures and the presence of faults result in a range of seam dipping from horizontal to vertical. A similar variety is encountered in the number, thickness, and density of the coal seams. In 1977, the average seam thickness mined was 2.35 m and the average mining depth was 760 m for the whole basin.

Coal production is currently about 10 million tonnes of clean coal per year. The cumulative past production (from 1830 to 1979) amounts to 600 million tonnes, and the remaining recoverable reserves are 240 million tonnes. Raw coal production amounts to 13.8 million tonnes per year. Therefore, about 28% of the weight of the raw coal is removed in the coal preparation process. The average ash content of clean coal is 13.4%. Higher calorific values of clean coal range from 33.5 to 35.6 MJ/kg.

In flat or slightly inclined seams (0–30°), longwall mining (advancing or retreating) is used either with caving or with pneumatic stowing to limit surface subsidence. In inclined and steep seams, hydraulic stowing is used exclusively. In 1977, 52% of production came from mechanized faces, the rest was mined using explosives.

The manpower requirements for coal mining and preparation amounted to 2,130 persons per million tonnes of clean coal produced in 1977, 60% being underground personnel. Underground productivity was 4.39 t per man-shift and that of the total mine (including coal preparation) was 2.66 t per man-shift in 1977.

The electricity requirements for pumping water from the mines alone are 28 kWh per tonne of clean coal produced, whereas the total electricity consumption is 99 kWh/t clean coal (40 kWh/t are consumed underground).

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*Data on the Lorraine basin were supplied mainly by Charbonnages de France (Lechevin 1979), additional data being derived from Coenillet (1980).

The energy requirements appear to be particularly high as a result of the great mining depth and extremely high water inflow (8.5 m^3/t) in the Lorraine basin. However, the overall energy efficiency of the coal-mining process, even under these extreme conditions, is still very high. For a total of 11.5 Mtce energy produced only 0.44 Mtce are autoconsumed to produce the necessary electricity for mining operations (i.e. 3.9% of the total coal production).

Equipment installed in the Lorraine basin for coal mining includes 35 single- or double-drum shearers, 60 selective cut-heading machines adapted to stoping, 6 continuous miners, and over 4,000 percussion, air, and rotary drills. The mining equipment and the additional roof support equipment installed amount to about 10,000 t (i.e. 1 kg per tonne of net annual production capacity). For underground transport, 175 locomotives, 7,000 cars, and 450 km of rails are in service, as well as 81 km of conveyor belts and 18 km of chain conveyors. Coal transportation at the faces is carried out by chain conveyors of a total length of 50 km.

The annual specific material consumption can be summarized as follows:

a. *Wood.* 0.0186 m^3 per tonne of clean coal produced.

b. *Sand.* At most faces (i.e. for 60% of total coal production) hydraulic stowing is used. For this purpose, sand produced in special quarries and schists from coal preparation (around 5% of total stowing material) are mixed with water and pumped underground. Each day 22,000 m^3 of sand and schists dispersed in 11,000 m^3 of water are transported underground. The water is then recovered and pumped out again. Total sand requirements are about $4 \cdot 10^6\,m^3$ per year or around 700 kg of sand per tonne of clean coal produced.

c. *Explosives.* 0.25 kg per tonne of clean coal produced.

d. *Metals.* In addition to the metals in the main equipment items (around 10,000 t), each year about 20,000 t of metals are consumed as roof support materials. The main items are metal sets and laggings (15,000 t/yr) and roof bolts (around 10^6/yr). Specific metal requirements estimated for the operational period are therefore of the order of 2 kg per tonne of clean coal produced.

The total land area directly occupied by surface installations and mine-related facilities (excluding power plants, rail lines, and villages occupied by mine employees) is 9.72 km^2, or about 1 m^2 per tonne of clean coal annual capacity.

The total undermined area in so-called "stabilized zones" (where exploitation finished more than five years ago) is 46.3 km^2. In "nonstabilized zones" (i.e. in which exploitation finished less than five years ago, which are currently being undermined, or which are envisaged for exploitation in the near future) the undermined area amounts to 38 km^2. The area affected by subsidence is approximately 80 km^2 in stabilized zones and around 60 km^2 in nonstabilized zones (i.e. 6 m^2 per tonne of coal annual capacity).

The water inflow to mines in the Lorraine basin is extremely high: about 8.5 m^3 per tonne of clean coal produced. It influences all natural resource requirements and cost indices of coal mining in the basin. One example, which has already been mentioned, is the influence on the energy requirements: 3.3 kWh are required for pumping one tonne (1 m^3) of water; thus 28 kWh are needed per tonne of clean coal produced, or nearly 30% of the total energy requirements.

The Trimmelkam and Schmitzberg–Hinterschlagen mines, Austria. Both mines are very similar in their deposits as well as the technologies used*. Annual output in both cases is currently 610,000 tonnes of raw coal. Two flat lignite seams at a maximum depth of 160–170 m are exploited in each mine by longwall mining. The average seam thickness is 1.7–2.2 m; the moisture content of the raw coal is 30–40%, and its average ash content is 14–24%. The calorific value of the raw coal produced is around 11.7 MJ/kg. Longwall mining with caving is used; transport operations are made by belt conveyors; access is provided by drifts.

The construction period of the Trimmelkam mine was four years. Electricity requirements during mine construction were 0.74 kWh per tonne of annual mine capacity installed**. Motor fuel requirements were 0.13 liter per tonne of annual capacity. Material requirements for construction included 14.7 t of steel and 58.8 m^3 of concrete per 10^3 t of installed capacity. The amount of waste rocks mined out during construction was 0.29 m^3 (approximately 0.65 t) per tonne of installed capacity. The operational WELMM requirements for both mines are summarized in Table 49.

Labor requirements are between 1,200 and 1,380 persons per million tonnes of raw coal produced annually. The corresponding labor productivities for the mines (excluding coal preparation) are 4.45 and 3.85 t per man-shift, respectively. Most of the energy requirements are for electricity (from two-thirds up to more than 90%); the electricity requirements range from 12.9 to 15.7 kWh/t raw coal produced. Material costs are between 36.2 and 48.9 AS(1980)/t raw coal produced, or between 1.6 and 2.2 US$(1975)***/t.

Environmental impacts per tonne of raw coal produced include a mine water discharge of up to 2 m^3, solid waste (from the mine and preparation plant) of up to 0.44 t, and an undermined surface area of around 0.41 m^2.

The Tahmoor mine, Australia. The Tahmoor mine† is located in the southwestern coalfield of the Sydney basin in New South Wales. Current coal reserves in the Sydney basin are estimated to amount to $23 \cdot 10^9$ t *in situ*. Production in the basin in 1979/80 was $41.2 \cdot 10^6$ t of clean coal per year, of which $21.9 \cdot 10^6$ t were exported (or 50% of the total coal exports of Australia) (Joint Coal Board 1980). The future potential for increasing coal production for export markets is considerable. The Tahmoor mine is projected to exploit around 100 million tonnes of medium coking coal reserves over a lifetime of 27 years. A flat coal seam 2 m thick is to be mined at the maximum depth of 460 m (average mining depth 410 m) with a recovery rate of 61%. Coking coal has a calorific value of 31.4 MJ/kg and a sulfur content of 0.35%; the ash content of washed coal is about 8%.

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*Data are based on questionnaires provided by the mining companies and on field trips.

**All construction data are based on 680,000 tonnes of raw coal annual capacity (projected).

***Conversion rates are given in Appendix D.

†Data are derived from Dames and Moore (1975) and a questionnaire completed by the mining company.

TABLE 49 Resource requirements for the operation of two Austrian underground mines.

Type of resource requirement	Trimmelkam mine	Schmitzberg–Hinterschlagen mine
Manpower		
(persons per 10^6 t raw coal)		
Manual, technical	489	1,188
Manual, nontechnical	508	
Nonmanual, technical	147	102
Nonmanual, nontechnical	52	90
Total	1,196	1,380
including:		
Underground	954	789
Coal preparation	91	n.a.
Energy		
(per tonne of raw coal)		
Electricity (kWh)	15.7	12.9
Motor fuel (l)	0.1	0.6
Other fuel (coal) (tce)	0	negl.
Materials		
(AS(1980)/t coal)[a]		
Wood	10.8	n.a.
Explosives	1.6	n.a.
Metals	7.1	6.0[b]
Spare parts	5.8	14.9[b]
Other	23.6	n.a.
Total	48.9	36.2[b]
Environmental aspects		
(per tonne of raw coal)		
Water inflow (m^3)	1.0	2.0
Water used in mine (m^3)	0.01	negl.
Solid waste from mine (t)	0.16	0.43
Solid waste from preparation plant (t)	0.09	0.01
Surface area undermined (m^2)	0.41	0.41
Production costs		
(AS(1980)/t raw coal)[a]		
Wages and salaries	219.9	240.2[c]
Social costs	74.0	52.9[c]
Depreciation	16.3	24.4[c]
Other costs	96.1	82.1[c]
Total	407.2	399.6[c]
Characteristics of mine		
Annual coal output:		
Raw coal (10^6 t)	0.614	0.61
Saleable coal (10^6 t)	0.56	n.a.
Number of seams mined	2	2
Average seam thickness (m)	1.7–2.2	2.1
Maximum mining depth (m)	160	170
Number of working days per year	251	250
Number of operating units	2	3

[a] Proposed exchange rate: 1 US \$(1975) = 22.54 AS(1980) (see Appendix D).

[b] Original 1978 data escalated by 17.7%.

[c] Original 1978 data escalated by 10.2%.

Source: Coal Mines Data Base, IIASA.

The projected mine capacity is 2.61 million tonnes of raw coal per year. Access is provided by two access shafts for workers and one inclined drift for coal haulage. The mining system to be used is the board-and-pillar system with continuous miners and shuttle cars. The mine is expected to operate for 230 days per year with 3 shifts (each of 7 hours) per day. The mine construction period is supposed to be 3.5 years; an additional 4 years will be required to reach anticipated full mine output. The specific resource requirements for the construction of the mine are presented in Table 50. Construction manpower requirements peak at 109 persons employed, mostly from contractors. The total weight of field materials required (timber, steel, concrete, etc.) amounts to approximately 38,000 t (i.e. 14.5 kg/t installed annual capacity). An additional 0.27 m^3 of stone has to be excavated per tonne of installed annual capacity. The specific investment costs for shafts, buildings, and surface facilities are 5.4 $A(1977) per tonne of raw coal capacity (or 5.6 US$(1975)/t)*. Total capital costs are 11.5 $A(1977) per tonne of raw coal capacity. The total land area leased for mining activities is 1.15 m^2/t, and the area temporarily occupied or affected by construction is 0.57 m^2/t (including 0.27 m^2 for buildings, facilities, and waste rock piles). (All values here are per tonne of raw coal annual capacity installed.)

TABLE 50 Specific resource requirements for the construction of an underground mine in the Sydney basin, Australia producing 2.6 million tonnes of raw coal per year.

Type of resource	Resource requirements (per 10^6 t raw coal annual capacity)
Peak annual manpower (persons):	
Manual, technical	9.6
Manual, nontechnical	28.4
Nonmanual, technical	2.3
Nonmanual, nontechnical	1.5
Total	41.8
Total manpower over construction period (man-years)	200 (approx.)
Construction materials (excluding equipment).	
Timber (m^3)	230
Steel (t)	958
Concrete (m^3)	5,364
Copper (t)	3.8
Excavated stone (m^3)	26,820
Investment costs:	
Shafts, buildings, and surface facilities (10^6 $A(1977))	5.4
Total capital costs	11.5

Source: Coal Mines Data Base, IIASA.

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*Appendix D gives the conversion rates used.

The estimated resource requirements for the operational period include 230.8 persons employed per million tonnes of raw coal produced, including 219.2 miners. The total specific manpower requirements can be further disaggregated into the following categories: nonmanual, technical, 7.7; nonmanual, nontechnical, 3.8; manual, technical, 46.2; and manual, nontechnical, 173.1 persons per million tonnes of raw coal produced. Based on the projected 230 working days per year, the labor productivity at the mine is estimated at 18.8 t of raw coal per man-shift, which is nearly twice as high as the 1979/80 average productivity at underground mines in New South Wales (9.8 t of raw coal per man-shift). Material requirements include 6.9 t of timber and 0.085 t of steel per 10^3 t of raw coal produced. The amount of solid waste produced is around 0.3 t per tonne of raw coal produced. The surface area affected by subsidence per year is not more than 0.077 m^2 per tonne of raw coal produced.

4.2.2 Statistical Analysis of Factors Influencing Natural Resource Requirements and Economics of Underground Mining

For an analysis of the resource requirements of underground coal mining, one first has to distinguish between the two different mining systems: room-and-pillar mining, predominantly used in the USA and Australia, and longwall mining, employed in Europe and the USSR. In this analysis, however, the main emphasis will be on longwall mines (excluding hydraulic mines, owing to the differences outlined in the structural analysis, Section 4.2.1). Unfortunately, the available data base for room-and-pillar mining is, at present, still insufficient to permit a detailed analysis; in addition, there is concern about data reliability, particularly of the estimates derived from a number of studies by the US Bureau of Mines, also mentioned earlier (Katell and Hemingway 1974a, b, Katell *et al*. 1976b).

The analysis of underground mines at the aggregate level of the mine can, of course, only take into consideration the complex relationships of geology and resource requirements in a simplified form. Many additional influences (tectonics, roof and floor conditions, etc.) are either unquantifiable or difficult to take into account at the aggregate level considered for the analysis (i.e. the underground mine, but excluding coal preparation). Therefore, the analysis will consider only a few main influencing factors (mining depth, seam thickness, mine size, water inflow, etc.) that are systematically available in the data base for all mines. The analysis is further complicated by the fact that many of the "independent" variables that should be taken into account are not really independent of each other. For example, tectonic faults, strata temperature, etc. are closely related to mining depth. On one hand, this alleviates the problem of simplification if, for instance, only the mining depth is taken into account. On the other hand, it attributes more importance to the influence of this particular (aggregate) variable than the variable has if considered alone. The direct influence in the case of the mining depth would be simply the influence of the transportation distances to the surface and of the ventilation requirements. A similar problem is represented in the actual data available for the analysis: very deep mines tend to exploit thinner seams, both factors implying, within a given economic context, that these mines also have generally higher capacities. In this respect, the data reflect nothing more than reality; only a limited range, or a certain combination, of the main deposit and technological characteristics corresponds to conditions in which mining is feasible for a given technology and economic environment.

Within the data sample available for analysis, a relationship can be observed between the maximum mining depth* and the average seam thickness mined, as well as with the mine output. The first relationship is represented by:

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*The maximum mining depth was taken as variable instead of the average mining depth because data on the former were more systematically available and therefore the number of observations for analysis of the natural resource requirements could be considerably increased. Similar analyses, as represented by eqns. (11) and (12) but with the ***average*** mining depth as variable, reveal the same type of relationship.

$$\begin{array}{lllr} & S_{\text{avg}} = 2.396 - 0.564 D_{\max} & & (11) \\ s & (0.517) \qquad\qquad (0.203) & & \end{array}$$

$n = 58$

$R_{D\max} = 0.35$

$R^2_{D\max} = 0.12$

where*

S_{avg} is the average seam thickness mined (m);
$D_{\max}$ is the maximum mining depth (km).

This relationship can be seen as a result of both the genesis of the deposit and the fact that very thick seams at greater depths (if such seams exist) prove difficult and costly to mine, and might not be considered as recoverable within given economic and technological conditions.

The relationship between maximum mining depth and the mine output variable is represented by:

$$\begin{array}{lllr} & O_{\text{raw}} = 1.45 + 2.35 D_{\max} & & (12) \\ s & (1.584) \qquad\qquad (0.621) & & \end{array}$$

$n = 58$

$R_{D\max} = 0.45$

$R^2_{D\max} = 0.20$

where

O_{raw} is the annual mine output (10^6 t raw coal per year).

This relationship reflects primarily the fact that coal at greater depths is more costly to produce. An effective way to offset these negative economic effects is to reduce the fixed costs per unit of output by developing high-output faces and high mine capacities with resulting economies of scale.

Of course, the fit of the available data by eqns. (11) and (12) is not very good, but it confirms earlier discussions in this report about the influence of natural conditions on the intensity of mining operations as well as on technological and organizational decisions, with the consequence that only a certain combination (or range of combinations) of deposit characteristics proves to be actually mineable.

Based on the consideration of the *linearity* of eqns. (11) and (12), any transformation of variables (e.g. in the form of residuals from (11) and (12)) to take into account this relationship between the geological and

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*The variable definitions, once presented, will not be repeated in the following equations and figures. They are summarized in Appendix B.1. Minimum and maximum values of the variables presented in the various equations and figures are summarized in Appendix B.2. Equation (3) gives the definitions of standard errors and multiple correlation coefficients.

technological variables will not affect* the statistical significance of their influence or the overall fit of the equation or the predicted values of any particular resource requirement variable studied by a *linear* regression model. Therefore, it is not possible to improve the fit of this model or the values predicted by using it with the original independent variables: in this case, maximum mining depth, average seam thickness, and mine output. This is an inherent feature of the stepwise linear regression model used for analysis and of the linearity of the relationship between the geological and technological variables in (11) and (12).

In view of the considerations above, the observed influence of some variables has therefore to be interpreted as being due partly to the available data base rather than as a completely accurate estimation of their relative importance or actual influence on the particular dependent variable studied. However, in the analysis presented the influence of the principal factors studied is important enough to justify an analysis even at an aggregate level.

Labor Requirements

The labor requirements of underground coal mining, which is one of the most labor-intensive industrial activities, could represent the most important obstacle to future increases in production from underground mines. The limited availability of qualified labor, problems of absenteeism, and the resulting research to achieve greater productivity by mechanization, or even complete substitution of underground personnel, are concerns for all coal-producing countries.

The issue whether the huge increases in coal output from underground mines that are projected in many global and national energy studies are feasible in the light of the labor requirements and resulting social or institutional problems has not received sufficient attention as yet. Because of the critical importance of certain skills (those of miners, for example), this analysis will first consider the underground personnel requirements and then the labor requirements for the whole mine. Supplementary statistical data on manpower requirements at a number of operating mines in various European countries (Bulgaria, France, the Federal Republic of Germany, Poland, and the United Kingdom) were available at IIASA and have been included in the analysis of the data contained in the CMDB.

The result of an analysis of *underground productivity* is presented here:

$$\begin{array}{lllllllll} & P_{\text{und}} = 5.24 & + & 0.46O_{\text{raw}} & - & 1.43D_{\max} & - & 0.36W & + & 0.67S_{\text{avg}} \\ s & \mathit{(1.03)} & & \mathit{(0.10)} & & \mathit{(0.61)} & & \mathit{(0.12)} & & \mathit{(0.32)} \end{array} \tag{13}$$

$$n = 43$$

$$R_{O\text{raw}} = 0.46,\ R_{O\text{raw},D\max} = 0.60,\ R_{O\text{raw},D\max,W} = 0.68,\ R_{O\text{raw},D\max,W,S\text{avg}} = 0.72$$

$$R^2_{O\text{raw}} = 0.21,\ R^2_{O\text{raw},D\max} = 0.36,\ R^2_{O\text{raw},D\max,W} = 0.47,\ R^2_{O\text{raw},D\max,W,S\text{avg}} = 0.52$$

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*This is contrary to the statistical analysis for opencast mines (Section 4.1.2). For opencast mines, because of the *nonlinearity* of the relationship between the overburden to coal ratio and the mine output variable the residuals from this relationship were also considered in order to verify whether the transformation of the mine output variable improved the fit of the *linear* regression models of the specific resource requirements.

where

P_{und} is the underground labor productivity (tonnes of raw (run-of-mine) coal per shift worked);
W is the water inflow (m^3 per tonne of raw coal produced).

Only mines exploiting flat or slightly inclined seams (up to 22.5°, or 25 gon) were considered for the analysis as represented by eqn. (13). For mines exploiting more steeply inclined seams, the productivity can be up to 30% lower than the value suggested by eqn. (13). The underground productivity was chosen as a dependent variable, instead of the specific underground labor requirements, because it is calculated using the number of shifts effectively worked underground (and thus includes overtime, for instance) and is therefore a more accurate measure.

One can conclude that the underground productivity increases with mine size and seam thickness, whereas it is negatively correlated with mining depth and water inflow. Of course, the effects of these variables are not unlimited: for instance, the technical possibilities of longwall mining are effective only at seam thicknesses of up to 5m; if the seam is even thicker the productivity decreases because of the necessity of working additional (production) slices. Therefore, the suggested linear regression model has to be interpreted only as representing the relationship within the given limited range of values*.

For an analysis of possible bottlenecks in the labor requirements of underground coal mining it is of course of interest to see how the productivity figures translate into the actual underground manpower requirements (mostly miners). The following equation presents the result for annual raw coal tonnage per person employed (only underground personnel are considered), in analogy with eqn. (13):

$$\begin{array}{lllllll} & O_{\text{MPund}} = 1.044 & + \; 0.205 S_{\text{avg}} & + \; 0.087 O_{\text{raw}} & - \; 0.364 D_{\max} & - \; 0.067 W & (14) \\ s & (0.223) & (0.069) & (0.022) & (0.134) & (0.026) & \end{array}$$

$n = 43$

$R_{S\text{avg}} = 0.45$, $R_{S\text{avg},O\text{raw}} = 0.60$, $R_{S\text{avg},O\text{raw},D\max} = 0.67$, $R_{S\text{avg},O\text{raw},D\max,W} = 0.73$

$R^2_{S\text{avg}} = 0.20$, $R^2_{S\text{avg},O\text{raw}} = 0.36$, $R^2_{S\text{avg},O\text{raw},D\max} = 0.45$, $R^2_{S\text{avg},O\text{raw},D\max,W} = 0.53$

where

O_{MPund} is the annual raw coal output per unit of underground personnel employed (10^3 t per year per person).

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*The reader is again referred to Appendix B.2, which presents the value ranges for the different variables included in the equations.

In summary, one can conclude that the underground labor productivity is determined to a large extent by the mine size, the average seam thickness mined, the maximum mining depth, and the water inflow. The overall approximation of the underground personnel productivity (tonnes produced per person employed) (or the reciprocal value: the specific underground labor requirements) is quite good, although the individual, independent variables have different degrees of influence.

Another conclusion, possibly the most important, is that the data on underground labor requirements from a variety of Western and Eastern European countries (including the USSR) are quite comparable, even at the aggregate level (longwall mining of flat or slightly inclined seams) considered for analysis. Finally, it appears that a particularly good possibility for compensating productivity losses caused by worsening geological conditions lies in the concentration of production in high-output mines, a historical trend that, in view of worsening mining conditions, is going to continue in the future at a significant rate. This is also indicated in Figure 17, which presents the total underground personnel requirements and the underground labor productivity as functions of the mine size.

For the analysis of the *total manpower requirements* for the mine (in terms of labor productivity as well as specific manpower requirements) only the reciprocal values of the specific manpower requirements were considered. The reason for this was that, after careful analysis of the available data, it appeared that (in contrast to data on underground productivity) the total mine productivity data were by no means calculated in a coherent form. This became especially clear when they were compared with the total number of personnel employed at a mine (or the specific manpower requirements): the available mine productivity data seem occasionally to exclude personnel for related services (social, health, etc.), a fact that can be attributed partly to different accounting methods in the various countries from which the data originate, though not entirely, because the same can also be observed in comparing the data from mines within the same country. Therefore, in view of the inconsistencies in the way the total mine productivity is calculated between different countries, and even between different mines in the same country, the total number of persons employed (including those in all related services but excluding coal preparation) and the indices derived from it were taken into account. The following equation presents the result for the annual raw coal tonnage per person employed (equivalent to eqn. (14), where only the underground personnel were considered):

$$\begin{array}{lllllll} & O_{\mathrm{MPtot}} = 0.467 & + & 0.077 O_{\mathrm{raw}} & + & 0.189 S_{\mathrm{avg}} & - & 0.069 W \\ s & (0.175) & & (0.015) & & (0.049) & & (0.021) \end{array} \tag{15}$$

$n = 43$

$R_{O\mathrm{raw}} = 0.54$, $R_{O\mathrm{raw},S\mathrm{avg}} = 0.67$, $R_{O\mathrm{raw},S\mathrm{avg},W} = 0.76$

$R^2_{O\mathrm{raw}} = 0.29$, $R^2_{O\mathrm{raw},S\mathrm{avg}} = 0.45$, $R^2_{O\mathrm{raw},S\mathrm{avg},W} = 0.57$

where

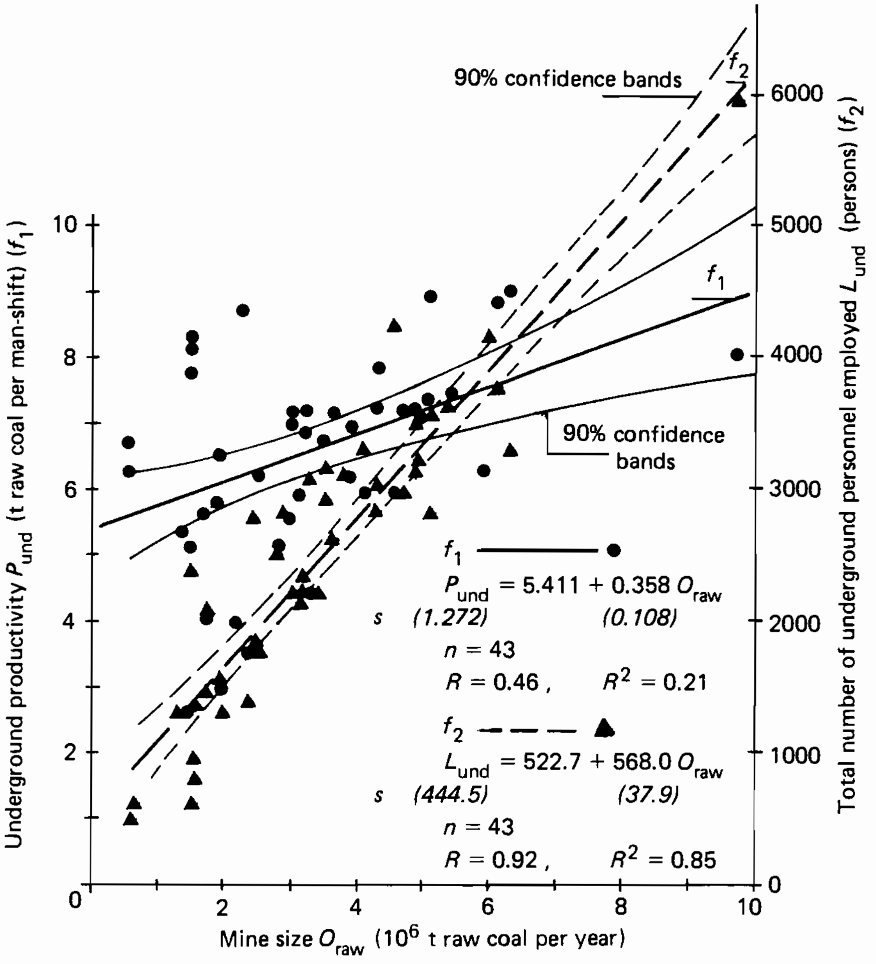

FIGURE 17 Underground productivity (f_1) and total number of underground personnel (f_2) as functions of mine size, for longwall mines exploiting flat or slightly inclined coal seams.
Source: Coal Mines Data Base, IIASA.

The confidence bands represent a probability of 0.9 that the true mean value of y_k *for any* x_k *considered lies within the indicated limits around the predicted value* $\hat{y}_k$. *This applies to all confidence bands in subsequent figures.*

O_{MPtot} is the annual raw coal output per unit of mine personnel employed (including social and other services but excluding coal preparation) (10^3 t per year per person).

The first observation on eqn. (15) is that the maximum mining depth did not pass the 90% significance test and appears not to be a significant influencing variable, as was the case for the underground manpower requirements. It appears that the influence of the mining depth on the underground manpower productivity (and requirements) is not important enough to have a significant effect on the totals for the whole mine. This phenomenon can be partly explained by the fact that mines operating at greater depths are usually more recently opened, with higher output and modern surface installations (and thus higher surface labor productivity), thus counterbalancing the adverse effects of mining depth on underground manpower productivity. Figure 18 shows the specific manpower requirements (the reciprocal of the dependent variable in eqn. (15)) and the total manpower employed plotted against mine size.

A preliminary analysis of the manpower requirements for room-and-pillar mines in the USA shows the same type of relationship as found for longwall mines: the specific manpower decreases with greater seam thickness mined and higher mine output. In fact, the economy of scale with respect to manpower requirements appears to be much stronger at room-and-pillar mines than at longwall mines; this is in addition to the much smaller labor requirements associated in general with room-and-pillar mining. Unfortunately, the available data base is not yet sufficient (or coherent enough) to suggest a particular reliable regression equation.

Electricity Requirements

The electricity requirements, as the most important energy requirements at longwall mines, are largely determined by the mining depth (electricity requirements for ventilation and for transport and lifting of materials), the degree of mechanization, and the extent of the mine workings, which in turn are closely related to the mine output; and by the water inflow (electricity requirements for water pumping). The influence of mining depth and mine output is so strong that the specific electricity requirements increase in a nonlinear fashion with these two factors.

Equation (16) presents the result of the analysis of the specific electricity requirements as a function of maximum mining depth and mine output:

$$\begin{array}{lllll} & \ln El_{\text{raw}} = 2.276 & + \; 1.226 D_{\max} & + \; 0.202 O_{\text{raw}} & \quad (16) \\ s & (0.426) & (0.384) & (0.108) & \end{array}$$

$$n = 21$$

$$R_{D\max} = 0.74, \quad R_{D\max, O\text{raw}} = 0.79$$

$$R^2_{D\max} = 0.54, \quad R^2_{D\max, O\text{raw}} = 0.62$$

where

El_{raw} represents the specific electricity requirements (excluding coal preparation) (kWh per tonne of raw coal produced).

No significant influence of the average seam thickness mined on the electricity requirements was found in the data sample available for analysis. The residual from the electricity requirements predicted from (16) was then further analyzed to include the water inflow (a linear type of relationship) too:

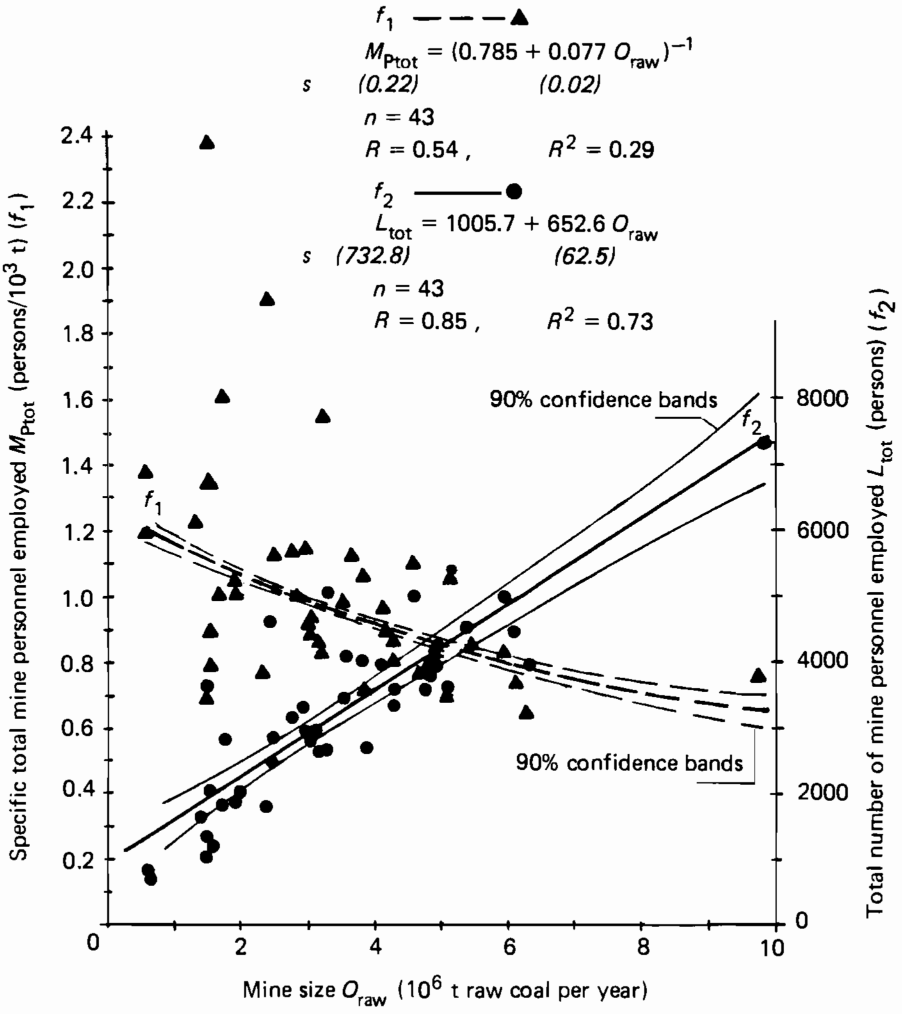

FIGURE 18 Specific manpower and total number of mine personnel employed (excluding coal preparation) plotted against mine size for longwall mines exploiting flat or slightly inclined coal seams.
Source: Coal Mines Data Base, IIASA.

$$\begin{array}{llllll} & El_{\text{raw}} & = -\ 4.626 & +\ 1.043 El_{\text{pred}} & +\ 3.615 W & \qquad (17) \\ s & (14.052) & & (0.198) & (1.637) & \end{array}$$

$n = 21$

$R_{El\,\text{pred}} = 0.79, \quad R_{El\,\text{pred}, W} = 0.84$

$R^2_{El\,\text{pred}} = 0.62, \quad R^2_{El\,\text{pred}, W} = 0.70$

where

El_{pred} is the value of the specific electricity requirements predicted from eqn. (16).

Substituting (16) into (17) yields:

$$El_{\mathrm{raw}} = -4.626 + 10.153 \exp(1.226 D_{\max} + 0.202 O_{\mathrm{raw}}) + 3.615 W \qquad (18)$$

The specific electricity requirements thus increase with water inflow, mining depth, and mine output*.

Similar analyses performed for all operating longwall mines in the USSR in 1976 (Astakhov 1977b) indicate that the increase of the specific electricity requirements with the mining depth is particularly important at mines exploiting thin seams (up to 1.5 m average thickness). In comparing the results from Astakhov (1977b) with the relationship obtained from eqns. (16) and (18) (shown in Figure 19), one can say that the result obtained is in good agreement with the empirical data from operating mines in the USSR for mines exploiting seam thicknesses over 2.2 m, or even over 1.5 m (square and triangle data plots, Figure 19). However, for mines exploiting thin seams, the values contained in the CMDB (including those from the USSR) are lower than suggested by the steep exponential curve based on an analysis of all operating longwall mines in the USSR. The difference may be attributed partly to the fact that no mine in the CMDB exploits seams thinner than 1.2 m, so that the interval for comparison of thin seams is not the same, and partly to differences in energy intensiveness when comparing a few modern mines with average indices for the whole coal-mining industry of a country. For a better overview, the data contained in the CMDB are plotted differently for the same seam thickness intervals as are used in the relationships from Astakhov (1977b). The electricity requirements predicted from eqn. (18) (including the influence of mine output and water inflow) are also plotted.

With respect to electricity requirements for water pumping, it should be mentioned that electricity consumption at hydraulic mines is considerably higher: up to 35 kWh/t more than at mines operating under similar conditions; the total electricity requirements at hydraulic mines can thus reach over 50 kWh/t.

Electricity requirements for room-and-pillar mining are considerably lower than for longwall mines, ranging from 13 to 21 kWh/t as compared with up to 87.3 kWh/t for longwall mines (values from the CMDB). This is mainly the result of very good mining conditions and high-capacity equipment characteristic of room-and-pillar mines.

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*This negative economy of scale can be explained by the fact that high-output underground mines require extensive underground workings to support the high output from a number of faces. Extensive workings result in additional energy requirements for ventilation and transport of materials, personnel, and coal. In addition, high-output mines are usually more recently opened with a higher degree of mechanization, resulting in higher specific energy (i.e. electricity) requirements and, more importantly, in higher labor productivity, as shown in the discussion of manpower requirements. Thus, in high-output mines labor is substituted by equipment, resulting in higher energy requirements.

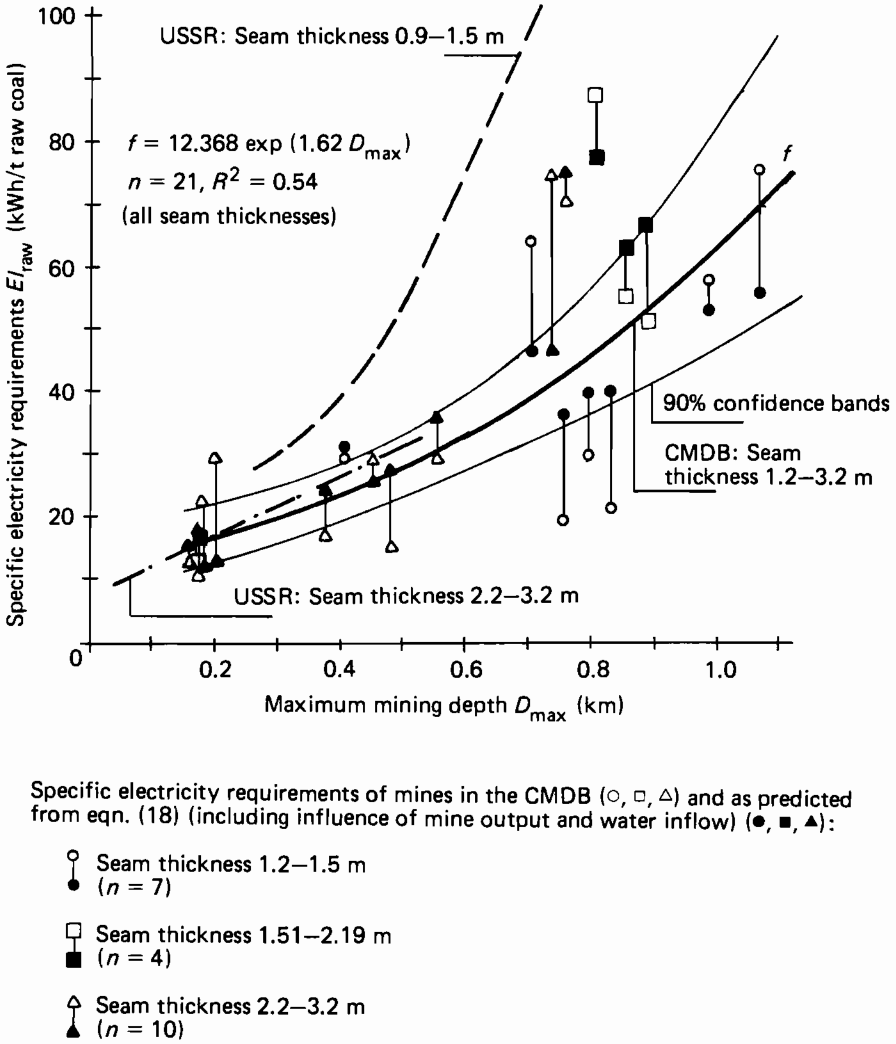

FIGURE 19 Specific electricity requirements as a function of mining depth for longwall mines in the Coal Mines Data Base, IIASA. For comparison, the same type of relationship is shown for longwall mines in the USSR (source: Astakhov 1977b).

Material Requirements

The large variety of materials consumed at underground mines makes it necessary to analyze the material requirements mainly in terms of cost. However, owing to the problem of comparing economic data, especially between centrally planned and market economies, as well as to the different accounting methods for material costs in different countries (for example, these costs sometimes include expenses for energy (motor fuel, etc.)), only data from longwall mines in the USSR were analyzed.

The most important factor influencing the material requirements was shown to be the average seam thickness mined. Figure 20 presents the result of the analysis and compares it with the same type of relationship obtained from an analysis of 1976 operating data on all longwall mines in the USSR (taken from Astakhov 1977b). As can be seen, the shapes of the two curves are nearly the same but the data contained in the CMDB are of a lower range (in addition to the one-year difference in base years): the reason for this is that the CMDB includes mainly recently opened or modernized mines, the indices of which are of course better than those obtained by considering all mines of a country. However, the fact that the analysis has shown a very similar trend, even on the basis of very few observations, can be considered a positive result.

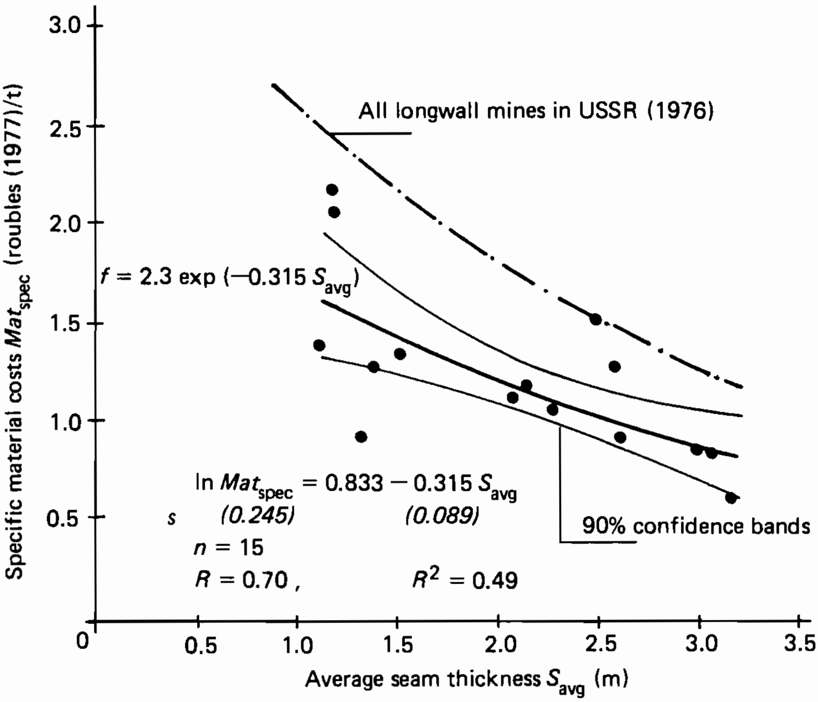

FIGURE 20 Relationship between the specific material costs and the average seam thickness mined for longwall mines in the USSR (plotted points are from the Coal Mines Data Base, IIASA), compared with the same type of relationship based on an analysis of all operating longwall mines in the USSR (source: Astakhov 1977b).

Another variable that affects specific material costs is the mining depth. The results shown in Figure 21 are again based on 1976 operating data for all longwall mines in the USSR. However, within the small data sample analyzed the mining depth (and mine output) did not pass the significance tests, and the results as presented in Figure 21 could not be compared with the data sample presently available. The data in the CMDB are difficult to compare with the values suggested by Figure 21 because of the difference between data from large modern mines and indices on all operating mines of a country, and because the depth of the mines in the CMDB is also far greater (as much as 1,070 m).

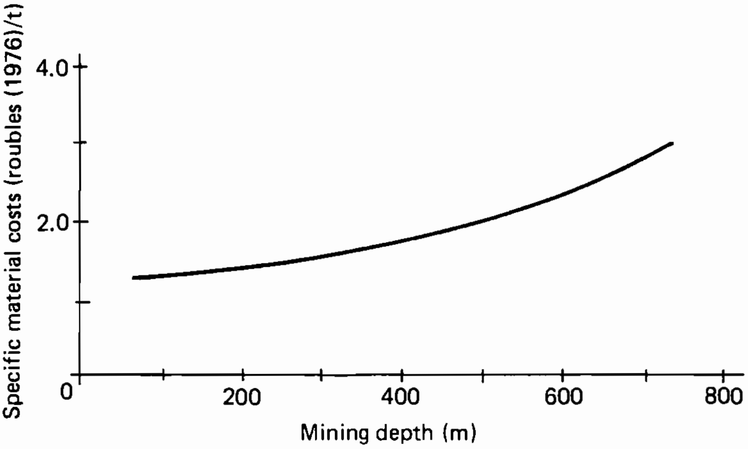

FIGURE 21 Relationship between the specific material costs and mining depth, based on an analysis of 1976 operating data for all longwall mines in the USSR.
Source: Astakhov (1977b).

Although the different material items can easily be aggregated when dealing in terms of cost, it would be more desirable to make a separate analysis for the most important materials, based on physical quantities. These can then more reasonably be compared between different countries. However, up to now, material requirements in physical terms are available only from the mines in the USSR, and even these only for a few items (wood, explosives, etc.) and not systematically. Therefore, a more detailed analysis of the material requirements would still require considerable effort in data collection.

Environmental Impacts

The environmental impacts of underground coal mining are primarily on the land required for mining and on the amount of waste rock produced that has to be disposed of at the surface.

The *direct land requirements* are limited to the areas for surface installations (such as shafts and coal preparation facilities). The surface area undermined (and thus the area that could be affected by subsidence) amounts, on average, to 0.4 m^2 per tonne of raw coal produced for the mines recorded in the CMDB. It depends very much on the total thickness of the coal seams mined, their angle of dip, and the density of coal *in situ*. The area undermined decreases when any of these factors increase. However, the character of the distortions of surface areas is quite different under different mining conditions.

The extent of surface subsidence, as well as the presence or absence of additional damage (faults), is highly dependent on the technology used for coal mining and on the engineering measures applied for roof control.

Room-and-pillar mines usually have less significant surface subsidence, especially compared with longwall mining, but this is counterbalanced by a considerable loss of coal reserves left in the pillars. Land disturbance by longwall mines is also generally not very serious, because if the entire roof is allowed to collapse there is usually a relatively uniform and smooth subsidence of the surface area. Nevertheless the characteristics of this subsidence, as well as depending on the thickness of the coal seam, depend highly on the geology of the overlying rock strata, and in consequence it is difficult to perform a numerical analysis of their influence. Still one can conclude that the effects of surface subsidence are more serious at mines exploiting thick coal seams at shallow depths.

The *amount of waste rock produced* has a direct effect on the energy consumption, the land areas required for waste rock piles, and on the cost of coal production in general. In its turn, the amount of waste rock mined out per tonne of coal produced depends on the average seam thickness mined; on the presence of rocks being mined out together with coal; on the physical properties of the rock strata surrounding the coal seam; and, finally, on the extent of development workings underground (which is closely related to the mining depth and the mine size). The analysis was performed on the data from the CMDB and included additional statistical data from other Western and Eastern European countries available at IIASA.

$$\begin{array}{llcccc} & Mat_{\mathrm{W}} = & 0.317 & + \; 0.160D_{\max} & + \; 0.027O_{\mathrm{raw}} & - \; 0.098S_{\mathrm{avg}} \\ s & & (0.123) & (0.074) & (0.011) & (0.045) \end{array} \qquad (19)$$

$n = 45$

$R_{D\max} = 0.59, \; R_{D\max,O\mathrm{raw}} = 0.63, \; R_{D\max,O\mathrm{raw},S\mathrm{avg}} = 0.68$

$R^2_{D\max} = 0.35, \; R^2_{D\max,O\mathrm{raw}} = 0.40, \; R^2_{D\max,O\mathrm{raw},S\mathrm{avg}} = 0.46$

where

Mat_{W} is the amount of waste rock produced (tonnes per tonne of raw coal mined).

The amount of waste rock produced thus decreases with an increase in the average seam thickness mined and rises with the extent of underground workings as reflected in the mining depth and mine size* variables.

The total amount of waste material produced from underground mines is considerably higher if waste material from the coal preparation facility is also included. The total amount of waste material can thus reach over 1.5 t per tonne of clean coal produced, which can present a considerable problem

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*The linear type of relationship between *specific* waste rock production and mine size, as presented in (19), means that the *total* amount of waste rock produced increases exponentially with the mine size.

of material handling and disposal.

As a final observation on the analyses performed on underground mines, we would like to emphasize again that any interpretation of the results should take into account the limited availability of data and the fact that the coal-mining process was dealt with at an aggregate level. The problem in using average indices to characterize an underground mine and its resource requirements is that the indices describe an aggregate of a number of production units, each of which can operate under quite diverse conditions. A solution may be to use systematically weighted averages (however, these are generally not available and would have to be calculated using more detailed data on each production unit) or to disaggregate the mining process further to the level of the production unit and to perform an analysis on that level. The results could thus be improved, in the view of the authors.

In connection with the problem of data availability, a prior objective for future work should be data completeness (at least for the most important variables discussed in this section), rather than a further increase in the amount of information stored per mine. The desire for disaggregation into production units does not necessarily contradict this objective, as only a few main parameters would be required and the remaining data base content could be reduced by concentrating on the main parameters discussed in this section.

Despite the relatively small and inhomogeneous data sample available for analysis, the influence of the principal geological and technological parameters on the resource requirements of the underground mining process, which was discussed in general in Section 3, was confirmed and could be ***quantified*** through the analyses performed. The results can be considered as quite satisfactory, especially since the relationships obtained are in good agreement with similar types of functional relationships based on an independent analysis of all operating mines of a country (in this case, the USSR) and thus on a much larger data sample.

4.3 HYDRAULIC UNDERGROUND MINING: EXAMPLES FROM THE USSR

Coal is mined by the hydraulic method in the USSR in two major coal basins: in the Kuzbass and, to a lesser extent, in the Donbass. About 10 million tonnes of coal were produced in 1977 from 10 underground hydraulic mines, the biggest of which is the Yubileynaya No. 2 mine in the Kuzbass, with an annual coal output reaching 3.6 million tonnes.

At present coal is mined by the hydraulic method under geological conditions that can be considered as slightly better than those typically prevailing in other mines of the Kuzbass and Donbass. A variety of coal-breaking methods have been used, including pure hydraulic, mechanical–hydraulic, and hydraulic combined with blasting. The general characteristics of hydromines in the Donbass and Kuzbass are summarized in Table 51. The subsequent WELMM analysis will be carried out for two hydromines operating in the Kuzbass, and compared with two mines that use conventional mining technology operating under similar conditions. The geological and technological characteristics of the mines under discussion are summarized in Table 52. The mines operate generally at a smaller depth and work thicker seams than average in the Kuzbass. The average coal output is also higher than average for the basin.

TABLE 51 General data on coal output by the hydraulic method in the Donbass and Kuzbass in 1976.

	Donbass	Kuzbass
Average daily output per mine (10^3 t)	3.2	7.4
Distribution of output by coal-breaking method (%):		
Hydraulic	46	33
Mechanical–hydraulic	48	62
Blasting–hydraulic	6	5
Average daily output per coal face (t)	520	700

Source: Astakhov (1977b).

The specific resource requirements and costs at hydromines are, in general, significantly lower than at conventional underground mines, because the hydraulic method requires less labor and material inputs – which are the most important in the overall requirements of the coal-mining process.

Labor Requirements

Labor requirements for the two hydraulic mines under consideration are between 33 and 56% lower than for mines with conventional underground technology operating under similar conditions. The main savings in labor requirements are usually achieved at coal faces (Table 53). One interesting point is that labor productivity achieved at the Yubileynaya No. 2 hydromine is comparable with the productivity typical for opencast mines in the Kuzbass. In 1977, labor productivity at the Yubileynaya No. 2 mine reached 254 t per month per worker (on books), compared with 384 t at the opencast mine

TABLE 52 Basic geological and technical characteristics of hydraulic and conventional underground mines in the Kuzbass in 1976.

Main characteristics	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zaryechnaya (hydraulic)	Inskaya No. 1 (conventional)
Mining depth (m)	200	175	228	200
Bedding of coal seams	Slightly inclined		Slightly inclined	
Thickness of seams (m)	0.8–4.0	0.9–4.3	1.6–4.0	0.8–4.1
Average thickness (m)	2.1	3.2	2.2	2.6
Number of seams to be mined	6	2	2	6
Annual raw coal output (10^6 t)	3.58	1.56	0.86	1.47
Total length of maintained workings, per 10^6 t annual coal output (km)	28.9	28.4	29.1	25.0

Source: Academy of Sciences of the USSR (1979).

with the highest labor productivity, located in the same basin. Of course, one should bear in mind that, owing to the more complex bedding conditions at opencast mines in the Kuzbass, labor productivity is lower than at opencast mines in the Kansk–Achinsk or Ekibastuz basin. Labor productivity at hydromines in the Kuzbass has reached a level comparable with that of opencast mines in recent years only. The rate of increase in productivity has been significantly higher in hydromines than in conventional underground or opencast mines.

TABLE 53 Comparative data on labor requirements of hydraulic and conventional underground mines in the Kuzbass in 1976 (man-shifts per 10^3 t coal produced).

	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zaryechnaya (hydraulic)	Inskaya No. 1 (conventional)
Total	85.7	188.3	131.2	197.2
Coal faces	42.1	85.0	28.0	89.1
Transport and lifting of coal and rocks	8.1	16.9	29.6	11.4
Maintenance and repair of equipment	2.3	6.8	6.4	7.6
Surface operations	13.5	37.7	39.2	44.4

Source: Academy of Sciences of the USSR (1979).

Electricity Requirements

Electricity requirements at hydraulic mines, as presented in Table 54, are considerably higher than at conventional underground mines operating in similar conditions. The main reasons are the electricity consumption of the hydraulic monitors and the larger amounts that have to be lifted to the surface (coal-and-water slurry, as opposed to coal alone at conventional underground mines). However, the total primary energy* consumed for the coal-mining process is only 1.5–3% of the energy produced in the case of the two hydromines analyzed.

Material Requirements

Material requirements of hydraulic mines, when compared with conventional mines, show a different picture (Table 54). The cost of materials used per tonne of coal mined is significantly lower at hydromines; in particular, the timber requirements are lower. In addition, the equipment requirements at hydromines are significantly reduced, both in weight and in terms of their specific costs.

TABLE 54 Energy and material requirements for hydraulic and conventional underground mines in the Kuzbass in 1976.

	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zaryechnaya (hydraulic)	Inskaya No. 1 (conventional)
Energy requirements:				
Electricity (kWh/t)	45.8	23.3	51.9	29.9
Other fuel (tonnes fuel/tonne coal)	–	0.01	0.01	0.01
Material requirements:				
Wood ($m^3/10^3$ t)	2.7	10.3	1.7	7.2
Explosives ($kg/10^3$ t)	12.7	n.a.	–	n.a.
Spare parts (roubles (1976)/t)	0.14	0.04	0.16	0.19
Total cost of materials (roubles (1976)/t)	0.41	0.58	0.58	1.19

Source: Academy of Sciences of the USSR (1979).

Table 55 presents comparative data on the weights and costs of equipment in operation at hydraulic and conventional underground mines in the Kuzbass. The specific weights of the equipment installed at hydraulic mines, and thus the steel requirements, are about half of those at conventional underground mines working under similar conditions; the same applies to the specific costs of the installed equipment.

Environmental Impacts

Environmental impacts of hydraulic mining (Table 56) do not differ significantly from those of conventional underground mining. Additional environmental impacts of hydraulic mining are due to the high water consumption. The wastewater remaining after separation of the coal from the coal–water slurry is polluted by fines. Cleaning of the wastewater is a necessary precondition for recycling to reduce the water requirements. Additional land areas at the surface are required for treatment of water in cleaning ponds. Finally, greater losses of the workable reserves *in situ* are associated with hydraulic mining. These operational losses can be up to 30% of the coal

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*Assuming that electricity is produced from coal with 30% conversion efficiency.

TABLE 55 Specific weights and costs of equipment used at hydraulic and conventional underground mines in the Kuzbass in 1976.

Mining operations	Weight of equipment (kg/t annual coal output)			Cost of equipment (roubles (1976)/t annual coal output)		
	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zyryanovskaya (conventional)	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zyryanovskaya (conventional)
Face operations	0.69	1.87	1.49	0.68	1.65	1.24
Driving of workings	0.06	0.20	0.35	0.07	0.15	0.31
Transport operations	0.16	0.42	0.58	0.20	0.22	0.42
Lifting	0.29	0.55	0.34	0.36	0.48	0.28
Other operations and services	0.21	0.69	0.85	0.18	0.58	0.70
Subtotal	1.41	3.73	3.61	1.49	3.08	2.95
Rails	0.31	0.55	0.23	–	–	–
Pipes	0.54	0.25	0.25	–	–	–
Total	2.26	4.53	4.09	–	–	–

Source: Academy of Sciences of the USSR (1979).

reserves *in situ* (and sometimes even higher), compared with operational coal losses of around 17% that are typical of conventional underground mines under similar conditions. However, there is potential for further reduction of these losses as more experience is gained with hydraulic mining. An indicator of this is that, in the USSR, the rate of reduction of coal losses has been higher in hydraulic mines than in conventional underground mines and this trend is continuing.

TABLE 56 Selected environmental impacts of hydraulic mines in the Kuzbass in 1976.

	Yubileynaya No. 2	Zaryechnaya
Total land area leased per tonne of annual coal output (m^2)	0.25	0.87
including: Land occupied by buildings, surface facilities, and roads (m^2)	0.04	0.15
Operational losses of coal reserves *in situ* (%)	20	25
Waste rock produced (tonnes per tonne of coal):		
From the mine	0.14	0.06
From coal preparation	0.08	0.05

Source: Academy of Sciences of the USSR (1979).

Operating Costs

Cost comparisons for operating hydraulic and conventional underground mines in the Kuzbass are presented in Table 57. The production costs are significantly lower at the hydromines considered. The main cost-reducing factors are the lower labor and material requirements. However, these few examples are indicative only and can hardly be generalized as a comparison of the different mining methods as a whole.

Construction Requirements

Some data related to the construction requirements for hydraulic and conventional underground mines are presented in Table 58. In the mines considered, the construction resource requirements are up to 50% lower for hydraulic mines than for conventional underground mines in the same area, thus confirming the comparative advantage of hydraulic mines over conventional underground mines operating in the Kuzbass.

TABLE 57 Coal production costs[a] at selected hydraulic and conventional underground mines in the Kuzbass (roubles (1976) per tonne of coal produced).

	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zaryechnaya (hydraulic)	Inskaya No. 1 (conventional)
Materials	0.41	0.58	0.58	1.19
Fuel	–	0.06	0.05	0.14
Electricity	0.32	0.22	0.61	0.55
Wages and social insurance	1.27	2.98	1.77	2.98
Total depreciation	0.85	1.51	1.60	1.18
including:				
Buildings, facilities, and workshops	0.46	0.48	0.85	0.28
Equipment	0.39	1.03	0.75	0.9
Other costs	0.53	0.49	0.29	1.32
Total production cost	3.38	5.84	4.90	7.36

[a] Assuming 5% escalation per year and the proposed exchange rate of 1 US$ = 0.7 rouble in 1975, the conversion factor proposed is: 1 rouble (1976) = 1.36 US$(1975) or 1 US$(1975) = 0.735 rouble (1976).

Sources: Academy of Sciences of the USSR (1979) and Coal Mines Data Base, IIASA.

TABLE 58 Requirements for the construction of selected hydraulic and conventional underground mines in the Kuzbass.

	Yubileynaya No. 2 (hydraulic)	Karagaylinskaya (conventional)	Zaryechnaya (hydraulic)	Inskaya No. 1 (conventional)
Total direct investment[a] (roubles (1976)[b] per tonne of annual mine capacity)	9.1	15.4	9.4	17.2
including:				
Industrial buildings and facilities	4.7	4.5	2.2	5.9
Workings	2.6	5.8	1.9	4.9
Equipment	1.8	5.1	5.3	6.4
Volume of buildings and facilities erected during mine construction (m^3 per 10^3 t annual mine capacity)	25.4	n.a.	36.4	n.a.

[a] "Industrial basic funds" (see footnote to Table 48 and footnote on p. 110).

[b] Conversion rate proposed: 1 rouble (1976) = 1.36 US$(1975), or 1 US$(1975) = 0.735 rouble (1976) (see footnote to Table 57).

Source: Academy of Sciences of the USSR (1979).

5 CONCLUSIONS

Although coal resources (and coal reserves) are large on a world scale, their relative availability at the national or regional level is constrained by the effects of resource depletion as well as by the growing impacts (economic, environmental, social, etc.) of resource extraction operations. Some experts (e.g. Fettweis 1979) consider that, in view of these constraints, and in the absence of a uniformly implemented international classification system for coal resources, the general enthusiasm about the relative abundance of coal resources and reserves might be far too optimistic.

Concern about the relationships between energy resources and other natural and human resources that have to be mobilized and/or are affected by the production (and subsequent conversion) of energy resources led to the development of the WELMM approach. The first objective of this report was therefore to discuss and to analyze the resource extraction process in general, through an application of the WELMM approach to coal mining.

A first conclusion from this exercise concerns the relative advantage of using WELMM-type, physical indicators over economic ones. These advantages may be summarized as follows. First, physical indicators represent more directly the influences of particular mining technologies and deposit characteristics on the mining process and the impacts of this process on the environment (in the broad sense of the word), since the indicators are geologically and technologically oriented and not affected by changing exogenous economic variables (e.g. interest rates). Second, in a broader (systems) context physical indicators provide a much wider description of the requirements and impacts of resource extraction operations, which constitute possible constraints for the future development of energy or mineral resources. Finally, economic data are (normally) derived from underlying physical quantities and can therefore always be recalculated relatively simply, if required, for any given economic context. These features are especially important for an analysis of the long-term perspectives of resource extraction industries, where economic data tend to be particularly unreliable. This conclusion is in fact confirmed by a long history of use of certain physical indicators, such as labor productivity or energy intensity, inside the coal-mining and other resource extraction industries, and if their use is systematized, as has been done in this study, this leads to a better comparability and broader description, although the task of comparison may become more complex.

The need for a deeper analysis and understanding of the resource extraction process, as well as the resulting data requirements, has not been sufficiently recognized up to now. Consequently, the modeling of coal (and other) mining activities (apart from a few (country-)specific exceptions) has been unsatisfactory until now. The difficulty in obtaining the necessary reliable and consistent data for this study demonstrates the necessity for establishing and standardizing data systems to support long-term analysis of resource extraction, based on physical indicators. The structure and implementation of the Coal Mines Data Base developed within this study could provide a good basis for this task of enriching and enlarging the data system by (and, equally, *for*) national studies. This is, of course, a longer-term process. However, experience in design and implementation of the CMDB has shown that the development of such a system, as well as the collection and updating of the required data, is feasible even with limited resources (as is the case at IIASA).

This in turn leads to conclusions about the actual contents of the CMDB: certainly the analysis has confirmed the *a priori* concern about highly aggregated values (for instance, on a sectoral basis). Information to be included in an information system like the CMDB has to be at the level of individual mines, or ultimately at the level of individual production units in order to avoid possible biases in the analysis stemming from the use of average indices for the mining operation as a whole. The information has to be specified for the various technologies and also for regions with different socioeconomic systems. In view of this, the number of mines included in the CMDB should still be considered as inadequate, particularly since some technologies are represented in too few examples to permit further analysis, e.g. opencast mining in the USSR or underground room-and-pillar mining in the USA, not to mention the lack of data on mines in developing countries (including small-scale mining). However, it is the construction process for which more data should first be made available, although experience throughout this study has shown the difficulties of obtaining such data. Direct contact with industries engaged in the design and construction of mines and manufacture of equipment could be a solution. Additional improvement could be made by considering the evolution of construction requirements in time.

With respect to data quality, experience within this study has shown that the most reliable data can be derived from the answers supplied directly by industry* on operating mines or detailed project data (although the indices derived from (a few) modern mines may not always be representative of the average situation for the whole of the basin where these mines are located). Next in quality are the data used within detailed micromodels to simulate resource impacts and economics of coal-mining operations (as was the (rather unique and positive) case for the models developed by Fluor Utah Inc. for opencast mining in the USA). Estimates from "literature" sources (e.g. in the form of Environmental Impact Statements, obligatory in the USA) or data from purely econometric studies performed to estimate production costs, without taking detailed account of technological and deposit characteristics (this applies particularly to a large number of studies published in the USA), can be considered only as rough estimates (if at all) and not as adequate data sources permitting one to consider in detail the impacts of resource extraction operations.

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* In this context the authors would again like to express their sincerest thanks and appreciation to the companies and mining research institutes that supplied data and answers to the detailed questionnaire.

Analysis has shown that resource requirements and impacts of coal-mining activities (and this is equally true for other energy or mineral resources) are highly differentiated according to the technology employed and the geology of the available deposits. Therefore, these requirements and impacts have to be estimated separately for the basically different mining technology classes. The influence of the deposit geology can then be estimated for each of these classes by further statistical analysis. Of course, one cannot deal with each individual mining technology in the same degree of detail, nor does this appear desirable for the purposes of long-term analysis; consequently, one will have to exclude specialized technology systems (e.g. mountain-top removal mining). In concentrating on the basic types of technologies employed, a sufficient number of mines should be analyzed inside each class of technologies in order to differentiate between the various coal regions (or even basins, if the differences in geology are significant) and especially between countries with different socioeconomic structures and systems.

Regression analysis, as used in this study, permits the determination of the influence of major geological factors on the impacts of mining operations and thus provides a good tool for assessing the effects of long-term resource depletion. The results obtained are nevertheless affected by an inevitable range of uncertainty. This is due, first, to the relatively small amount of data available for analysis (and, in consequence, the difficulty of systematically analyzing the different technologies separately) and, second, to the fact that the mining process, for reasons of data availability and simplicity, was dealt with as an aggregation of individual subprocesses employed at a mine. This approach, however, appears justified in view of the information generally available on the reserves and/or part of the resource base, allowing only an aggregated model (i.e. not at the level of a detailed engineering study for a given mine deposit) to be used in a long-term perspective. The interpretation of the results, as well as direct comparisons between mines in different countries, should always consider the significant differences in the geology of the deposits mined, in the socioeconomic conditions, and sometimes in the statistical definitions and practice.

With respect to the uncertainty in the results, one should note that the results reflect the available data base, where only selected coal mines are recorded whose indices are not necessarily the same as the average for all mines in the same basin or even the average for all mines of a country. Yet the functional relationships obtained are in good agreement with similar types of published results (where these were available) that are based on much larger data samples and thus reflect more accurately the situation of the whole coal industry of a country.

In extrapolating the relationships presented in this report in order to describe the resource impacts of extractive industries in the future, one ought to bear in mind that this can only be done if it is assumed that there will be no drastic changes in technologies (e.g. a technological breakthrough in underground coal gasification) and socioeconomic conditions (this first of all concerns cost data). In this respect the authors would like to emphasize again earlier statements about assumptions of linearity in the functional relationships described, and about the intervals within which these linear functions can be considered as reasonably good approximations, beyond which no extrapolation should be attempted (this applies equally to other types of relationships presented).

With these precautions in mind, the authors take a modest attitude toward the first results presented here, which were achieved as a consequence of the limits imposed by a relatively small and inhomogeneous data base, but consider the results interesting and the approach worth while, especially since, as far as they know, the approach taken is the first of its type in comparing resource requirements and economics of coal mines in different countries and under such a broad spectrum of geological conditions. Therefore, the results are presented in the hope that this study will create interest and stimulate further research, leading to an enlargement of the data base and to an improvement of these first results.

The data and the present results of the structural analysis of the coal-mining process are considered as a direct input to gaining a better understanding of the implications of long-term energy options, which, in most cases, rely heavily on coal as the most important fossil energy resource (e.g. the WOCOL study or the scenarios developed within IIASA's Energy Systems Program). For certain areas of the study (e.g. labor requirements, land impacts of opencast mining, or energy intensiveness of extractive industries) the results are considered sufficiently reliable to be applied directly in a (high-level) long-term model. Furthermore, the approach taken and the tools developed may also be applied to other types of energy or mineral resource extraction. Thus better understanding and modeling of long-term impacts and possible constraints of resource extraction operations can be achieved.

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APPENDIX A STRUCTURE AND CONTENTS OF THE COAL MINES DATA BASE

APPENDIX A.1 QUESTIONNAIRE, PART ONE: GENERAL CHARACTERISTICS OF A MINE

Computerized version used as input files for interactive data entry program.

DATABASE NAME: welmm
RELATION NAME: ominesa
FILE FUNCTION: append

QUESTION TO BE ASKED	DOMAIN NAME	FRMT	RANGE OF ANSWER	RESPONSE	NAME OF UNITS OF MEASUREMENT	BUFFER
code of mine	code	c10	s-*			sto a
			u-*			sto a
						rcl a
process	proc	c4	-1	-1	data not available	
			n*	-1	data not available	
			m	m	mining	
			mp	m+p	mining and preparation	
			m+p	m+p	mining and preparation	
type of technology	techno	c6	-1	-1	data not available	
			n*	-1	data not available	
			s*	surf	opencast	
			u*	und	underground	
data origin	origin	c6	-1	-1	data not available	
			n*	-1	data not available	
			ac*	actual	existing, operating mine	
			es*	estim	estimated (for a given field)	
			pr*	proj	projected (for typical cond.)	
reference year	rfyear	i2	n*	-1	data not available	
			-1	-1	data not available	
			> 2050	~	reference year	
			> 1900		reference year	
country	country	c16	n*	-1	data not available	
			-1	-1	data not available	
country code (Tree)	ccode	c2	-1	-1	data not available	
region	region	c16	-1	-1	data not available	
state	state	c16	-1	-1	data not available	
basin	basin	c16	-1	-1	data not available	
basin code	bcode	c3	-1	-1	data not available	
field, mine	minename	c24	-1	-1	data not available	

```
DATABASE! NAME: welmm
RELATION NAME: cminesb
FILE FUNCTION: append,print,verbose
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
+   QUESTION   TO   BE   ASKED ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT !BUFFER!
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! code of mine                 ! code        ! c10! s-*           !           !                             ! sto a!
!                              !             !    ! u-*           !           !                             ! sto a!
!                              !             !    !               !           !                             ! rcl a!
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! area extension of seams      ! seamarea    ! i4 ! -1            !   -1      ! data not available          !      !
!                              !             !    ! n*            !   -1      ! data not available          !      !
!                              !             !    ! > 0           !           ! square meters               !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! maximum depth of seams       ! maxdseam    ! i2 ! -1            !    -1     ! data not available          !      !
!                              !             !    ! n*            !    -1     ! data not available          !      !
!                              !             !    ! > 2000        !    ~      ! meters                      !      !
!                              !             !    ! ] 0           !           ! meters                      !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! marginal depth of seams      ! mard        ! i2 ! -1            !    -1     ! data not available          !      !
!                              !             !    ! n*            !    -1     ! data not available          !      !
!                              !             !    ! > 2000        !   ~       ! meters                      !      !
!                              !             !    ! ] 0           !           ! meters                      !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! total number of seams        ! seamt       ! i2 ! n*            !  -1       ! data not available          !      !
!                              !             !    ! -1            !   -1      ! data not available          !      !
!                              !             !    ! > 100         !   ~       ! seams                       !      !
!                              !             !    ! > 0           !           ! seams                       !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! seams to be mined out        ! seamtm      ! i2 ! n*            !  -1       ! data not available          !      !
!                              !             !    ! -1            !   -1      ! data not available          !      !
!                              !             !    ! > 100         !   ~       ! seams                       !      !
!                              !             !    ! > 0           !           ! seams                       !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! seams mined in ref year      ! seamm       ! i2 ! n*            !   -1      ! data not available          !      !
!                              !             !    ! -1            !   -1      ! data not available          !      !
!                              !             !    ! > 100         !    ~      ! seams                       !      !
!                              !             !    ! > 0           !           ! seams                       !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! total seams thickness min    ! seamitotth  ! f4 ! n*            !  -1       ! data not available          !      !
!                              !             !    ! -1            !   -1      ! data not available          !      !
!                              !             !    ! > 500         !   ~       ! meters                      !      !
!                              !             !    ! > 0           !           ! meters                      !      !
+------------------------------+-------------+----+---------------+-----------+-----------------------------+------+
! total seams thickness max    ! seamatotth  ! f4 ! n*            !  -1       ! data not available          !      !
!                              !             !    ! -1            !   -1      ! data not available          !      !
!                              !             !    ! > 500         !    ~      ! meters                      !      !
!                              !             !    ! > 0           !           ! meters                      !      !
```

total seams thickness avg	seamtotth	f4	n* -1 > 500 > 0	-1 -1 ~	data not available data not available meters meters	
avg seam thickn. w.part. min	seamathpmin	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available meters meters	
avg seam thickn. w.part. max	seamathpmax	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available meters meters	
avg seam thickn. w. partings	seamathp	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available meters meters	
avg seam thickn. w/o part.min	seamminath	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available meters meters	
avg seam thickn. w/o part.max	seammaxath	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available meters meters	
avg seam thickn. w/o partings	seamavgth	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available meters meters	
maximum mining depth in refyr	maxd	i2	n* -1 > 2000] 0	-1 -1 ~	data not available data not available meters meters	

DATABASE! NAME: welmm
RELATION NAME: cminesc
FILE FUNCTION: append,print,verbose

QUESTION TO BE ASKED	DOMAIN NAME	FRMT	RANGE OF ANSWER	RESPONSE	NAME OF UNITS OF MEASUREMENT	BUFFER
code of mine	code	c10	s-*			sto a
			u-*			sto a
						rcl a
sequential number (stratigr.)	num	i2	>0			
seam (strata) name or number	seamnum	c8	-1	-1	data not available	
			n*	-1	data not available	
seam mined in ref year	seammined	c4	-1	-1	data not available	
			y*	yes		
			no*	no		
			0	0	not applicable	
lower thickness of seam	slowth	f4	-1	-1	data not available	
			n*	-1	data not available	
			> 200	~	meters	
			] 0		meters	
upper thickness of seam	suppth	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 200	~	meters	
			> 0		meters	
average thickness of seam min	savgthmin	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 200	~	meters	
			> 0		meters	
average thickness of seam max	savgthmax	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 200	~	meters	
			> 0		meters	
average thickness of seam	savgth	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 200	~	meters	
			> 0		meters	
depth of seam min	sdepthmin	f4	n*	-1	data not available	
			-1	-1	data not available/applicable	
			> 2000	~	meters	
			] 0		meters	
			0	0	not applicable	

depth of seam max	sdepthmax	f4	-1	-1	data not available	
			> 2000	~	meters	
			> 0		meters	
			0	0	not applicable	
depth of seam (avg)	sdepth	f4	-1	-1	data not available	
			> 2000	~	meters	
			> 0		meters	
			0	0	not applicable	
interval from above seam(min)	sintermin	f4	-1	-1	data not available	
			> 2000	~	meters	
			> 0		meters	
			0	0	not applicable	
interval from above seam(max)	sintermax	f4	-1	-1	data not available	
			> 2000	~	meters	
			> 0		meters	
			0	0	not applicable	
interval from above seam(avg)	sinter	f4	-1	-1	data not available	
			> 2000	~	meters	
			> 0		meters	
			0	0	not applicable	
predominant dip of seam	sdip	c5	-1	-1	data not available	
			> 0		gon	
			h*	horiz	horizontal (0-20g)	
			f*	flat	flat (20-40g)	
			i*	incli	inclined (40-60g)	
			s*	steep	steep (>60g)	
			0	0	not applicable	
upper ash content of seam	sash	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 100	~	percent	
			> 0		percent	
			0	0	not applicable	

```
DATABASE NAME: welmm
RELATION NAME: cminesd
FILE FUNCTION: append,print,verbose
+------------------------------+------------+----+----------------+----------+------------------------------+------+
+   QUESTION   TO   BE  ASKED  ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT !BUFFER!
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! code of mine                 ! code       ! c10! s-*            !          !                              ! sto a!
!                              !            !    ! u-*            !          !                              ! sto a!
!                              !            !    !                !          !                              ! rcl a!
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! total geological resources   ! cresource  ! f4 ! -1             !    -1    ! data not available           !      !
!                              !            !    ! n*             !    -1    ! data not available           !      !
!                              !            !    ! > 0            !          ! 10e6 metric tons             !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! resources in seams mined     ! sresource  ! f4 ! -1             !     -1   ! data not available           !      !
!                              !            !    ! n*             !     -1   ! data not available           !      !
!                              !            !    ! > 0            !          ! 10e6 metric tons             !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! coal losses in pillars       ! closspill  ! f4 ! -1             !     -1   ! data not available           !      !
!                              !            !    ! n*             !     -1   ! data not available           !      !
!                              !            !    ! > 100          !    ~     ! percent                      !      !
!                              !            !    ! ] 0            !          ! percent                      !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! operational coal losses      ! clossop    ! f4 ! n*             !   -1     ! data not available           !      !
!                              !            !    ! -1             !    -1    ! data not available           !      !
!                              !            !    ! > 100          !    ~     ! percent                      !      !
!                              !            !    ! ] 0            !          ! percent                      !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! econ & tech recov reserves   ! creserves  ! f4 ! n*             !   -1     ! data not available           !      !
!                              !            !    ! -1             !    -1    ! data not available           !      !
!                              !            !    ! > 0            !          ! 10e6 metric tons             !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! ratio geol to seam resource  ! recoveryba ! f4 ! n*             !    -1    ! data not available           !      !
!                              !            !    ! -1             !    -1    ! data not available           !      !
!                              !            !    ! > 100          !     ~    ! percent                      !      !
!                              !            !    ! > 0            !          ! percent                      !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! ratio geol resource/reserves ! recoveryea ! f4 ! n*             !   -1     ! data not available           !      !
!                              !            !    ! -1             !    -1    ! data not available           !      !
!                              !            !    ! > 100          !   ~      ! percent                      !      !
!                              !            !    ! > 0            !          ! percent                      !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
! ratio seam resource/reserves ! recoveryeb ! f4 ! n*             !   -1     ! data not available           !      !
!                              !            !    ! -1             !    -1    ! data not available           !      !
!                              !            !    ! > 100          !     ~    ! percent                      !      !
!                              !            !    ! > -1           !          ! percent                      !      !
+------------------------------+------------+----+----------------+----------+------------------------------+------+
```

```
DATABASE! NAME: welmm
RELATION NAME: cminese
FILE FUNCTION: append,print,verbose
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
+    QUESTION   TO   BE  ASKED ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE   ! NAME OF UNITS OF MEASUREMENT   !BUFFER!
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! code of mine                 ! code        ! c10! s-*           !            !                                ! sto a!
!                              !             !    ! u-*           !            !                                ! sto a!
!                              !             !    !               !            !                                ! rcl a!
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! tectonic distortions         ! tectonic    ! c8 ! -1            !  -1        ! data not available             !       !
!                              !             !    ! dist*         !  dist      ! disturbed                      !       !
!                              !             !    ! hi*           !  highdist! highly disturbed              !       !
!                              !             !    ! reg*          !  regbed    ! regular bedding                !       !
!                              !             !    ! some*         !  somedist! some distortions              !       !
!                              !             !    ! go*           !  good      ! very good conditions           !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! coal density in situ         ! coaldens    ! f4 ! -1            !    -1      ! data not available             !       !
!                              !             !    ! n*            !    -1      ! data not available             !       !
!                              !             !    ! > 5           !    ~       ! metric tons per cu meter       !       !
!                              !             !    ! > 0.5         !            ! metric tons per cu meter       !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! type of rocks                ! rocks       ! c8 ! -1            !    -1      ! data not available             !       !
!                              !             !    ! n*            !    -1      ! data not available             !       !
!                              !             !    ! sa,si,sh      ! sa,si,sh   ! sand-,siltstone,shale          !       !
!                              !             !    ! sa,cl         ! sa,cl      ! sandstone,claystone            !       !
!                              !             !    ! sh,sa         ! sh,sa      ! shale,sandstone                !       !
!                              !             !    ! sa,si         ! sa,si      ! sandstone,siltstone            !       !
!                              !             !    ! s,cla         ! s,cla      ! sand,clay                      !       !
!                              !             !    ! sa,s,cla      ! sa,s,cla   ! sandstone,sand,clay            !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! rock density (average)       ! burddens    ! f4 ! n*            !  -1        ! data not available             !       !
!                              !             !    ! -1            !   -1       ! data not available             !       !
!                              !             !    ! > 5           !   ~        ! metric tons per cu meter       !       !
!                              !             !    ! > 0.5         !            ! metric tons per cu meter       !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! gas emanation tendency       ! gas         ! c4 ! -1            !  -1        ! data not available             !       !
!                              !             !    ! y*            !   yes      !                                !       !
!                              !             !    ! no            !   no       !                                !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! gas emanation (quantity)min  ! methanemin  ! f4 ! n*            !   -1       ! data not available             !       !
!                              !             !    ! -1            !   -1       ! data not available             !       !
!                              !             !    ! 10            !            ! cu meter/ton daily coal prod   !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! gas emanation (quantity)max  ! methanemax  ! f4 ! n*            !  -1        ! data not available             !       !
!                              !             !    ! -1            !   -1       ! data not available             !       !
!                              !             !    ! 10            !            ! cu meter/ton daily coal prod   !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! gas emanation (quantity)     ! methane     ! f4 ! n*            !  -1        ! data not available             !       !
!                              !             !    ! -1            !   -1       ! data not available             !       !
!                              !             !    ! 10            !            ! cu meter/ton daily coal prod   !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! spontan. combustion tendency ! fire        ! c4 ! -1            !  -1        ! data not available             !       !
!                              !             !    ! y*            !   yes      !                                !       !
!                              !             !    ! no            !   no       !                                !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
! water inflow (maximum)       ! water       ! i4 ! n*            !   -1       ! data not available             !       !
!                              !             !    ! -1            !   -1       ! data not available             !       !
!                              !             !    ! 10            !            ! cu meters per year             !       !
+------------------------------+-------------+----+---------------+------------+--------------------------------+-------+
```

```
DATABASE NAME: welmm
RELATION NAME: cminesf
FILE FUNCTION: append,print,verbose
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
+    QUESTION   TO   BE   ASKED     ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT !BUFFER!
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! code of mine                      ! code         ! c10! s-*            !          !                                    ! sto a!
!                                   !              !    ! u-*            !          !                                    ! sto a!
!                                   !              !    !                !          !                                    ! rcl a!
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! grade of coal                     ! cgrad        ! c6 ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! an*            ! anthr    ! anthracite                         !      !
!                                   !              !    ! bi*            ! bitum    ! bituminous coal                    !      !
!                                   !              !    ! br*            ! brown    ! brown coal                         !      !
!                                   !              !    ! li*            ! lignit   ! lignite                            !      !
!                                   !              !    ! su*            ! subbit   ! subbituminous coal                 !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! coking coal                       ! coke         ! c4 ! -1             !  -1      !                                    !      !
!                                   !              !    ! y*             !  yes     !                                    !      !
!                                   !              !    ! no             !  no      !                                    !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! moisture content minimum          ! cmoistmin    ! f4 ! n*             !  -1      ! data not available                 !      !
!                                   !              !    ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! > 100          !  ~       ! percent                            !      !
!                                   !              !    ! > 0            !          ! percent                            !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! moisture content maximum          ! cmoistmax    ! f4 ! n*             ! -1       ! data not available                 !      !
!                                   !              !    ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! > 100          !  ~       ! percent                            !      !
!                                   !              !    ! > 0            !          ! percent                            !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! moisture content average          ! cmoistavg    ! f4 ! n*             ! -1       ! data not available                 !      !
!                                   !              !    ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! > 100          !  ~       ! percent                            !      !
!                                   !              !    ! > -1           !          ! percent                            !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! calorific cont raw coal min       ! caloricmin   ! f4 ! n*             !  -1      ! data not available                 !      !
!                                   !              !    ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! > 10000        !   ~      ! kcal per kilogram                  !      !
!                                   !              !    ! > 0            !          ! kcal per kilogram                  !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! calorific cont raw coal max       ! caloricmax   ! f4 ! n*             ! -1       ! data not available                 !      !
!                                   !              !    ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! > 10000        !  ~       ! kcal per kilogram                  !      !
!                                   !              !    ! > 0            !          ! kcal per kilogram                  !      !
+-----------------------------------+--------------+----+----------------+----------+------------------------------------+------+
! calorific cont raw coal avg       ! caloricavg   ! f4 ! n*             ! -1       ! data not available                 !      !
!                                   !              !    ! -1             !  -1      ! data not available                 !      !
!                                   !              !    ! > 10000        !  ~       ! kcal per kilogram                  !      !
!                                   !              !    ! > 0            !          ! kcal per kilogram                  !      !
```

calorific content waf min	wafmin	f4	n* -1 > 10000 > 0	-1 -1 ~	data not available data not available kcal per kilogram kcal per kilogram	
calorific content waf max	wafmax	f4	n* -1 > 10000 > 0	-1 -1 ~	data not available data not available kcal per kilogram kcal per kilogram	
calorific content waf avg	wafavg	f4	n* -1 > 10000 > 0	-1 -1 ~	data not available data not available kcal per kilogram kcal per kilogram	
ash content raw coal min	ashrawmin	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
ash content raw coal max	ashrawmax	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
ash content raw coal avg	ashrawavg	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
ash content dry coal min	ashdrymin	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
ash content dry coal max	ashdrymax	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
ash content dry coal avg	ashdryavg	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	

```
DATABASE NAME: welmm
RELATION NAME: cminesg
FILE FUNCTION: append,print,verbose
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
+    QUESTION    TO    BE    ASKED      ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE  ! NAME OF UNITS OF MEASUREMENT      !BUFFER!
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! code of mine                          ! code         ! c10! s-*            !           !                                   ! sto a!
!                                       !              !    ! u-*            !           !                                   ! sto a!
!                                       !              !    !                !           !                                   ! rcl a!
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! fixed carbon min                      ! carbonmin    ! f4 ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! n*             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !    ~      ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! fixed carbon max                      ! carbonmax    ! f4 ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! n*             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !    ~      ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! fixed carbon average                  ! carbon       ! f4 ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! n*             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !    ~      ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! hydrogen content min                  ! hydrogmin    ! f4 ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! n*             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !   ~       ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! hydrogen content max                  ! hydrogmax    ! f4 ! n*             !   -1      ! data not available                !       !
!                                       !              !    ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !   ~       ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! hydrogen content average              ! hydrogen     ! f4 ! n*             !   -1      ! data not available                !       !
!                                       !              !    ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !   ~       ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! sulfur content dry coal min           ! drysulmin    ! f4 ! n*             !    -1     ! data not available                !       !
!                                       !              !    ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !    ~      ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
+---------------------------------------+--------------+----+----------------+-----------+-----------------------------------+-------+
! sulfur content dry coal max           ! drysulmax    ! f4 ! n*             !   -1      ! data not available                !       !
!                                       !              !    ! -1             !    -1     ! data not available                !       !
!                                       !              !    ! > 100          !   ~       ! percent                           !       !
!                                       !              !    ! > 0            !           ! percent                           !       !
```

sulfur content dry coal avg	drysulavg	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
volatile matter min	volmin	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
volatile matter max	volmax	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
volatile matter average	volatile	f4	n* -1 > 100 > 0	-1 -1 ~	data not available data not available percent percent	
regularity of coal quality	regular	c8	-1 regular nonreg	-1	data not available quality factors regular quality factors non regular	

```
DATABASE NAME: welmm
RELATION NAME: cminesh
FILE FUNCTION: append,print,verbose
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
+    QUESTION   TO   BE   ASKED    ! DOMAIN NAME  !FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT    !BUFFER!
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
! code of mine                     ! code         ! c10! s-*           !           !                                  ! sto a!
!                                  !              !    ! u-*           !           !                                  ! sto a!
!                                  !              !    !               !           !                                  ! rcl a!
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
! possible other minerals          ! minerals     ! c4 ! -1            !   -1      ! data not available               !       !
!                                  !              !    ! y*            !  yes      ! (see footnote)                   !       !
!                                  !              !    ! no            !   no      !                                  !       !
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
! surface landscape                ! landscape    ! c8 ! -1            !   -1      ! data not available               !       !
!                                  !              !    ! flat          ! flat      ! flat landscape                   !       !
!                                  !              !    ! hill          ! hill      ! hilly landscape                  !       !
!                                  !              !    ! flath*        ! flathill  ! flat & hilly landscape           !       !
!                                  !              !    ! m*            ! mountain  ! mountain landscape               !       !
!                                  !              !    ! hillm*        ! hillmont  ! hilly mountain landscape         !       !
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
! land use                         ! landusea     ! c8 ! -1            !   -1      ! data not available               !       !
!                                  !              !    ! v*            ! virgin    ! virgin land                      !       !
!                                  !              !    ! p*            ! partused  ! partly used land                 !       !
!                                  !              !    ! u*            ! used      ! land use (below)                 !       !
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
! land use (description)           ! landuseb     ! c8 ! -1            !   -1      ! data not available               !       !
!                                  !              !    ! de*           ! desert    !                                  !       !
!                                  !              !    ! wo*           ! woodland  !                                  !       !
!                                  !              !    ! bu*           ! bush      !                                  !       !
!                                  !              !    ! gr*           ! grazing   !                                  !       !
!                                  !              !    ! fo*           ! forest    ! forestry                         !       !
!                                  !              !    ! ag*           ! agricul   ! farming                          !       !
!                                  !              !    ! ar*           ! arable    ! arable land                      !       !
!                                  !              !    ! hi*           ! highagri  ! highest agricultural use         !       !
!                                  !              !    ! po*           ! polar     !                                  !       !
!                                  !              !    ! ur*           ! urban     ! urban area                       !       !
+----------------------------------+--------------+----+---------------+-----------+----------------------------------+-------+
! land use (description cont.)     ! landusec     ! c8 ! -1            !  -1       ! data not available               !       !
!                                  !              !    ! de*           ! desert    !                                  !       !
!                                  !              !    ! wo*           ! woodland  !                                  !       !
!                                  !              !    ! bu*           ! bush      !                                  !       !
!                                  !              !    ! gr*           ! grazing   !                                  !       !
!                                  !              !    ! fo*           ! forest    ! forestry                         !       !
!                                  !              !    ! ag*           ! agricul   ! farming                          !       !
!                                  !              !    ! ar*           ! arable    ! arable land                      !       !
!                                  !              !    ! hi*           ! highagri  ! highest agricultural use         !       !
!                                  !              !    ! po*           ! polar     !                                  !       !
!                                  !              !    ! ur*           ! urban     ! urban area                       !       !
```

land use (description cont.)	landused	c8	-1	-1	data not available	
			de*	desert		
			wo*	woodland		
			bu*	bush		
			gr*	grazing		
			fo*	forest	forestry	
			ag*	agricul	farming	
			ar*	arable	arable land	
			hi*	highagri	highest agricultural use	
			po*	polar		
			ur*	urban	urban area	
hydrology: river system	hydrogeo	c8	-1	-1	data not available	
			gr*	great	river system	
			sm*	small	river system	
			no*	no	rivers around	
river name A	rivera	c16	-1	-1	data not available	
river name B	riverb	c16	-1	-1	data not available	
water in coal bearing bed	aquifer	c8	-1	-1	data not available	
			littlen*	littleno	little or not watery coal bed	
			no*	no	not watery coal bed	
			little*	little	little watery coal bed	
			mo*	moderate	moderately watery coal bed	
			hi*	high	highly watery coal bed	

```
DATABASE NAME: welmm
RELATION NAME: cminesi
FILE FUNCTION: append,print,verbose
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
+   QUESTION   TO   BE   ASKED       ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT     !BUFFER!
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! code of mine                       ! code       ! c10! s-•            !          !                                  ! sto a!
!                                    !            !    ! u-•            !          !                                  ! sto a!
!                                    !            !    !                !          !                                  ! rcl a!
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! average january temperature        ! jantem     ! f4 ! n•             !   -1     ! data not available               !      !
!                                    !            !    ! -1.0           ! -1.001   ! avg temp: -1 degree celsius      !      !
!                                    !            !    ! > +50          !    ~     ! degrees celsius                  !      !
!                                    !            !    ! > -50          !          ! degrees celsius                  !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! average july temperature           ! jultem     ! f4 ! n•             !   -1     ! data not available               !      !
!                                    !            !    ! -1.0           !  -1.001  ! avg temp: -1 degree celsius      !      !
!                                    !            !    ! > +50          !    ~     ! degrees celsius                  !      !
!                                    !            !    ! > -50          !          ! degrees celsius                  !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! annual precipitation min           ! minrain    ! i2 ! -1             !   -1     ! data not available               !      !
!                                    !            !    ! n•             !   -1     ! data not available               !      !
!                                    !            !    ! > 5000         !    ~     ! millimeters                      !      !
!                                    !            !    ! ] 0            !          ! millimeters                      !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! annual precipitation max           ! maxrain    ! i2 ! n•             !  -1      ! data not available               !      !
!                                    !            !    ! -1             !   -1     ! data not available               !      !
!                                    !            !    ! > 5000         !   ~      ! millimeters                      !      !
!                                    !            !    ! ] 0            !          ! millimeters                      !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! annual precipitation avg           ! avgrain    ! i2 ! n•             !  -1      ! data not available               !      !
!                                    !            !    ! -1             !   -1     ! data not available               !      !
!                                    !            !    ! > 5000         !   ~      ! millimeters                      !      !
!                                    !            !    ! ] 0            !          ! millimeters                      !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! depth of ground freezing min       ! minfreez   ! f4 ! n•             !   -1     ! data not available               !      !
!                                    !            !    ! -1             !   -1     ! data not available               !      !
!                                    !            !    ! > 20           !    ~     ! meters                           !      !
!                                    !            !    ! ] 0            !          ! meters                           !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! depth of ground freezing max       ! maxfreez   ! f4 ! n•             !  -1      ! data not available               !      !
!                                    !            !    ! -1             !   -1     ! data not available               !      !
!                                    !            !    ! > 20           !   ~      ! meters                           !      !
!                                    !            !    ! ] 0            !          ! meters                           !      !
+------------------------------------+------------+----+----------------+----------+----------------------------------+------+
! depth of ground freezing avg       ! avgfreez   ! f4 ! n•             !  -1      ! data not available               !      !
!                                    !            !    ! -1             !   -1     ! data not available               !      !
!                                    !            !    ! > 20           !   ~      ! meters                           !      !
!                                    !            !    ! ] 0            !          ! meters                           !      !
```

industrial development	indusdev	c8	-1	-1	data not available	
			hi*	high	highly developed industry	
			de*	develop	developed industry	
			pa*	partial	partial developed industry	
			no*	none	no industry	
population density (data)	populata	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 1000	~	inhabitants per square km	
			] 0		inhabitants per square km	
population density (descrip.)	populatb	c8	-1	-1	data not available	
			gr*	great	great population density	
			in*	inhabitd	inhabited area	
			th*	thin	thinly populated	
long distance transportation	ldtrans	c8	-1	-1	data not available	
			exist*	existing	existing/possible	
			de*	develop	to be developed	
			pr*	problem	great problems	
			lo*	local	local coal use	
			existloc*	existloc	existing but local coal use	

```
DATABASE NAME: welmm
RELATION NAME: cminesj
FILE FUNCTION: append,print,verbose
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
+    QUESTION   TO   BE   ASKED     ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT  !BUFFER!
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! code of mine                      ! code        ! c10! s-*            !          !                                  ! sto a!
!                                   !             !    ! u-*            !          !                                  ! sto a!
!                                   !             !    !                !          !                                  ! rcl a!
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! annual capacity raw coal          ! ancaprom    ! f4 ! -1             !    -1    ! data not available               !       !
!                                   !             !    ! n*             !    -1    ! data not available               !       !
!                                   !             !    ! > 0            !          ! 10e6 metric tons                 !       !
!                                   !             !    ! > 200          !    ~     ! 10e6 metric tons                 !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! annual capacity sale coal         ! ancapsal    ! f4 ! -1             !    -1    ! data not available               !       !
!                                   !             !    ! n*             !    -1    ! data not available               !       !
!                                   !             !    ! 0              !     0    ! only raw coal production         !       !
!                                   !             !    ! > 200          !    ~     ! 10e6 metric tons                 !       !
!                                   !             !    ! > 0            !          ! 10e6 metric tons                 !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! construction period               ! constdur    ! f4 ! -1             !    -1    ! data not available               !       !
!                                   !             !    ! n*             !    -1    ! data not available               !       !
!                                   !             !    ! > 20           !   ~      ! years                            !       !
!                                   !             !    ! > 0            !          ! years                            !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! mine output increasing period     ! devdu       ! f4 ! n*             !  -1      ! data not available               !       !
!                                   !             !    ! -1             !   -1     ! data not available               !       !
!                                   !             !    ! > 20           !   ~      ! years                            !       !
!                                   !             !    ! > 0            !          ! years                            !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! total life period of mine         ! lifet       ! i2 ! n*             !  -1      ! data not available               !       !
!                                   !             !    ! -1             !   -1     ! data not available               !       !
!                                   !             !    ! > 200          !   ~      ! years                            !       !
!                                   !             !    ! > 0            !          ! years                            !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! year of exploitation start        ! prodst      ! i2 ! n*             !    -1    ! data not available               !       !
!                                   !             !    ! -1             !    -1    ! data not available               !       !
!                                   !             !    ! > 2100         !    ~     ! calendar year                    !       !
!                                   !             !    ! > 1900         !          ! calendar year                    !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! year of last modernization        ! modern      ! i2 ! n*             !  -1      ! data not available               !       !
!                                   !             !    ! -1             !   -1     ! data not available               !       !
!                                   !             !    ! 0              !  0       ! not applicable (new mine)        !       !
!                                   !             !    ! > 1986         !   ~      ! calendar year                    !       !
!                                   !             !    ! > 1900         !          ! calendar year                    !       !
+-----------------------------------+-------------+----+----------------+----------+----------------------------------+-------+
! coal output raw coal              ! outrom      ! f4 ! n*             !  -1      ! data not available               !       !
!                                   !             !    ! -1             !   -1     ! data not available               !       !
!                                   !             !    ! > 200          !    ~     ! 10e6 metric tons                 !       !
!                                   !             !    ! > 0            !          ! 10e6 metric tons                 !       !
```

coal output sale coal	outsale	f4	n* -1 0 > 200 > 0	-1 -1 0 ~	data not available data not available only raw coal production 10e6 metric tons 10e6 metric tons	
number of working days	workdays	i2	n* -1 > 367 > 0	-1 -1 ~	data not available data not available days days	
lower limit of scaling factor	scalelow	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available 10e6 metric tons 10e6 metric tons	
upper limit of scaling factor	scaleup	f4	n* -1 > 200 > 0	-1 -1 ~	data not available data not available 10e6 metric tons 10e6 metric tons	
exponential scaling factor Se	scaling	f4	n* -1 > 1] 0	-1 -1 ~	data not available data not available output increase exponent Se output increase exponent Se	

```
DATABASE NAME: welmm
RELATION NAME: cminesk
FILE FUNCTION: append,print,verbose
+--------------------------------+-------------+----+-----------------+-----------+--------------------------------+------+
+    QUESTION   TO   BE  ASKED   ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT !BUFFER!
+--------------------------------+-------------+----+-----------------+-----------+--------------------------------+------+
! code of mine                   ! code        ! c10! s-*             !           !                                ! sto a!
!                                !             !    ! u-*             !           !                                ! sto a!
!                                !             !    !                 !           !                                ! rcl a!
+--------------------------------+-------------+----+-----------------+-----------+--------------------------------+------+
! calendar year                  ! year        ! i2 ! -1              !    -1     ! data not available             !      !
!                                !             !    ! n*              !    -1     ! data not available             !      !
!                                !             !    ! > 1900          !           !                                !      !
!                                !             !    ! > 2100          !           !                                !      !
+--------------------------------+-------------+----+-----------------+-----------+--------------------------------+------+
! capacity raw coal in year      ! caprom      ! f4 ! -1              !    -1     ! data not available             !      !
!                                !             !    ! n*              !    -1     ! data not available             !      !
!                                !             !    ! > 200           !    ~      ! 10e6 metric tons raw coal      !      !
!                                !             !    ! > 0             !           ! 10e6 metric tons raw coal      !      !
+--------------------------------+-------------+----+-----------------+-----------+--------------------------------+------+
! capacity sale coal in year     ! capsal      ! f4 ! -1              !    -1     ! data not available             !      !
!                                !             !    ! n*              !    -1     ! data not available             !      !
!                                !             !    ! 0               !     0     ! only raw coal production       !      !
!                                !             !    ! > 200           !     ~     ! 10e6 metric tons sale coal     !      !
!                                !             !    ! > 0             !           ! 10e6 metric tons sale coal     !      !
+--------------------------------+-------------+----+-----------------+-----------+--------------------------------+------+
```

```
DATABASE NAME: welmm
RELATION NAME: cminesm
FILE FUNCTION: append,print,verbose
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
+    QUESTION   TO   BE  ASKED ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT !BUFFER!
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! code of mine                ! code        ! c10! u-*              !          !                                 ! sto a!
!                             !             !    ! s-*              !    ~     !                                 !      !
!                             !             !    !                  !          !                                 ! rcl a!
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! number of operating units   ! units       ! i1 ! -1               !   -1     ! data not available              !      !
!                             !             !    ! n*               !   -1     ! data not available              !      !
!                             !             !    ! > 50             !    ~     ! operating units                 !      !
!                             !             !    ! > 0              !          ! operating units                 !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! average output from unit    ! unitout     ! i2 ! -1               !   -1     ! data not available              !      !
!                             !             !    ! n*               !   -1     ! data not available              !      !
!                             !             !    ! > 0              !          ! metric tons per day             !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! # of working days/year: coal ! daycw      ! i2 ! -1               !   -1     ! data not available              !      !
!                             !             !    ! n*               !   -1     ! data not available              !      !
!                             !             !    ! > 367            !    ~     ! days                            !      !
!                             !             !    ! > 0              !          ! days                            !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! # of shifts/day: coal winning! cshift     ! i1 ! n*               !  -1      ! data not available              !      !
!                             !             !    ! -1               !   -1     ! data not available              !      !
!                             !             !    ! > 10             !    ~     ! shifts per day                  !      !
!                             !             !    ! > 0              !          ! shifts per day                  !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! # of shifts/day: maintenance ! mshift     ! i1 ! n*               !  -1      ! data not available              !      !
!                             !             !    ! -1               !   -1     ! data not available              !      !
!                             !             !    ! > 5              !    ~     ! shifts per day                  !      !
!                             !             !    ! > 0              !          ! shifts per day                  !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! number of hours per shift   ! hours       ! f4 ! n*               !   -1     ! data not available              !      !
!                             !             !    ! -1               !   -1     ! data not available              !      !
!                             !             !    ! > 12             !    ~     ! hours                           !      !
!                             !             !    ! > 0              !          ! hours                           !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! system of seam opening      ! seamopen    ! c8 ! n*               !  -1      ! data not available              !      !
!                             !             !    ! -1               !   -1     ! data not available              !      !
!                             !             !    ! sha*             ! shaft    !                                 !      !
!                             !             !    ! dr*              ! drift    !                                 !      !
!                             !             !    ! slo*             ! slope    !                                 !      !
!                             !             !    ! shadr*           ! sha-dri  ! shafts and drifts combined      !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! # of main shafts/drifts/... ! shafts      ! i1 ! n*               !  -1      ! data not available              !      !
!                             !             !    ! -1               !   -1     ! data not available              !      !
!                             !             !    ! > 20             !    ~     ! shafts/drifts/slopes            !      !
!                             !             !    ! > 0              !          ! shafts/drifts/slopes            !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
! method of mining            ! method      ! c8 ! n*               !  -1      ! data not available              !      !
!                             !             !    ! -1               !   -1     ! data not available              !      !
!                             !             !    ! long*            ! longwall ! longwall mining                 !      !
!                             !             !    ! short*           ! shortwal ! shortwall mining                !      !
!                             !             !    ! roomp*           ! roompill ! room and pillar                 !      !
!                             !             !    ! hyd*             ! hydro    ! hydraulic mining                !      !
!                             !             !    ! bordp            ! bordpill ! board and pillar                !      !
+-----------------------------+-------------+----+------------------+----------+---------------------------------+------+
```

```
DATABASE NAME: welmm
RELATION NAME: cmines1
FILE FUNCTION: append,print,verbose
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
+    QUESTION  TO  BE  ASKED    ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT  !BUFFER!
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! code of mine                  ! code       ! c10! s-*            !          !                               ! sto a!
!                               !            !    ! u-*            !    ~     !                               !      !
!                               !            !    !                !          !                               ! rcl a!
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! number of operating units     ! units      ! i1 ! -1             !   -1     ! data not available            !      !
!                               !            !    ! n*             !   -1     ! data not available            !      !
!                               !            !    ! > 50           !   ~      ! operating units               !      !
!                               !            !    ! > 0            !          ! operating units               !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! # of operating units (coal)   ! cunits     ! i1 ! -1             !   -1     ! data not available            !      !
!                               !            !    ! n*             !   -1     ! data not available            !      !
!                               !            !    ! > 50           !   ~      ! operating units               !      !
!                               !            !    ! > 0            !          ! operating units               !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! # of operating units (overb.)! ounits      ! i1 ! -1             !   -1     ! data not available            !      !
!                               !            !    ! n*             !   -1     ! data not available            !      !
!                               !            !    ! > 50           !  ~       ! operating units               !      !
!                               !            !    ! > 0            !          ! operating units               !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! average output from unit      ! unitout    ! i2 ! n*             !  -1      ! data not available            !      !
!                               !            !    ! -1             !   -1     ! data not available            !      !
!                               !            !    ! > 0            !          ! metric tons per day           !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! working days/yr: coal winning! daycw       ! i2 ! n*             !  -1      ! data not available            !      !
!                               !            !    ! -1             !   -1     ! data not available            !      !
!                               !            !    ! > 367          !  ~       ! days                          !      !
!                               !            !    ! > 0            !          ! days                          !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! working days/yr: overburden   ! dayow      ! i2 ! n*             !   -1     ! data not available            !      !
!                               !            !    ! -1             !   -1     ! data not available            !      !
!                               !            !    ! > 367          !   ~      ! days                          !      !
!                               !            !    ! > 0            !          ! days                          !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! # of shifts/day: coal winning! cshift      ! i1 ! n*             !  -1      ! data not available            !      !
!                               !            !    ! -1             !   -1     ! data not available            !      !
!                               !            !    ! > 10           !  ~       ! shifts per day                !      !
!                               !            !    ! > 0            !          ! shifts per day                !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! # of shifts/day: overburden   ! oshift     ! i1 ! n*             !  -1      ! data not available            !      !
!                               !            !    ! -1             !   -1     ! data not available            !      !
!                               !            !    ! > 10           !   ~      ! shifts per day                !      !
!                               !            !    ! > 0            !          ! shifts per day                !      !
+-------------------------------+------------+----+----------------+----------+-------------------------------+------+
! number of hours per shift     ! hours      ! f4 ! n*             !  -1      ! data not available            !      !
!                               !            !    ! -1             !   -1     ! data not available            !      !
!                               !            !    ! > 12           !  ~       ! hours                         !      !
!                               !            !    ! > 0            !          ! hours                         !      !
```

method of mining	method	c8	n*	-1	data not available	
			-1	-1	data not available	
			area stripping	arstrip	area stripping with draglines	
			area mining	arminc	conv.area mining w. shovels	
			arminc	arminc	conv.area mining w. shovels	
			arstrip*	arstrip	area stripping with draglines	
			cyclic cont*	ccstrip	cycl.cont.stripping:draglines	
			ccstrip*	ccstrip	cycl.cont.stripping:draglines	
			contour strip*	ctstrip	contour stripping	
			ctstrip*	ctstrip	contour stripping	
			multiple dipp*	mdippsm	multiple dipping seam mining	
			mdipp*	mdippsm	multiple dipping seam mining	
			mountain top*	mtoprem	mountain top removal	
			mtop*	mtoprem	mountain top removal	
			strip	strip	stripping with draglines	
			bucket wheel*	stripbw	stripping:bucket wheel excav.	
			bw*	stripbw	stripping:bucket wheel excav.	
			stripbw*	stripbw	stripping:bucket wheel excav.	
			combine*	striprw	combin.strip.& rotary wheel	
			rw*	striprw	combin.strip.& rotary wheel	
			striprw*	striprw	combin.strip.& rotary wheel	
			transport sce*	stripts	stripping w. transport scheme	
			tr*	stripts	stripping w. transport scheme	
			stripts*	stripts	stripping w. transport scheme	
necessity of rock blasting	rex	c4	-1	-1	data not available	
			yes			
			no			
necessity of coal blasting	cex	c4	-1	-1	data not available	
			yes			
			no			
overburden to coal ratio	ovtocratio	f4	n*	-1	data not available	
			-1	-1	data not available	
			> 50	~	cu meters per metric ton	
			> 0		cu meters per metric ton	

```
DATABASE NAME: welmm
RELATION NAME: cminesn
FILE FUNCTION: append,print,verbose
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
+   QUESTION    TO    BE   ASKED          ! DOMAIN NAME!FRMT! RANGE OF ANSWER! RESPONSE ! NAME OF UNITS OF MEASUREMENT !BUFFER!
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! code of mine                            ! code       ! c10! s-*              !              !                                      ! sto a!
!                                         !            !    ! u-*              !              !                                      ! sto a!
!                                         !            !    !                  !              !                                      ! rcl a!
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! equipment for                           ! equipuse   ! c8 ! wi*              ! winning      ! coal winning                         !       !
!                                         !            !    ! ov*              ! overburd     ! overburden operations                !       !
!                                         !            !    ! pro*             ! product      ! coal and overburden                  !       !
!                                         !            !    ! d*               ! develop      ! development work                     !       !
!                                         !            !    ! t*               ! transp       ! transportation                       !       !
!                                         !            !    ! prep*            ! prep         ! preparation                          !       !
!                                         !            !    ! oth*             ! others       ! not specified                        !       !
!                                         !            !    ! -1               !  -1          ! data not available                   !       !
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! equipment number                        ! equipnum   ! i2 ! -1               ! -1           ! data not available                   !       !
!                                         !            !    ! n*               ! -1           ! data not available                   !       !
!                                         !            !    ! >0               !              !                                      !       !
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! equipment item                          ! item       ! c20!                  !              !                                      !       !
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! equipment model                         ! model      ! c12! -1               ! -1           ! data not available                   !       !
!                                         !            !    !                  !              !                                      !       !
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! equipment manufacturer                  ! manufact   ! c16! -1               ! -1           ! data not available                   !       !
!                                         !            !    !                  !              !                                      !       !
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
! equipment working weight                ! weightons  ! f4 ! n*               !  -1          ! data not available                   !       !
!                                         !            !    ! -1               !  -1          ! data not available                   !       !
!                                         !            !    ! >100000          !   ~          ! metric tons                          !       !
!                                         !            !    ! >0               !              ! metric tons                          !       !
+-----------------------------------------+-----------+----+------------------+--------------+--------------------------------------+-------+
```

APPENDIX A.2 QUESTIONNAIRE, PART TWO: WELMM REQUIREMENTS FOR CONSTRUCTION AND OPERATION OF A MINE

Final version used for data collection.

B. WELMM ANALYSIS OF THE CONSTRUCTION

(including preparation plant)

1. WATER [m^3]

WATER INFLOW DURING THE CONSTRUCTION PERIOD	*DATA:*
WATER USED FOR CONSTRUCTION DURING THE SAME PERIOD	*DATA:*
IMPACT OF THE CONSTRUCTION ON LOCAL WATER RESOURCES (QUALITATIVE AND QUANTITATIVE IMPACTS, IF THERE ARE ANY)	*SHORT DESCRIPTION:* *(e.g. LOWERING OF GROUND WATER LEVEL)*

2. ENERGY USED DURING THE CONSTRUCTION PERIOD:

ELECTRICITY [kWh]	*DATA:*
MOTOR FUEL, QUANTITY IN [liters]	*DATA:*

3. LAND [km^2 or m^2]

AREA TEMPORARILY OCCUPIED OR AFFECTED BY THE PROCESS OF CONSTRUCTION	*DATA:*
TOTAL LEASED OR BOUGHT LAND AREA OF THE MINE FIELD INCLUDING AREA OCCUPIED BY OUTER WASTE ROCK PILES	*DATA:*
LAND OCCUPIED BY MINE BUILDINGS, RELATED FACILITIES AND WASTE ROCK PILES	*DATA:*

4. MANPOWER USED DURING THE CONSTRUCTION PERIOD [MAN YEARS OR MAN SHIFTS]

MANUAL TECHNICAL (TECHNICIANS, QUALIFIED WORKERS.......)	*DATA:*
OF THESE – WORKERS WITH MINING QUALIFICATIONS	*DATA:*
MANUAL NON-TECHNICAL (NON-QUALIFIED MANPOWER)	*DATA:*
NON-MANUAL TECHNICAL	*DATA:*
OF THESE – FOREMEN	*DATA:*
– ENGINEERS	*DATA:*
NON-MANUAL NON-TECHNICAL (EMPLOYEES, . . .)	*DATA:*
TOTAL PERSONNEL	*DATA:*
OF THESE – UNDERGROUND PERSONNEL	*DATA:*

5. MATERIALS FOR CONSTRUCTION*

e.g. WOOD [m^3]/STRUCTURAL STEEL & OTHER FIELD METALS [metric tons]/
CONCRETE [m^3]/CEMENT [m^3]/SANDS [m^3]/EXPLOSIVES [metric tons]/ . . .

TOTAL AMOUNT OF WASTE ROCKS (OVERBURDEN) MINED OUT AND STORED AT SURFACE DURING THE CONSTRUCTION PERIOD OF THE MINE	
[m^3]	*DATA:*
[metric tons]	*DATA:*

*If more detailed data available, please specify.

6. INVESTMENTS

6.1 TOTAL INVESTMENT DURING THE CONSTRUCTION PERIOD**	*DATA:**
INFRASTRUCTURE INVESTMENTS	*DATA:**
INDIRECT INVESTMENTS [e.g. LAND, INTERESTS,....]	*DATA:**
TOTAL DIRECT INVESTMENT	*DATA:**
MINE BUILDINGS AND OTHER FACILITIES (INCLUDING PREPARATION)	*DATA:**
MINE OPENING AND DEVELOPMENT	*DATA:**
MINE EQUIPMENT	*DATA:**

***Please indicate all cost data in national currency for the reference year.**

****Construction period: until reaching projected output.**

C. WELMM ANALYSIS FOR THE OPERATION (in the reference year)

(including preparation plant)

1. WATER [m^3 PER YEAR] AND/OR [m^3 PER METRIC TON OF SALEABLE COAL]

TOTAL WATER INFLOW	*DATA:*
ADDITIONAL WATER SUPPLY	*DATA:*
WATER USED BY THE MINE WATER USED BY THE PREPARATION PLANT	*DATA:* *DATA:*
TOTAL AMOUNT OF WATER PUMPED OUT	*DATA:*
POLLUTION DATA OF WATER RETURNED TO THE ENVIRONMENT AFTER/WITHOUT USE	*SHORT DESCRIPTIONS WITH POSSIBLE DATA:*

2. ENERGY PER YEAR (PER METRIC TON OF SALEABLE COAL)

ELECTRICITY [kWh]	*DATA:*
MOTOR FUEL [liters]	*DATA:*
FUEL FOR PROCESS HEAT [QUANTITY] & [CALORIFIC CONTENT]	*DATA:* *DATA:*

3. LAND [in km^2 or m^2] UNDERMINED/DISTURBED IN THE REFERENCE YEAR

3.1 OPEN CUT MINING

SURFACE AREA WHICH IS DISTURBED BY MINING [m^2/yr] OR [m^2/yr PER METRIC TON OF ANNUAL MINE OUTPUT]	*DATA:*
HEIGHT OF TOPSOIL [m]	*DATA:*
WHAT MEASURES ARE TAKEN FOR THE RECULTIVATION OF THE AREA DISTURBED (QUALITATIVE AND QUANTITATIVE CHARACTERISTICS)?	*SHORT DESCRIPTION:*
LAND AREA RECLAIMED [m^2/yr] OR [m^2/yr PER METRIC TON OF ANNUAL MINE OUTPUT]	*DATA:*
RECLAMATION COST OF LAND DISTURBED DURING THE YEAR (IN NATIONAL CURRENCY UNITS)	*DATA:*
[PER METRIC TON OF COAL PRODUCED]	*DATA:*
[PER m^2 RECLAIMED]	*DATA:*
HOW LONG IS THE AREA DISTURBED ON AVERAGE [years]?	*DATA:*
TOTAL AREA DISTURBED BY MINING OVER LIFETIME OF PROJECT [km^2]	*DATA:*
TOTAL AREA RECLAIMED OVER LIFETIME OF PROJECT [km^2]	*DATA:*

3.2 UNDERGROUND MINING

SURFACE AREA UNDERMINED [m^2/yr] OR [m^2/yr PER METRIC TON OF ANNUAL MINE OUTPUT]	*DATA:*
CHARACTERISTICS OF THE DISTURBANCES	*SHORT DESCRIPTION:*
WHAT MEASURES ARE TO BE TAKEN FOR RESTORATION OF AREA DISTURBED (QUALITATIVE AND QUANTITATIVE CHARACTERISTICS)?	*SHORT DESCRIPTION:*
RECLAMATION COST OF LAND DISTURBED DURING THE YEAR (IN NATIONAL CURRENCY UNITS)	
[PER METRIC TON OF COAL PRODUCED]	*DATA:*
[PER m^2 RECLAIMED]	*DATA:*
HOW LONG IS THE AREA DISTURBED ON AVERAGE [years] ?	*DATA:*
TOTAL AREA DISTURBED BY MINING OVER LIFETIME OF PROJECT [km^2]	*DATA:*
TOTAL AREA RECLAIMED OVER LIFETIME OF PROJECT [km^2]	*DATA:*

4. MANPOWER (REFERENCE YEAR) IN [MAN SHIFTS PER YEAR] OR IN [SHIFTS PER METRIC TON PRODUCED]

4.1 MANUAL TECHNICAL (TECHNICIANS, QUALIFIED WORKERS, . . .)	*DATA:*
OF THESE – WORKERS WITH MINING QUALIFICATIONS	*DATA:*
4.2 MANUAL NON-TECHNICAL (NON-QUALIFIED MANPOWER)	*DATA:*
4.3 NON-MANUAL TECHNICAL	*DATA:*
OF THESE – FOREMEN	*DATA:*
– ENGINEERS	*DATA:*
4.4 NON-MANUAL NON-TECHNICAL (EMPLOYEES, . . .)	*DATA:*

4.5 TOTAL PERSONNEL [MAN SHIFTS]	*DATA:*
OF THESE – UNDERGROUND PERSONNEL	*DATA:*
– PREPARATION	*DATA:*
4.6 TOTAL PERSONNEL OF MINE ON BOOKS [PERSONS]	*DATA:*
4.7 PRODUCTIVITY [METRIC TONS PER MAN SHIFT]	
COALFACE	*DATA:*
MINE (UNDERGROUND OR OPEN PIT)	*DATA:*
MINE COMPLEX	*DATA:*
4.8 SHIFT LOSSES [%]	*DATA:*
[MAN SHIFTS PER YEAR]	*DATA:*
4.9 TOTAL PERSONNEL OF OTHER/AUXILIARY UNDERTAKINGS OR COMPANIES SERVING THE MINE (IF THERE ARE ANY) [PERSONS]	*DATA:*

5. MATERIAL ASPECTS FOR OPERATION [QUANTITIES PER YEAR AND/OR PER METRIC TON OF SALEABLE COAL]

5.1 LIST OF MATERIALS, e.g. WOOD [m^3]/EXPLOSIVES [kg]/ METALS [metric tons] *	*DATA:*
5.2 TOTAL MATERIALS [UNITS OF NATIONAL CURRENCY]	*DATA:*
5.3 SOLID WASTE FROM THE MINE, INCLUDING OVERBURDEN, TO BE DISPOSED OF AT THE SURFACE [metric tons]	*DATA:*
5.4 SOLID WASTE FROM THE PREPARATION PLANT [metric tons]	*DATA:*
5.5 SOLID WASTE USED AS STOWING MATERIAL IN THE MINE [metric tons]	*DATA:*

*If more detailed data available, please specify.

(OPTIONAL)

6. OPERATIONAL COSTS OF COAL MINING [UNITS OF NATIONAL CURRENCY PER YEAR AND/OR PER METRIC TON OF RUN-OF-MINE COAL]

TOTAL (EXCLUDING TAXES) *DATA:*

OF THESE:

6.1 WAGES AND SALARIES	*DATA:*
6.2 SOCIAL COSTS	*DATA:*
6.3 DEPRECIATION	*DATA:*
6.4 MATERIALS AND SERVICES	*DATA:*
6.5 OTHER COSTS	*DATA:*

APPENDIX A.3 EXAMPLE OF A PRINTOUT FOR AN OPENCAST MINE IN AUSTRIA

```
g e n e r a l   c h a r a c t e r i s t i c s   o f   m i n e
==============================================================


g e n e r a l   d a t a
-----------------------

process                       :m+p                    mining and preparation
type of technology            :surf                   opencast
data origin                   :proj                   projected (for typical cond.)
reference year                :1983                   reference year
country                       :austria
country code (Tree)           :eb
region                        :southern
state                         :styria
basin                         :voitsberg-koeflach
basin code                    :vkk
field, mine                   :oberdorf

c o a l   i n   p l a c e
-------------------------

area extension of seams       :1390000                square meters
maximum depth of seams        :90                     meters
marginal depth of seams       :180                    meters
total number of seams         :2                      seams
seams to be mined out         :2                      seams
seams mined in ref year       :1                      seams
total seams thickness min     :-1                     meters
total seams thickness max     :-1                     data not available
total seams thickness avg     :30                     meters
avg seam thickn. w.part. min :-1                      data not available
avg seam thickn. w.part. max :-1                      data not available
avg seam thickn. w.partings  :20                      meters
avg seam thickn. w/o part.min:-1                      data not available
avg seam thickn. w/o part.max:-1                      data not available
avg seam thickn. w/o partings:17.3                    meters
maximum mining depth in refyr:14                      meters
```

```
conditions of seams to be mined
-------------------------------------------------------------

seamnum   = seam (strata) name or number
seammined = seam mined in reference year
slowth    = lower thickness of seam in meters
suppth    = upper thickness of seam in meters
savgth    = average thickness of seam in meters
sdepth    = (average) depth of seam in meters
sintermin = interval from above seam (min) in meters
sintermax = interval from above seam (max) in meters
sinter    = interval from above seam (avg) in meters
sdip      = predominant dip of seam in gon (or verbose)
sash      = upper ash content of seam in percent

|seamnum |seammined|slowth    |suppth    |savgth    |sdepth    |
|--------|---------|----------|----------|----------|----------|
|overburd|-1       |    -1.000|    -1.000|    -1.000|     0.000|
|upper ba|yes      |    -1.000|    35.000|    12.000|    -1.000|
|lower ba|no       |    -1.000|    25.000|    18.000|    -1.000|
|--------|---------|----------|----------|----------|----------|


|seamnum |sintermin |sintermax |sinter    |sdip  |sash      |
|--------|----------|----------|----------|------|----------|
|overburd|     0.000|     0.000|     0.000|      |     0.000|
|upper ba|    -1.000|    -1.000|    -1.000|horiz |    -1.000|
|lower ba|    -1.000|    -1.000|    -1.000|horiz |    -1.000|
|--------|----------|----------|----------|------|----------|


coal resources and reserves in
-----------------------------------------------------------
reference year
--------------------------

total geological resources   :34.659               10e6 metric tons
resources in seams mined     :31.959               10e6 metric tons
coal losses in pillars       :-1                   data not available
operational coal losses      :2.3                  percent
econ & tech recov reserves   :31.225               10e6 metric tons
ratio geol to seam resource  :92                   percent
ratio geol resource/reserves :90                   percent
ratio seam resource/reserves :97.7                 percent
```

```
g e o t e c h n i c a l   c o n d i t i o n s
---------------------------------------------

tectonic distortions         :regbed              regular bedding
coal density in situ         :1.275               metric tons per cu meter
type of rocks                :s,cla               sand,clay
rock density (average)       :1.95                metric tons per cu meter
gas emanation tendency       :-1                  data not available
gas emanation (quantity)min  :-1                  data not available
gas emanation (quantity)max  :-1                  data not available
gas emanation (quantity)     :-1                  data not available
spontan. combustion tendency :yes
water inflow (maximum)       :315360              cu meters per year

c o a l   q u a l i t y
-----------------------

grade of coal                :subbit              subbituminous coal
coking ooal                  :no
moisture content minimum     :26.44               percent
moisture content maximum     :38.05               percent
moisture content average     :31.98               percent
calorific cont raw coal min  :1980.00             kcal per kilogram
calorific cont raw coal max  :2977.00             kcal per kilogram
calorific cont raw coal avg  :2493.00             kcal per kilogram
calorific content waf min    :-1                  data not available
calorific content waf max    :6400.00             kcal per kilogram
calorific content waf avg    :6000.00             kcal per kilogram
ash content raw coal min     :12.35               percent
ash content raw coal max     :33.23               percent
ash content raw coal avg     :23.66               percent
ash content dry coal min     :19.59               percent
ash oontent dry ooal max     :47.27               percent
ash content dry coal avg     :34.42               percent

o o a l   q u a l i t y   (continued)
-------------------------------------

fixed oarbon min             :-1                  data not available
fixed carbon max             :-1                  data not available
fixed carbon average         :-1                  data not available
hydrogen content min         :-1                  data not available
hydrogen content max         :-1                  data not available
hydrogen content average     :-1                  data not available
sulfur content dry coal min  :-1                  data not available
sulfur content dry coal max  :1.05                percent
sulfur content dry coal avg  :0.70                percent
volatile matter min          :-1                  data not available
volatile matter max          :-1                  data not available
volatile matter average      :-1                  data not available
regularity of coal quality   :regular             quality factors regular
```

```
l a n d s c a p e   a n d   h y d r o l o g y   d a t a
-------------------------------------------------------
possible other minerals      :no
surface landscape            :hillmont             hilly mountain landscape
land use                     :used                 land use (below)
land use (description)       :grazing
land use (description cont.) :forest               forestry
land use (description cont.) :agricul              farming
hydrology: river system      :small                river system
river name A                 :Kainach
river name B                 :-1                   data not available
water in coal bearing bed    :moderate             moderately watery coal bed

c l i m a t e ,   p o p u l a t i o n   &   i n f r a s t r u c t u r e   d a t a
-------------------------------------------------------------------------------

average january temperature  :-1                   data not available
average july temperatue      :15                   degrees celsius
annual precipitation min     :-1                   data not available
annual precipitation max     :-1                   data not available
annual precipitation avg     :-1                   data not available
depth of ground freezing min :-1                   data not available
depth of ground freezing max :-1                   data not available
depth of ground freezing avg :-1                   data not available
industrial development       :develop              developed industry
population density (data)    :-1                   data not available
population density (descrip.):great                great population density
long distance transportation :existing             existing/possible

m i n e   c a p a c i t y   a n d   l i f e t i m e
---------------------------------------------------

annual capacity raw coal     :1.25                 10e6 metric tons
annual capacity sale coal    :1.25                 10e6 metric tons
construction period          :5                    years
mine output increasing period:3                    years
total life period of mine    :28                   years
year of exploitation start   :1980                 calendar year
year of last modernization   :0                    not applicable (new mine)
coal output raw coal         :1.25                 10e6 metric tons
coal output sale coal        :1.25                 10e6 metric tons
number of working days       :252                  days
lower limit of scaling factor:-1                   data not available
upper limit of scaling factor:-1                   data not available
exponential scaling factor Se:-1                   data not available
```

```
e v o l u t i o n   a n d   m i n e  c a p a c i t y   o v e r   l i f e t i m e
-------------------------------------------------------------------------------------

caprom = capacity raw coal in year in 10e6 metric tons raw coal
capsal = capacity sale coal in year in 10e6 metric tons sale coal

note : if capacity remains stable only first and last year are given !

¦year  ¦caprom    ¦capsal     ¦
¦-----------------------------¦
¦  1980¦     0.100¦      0.100¦
¦  1981¦     0.350¦      0.350¦
¦  1982¦     0.620¦      0.620¦
¦  1983¦     0.920¦      0.920¦
¦  1984¦     1.230¦      1.230¦
¦  1985¦     1.370¦      1.370¦
¦  1986¦     1.250¦      1.250¦
¦  2002¦     1.250¦      1.250¦
¦  2003¦     1.000¦      1.000¦
¦  2008¦     1.000¦      1.000¦
¦-----------------------------¦

s p e c i a l   p a r a m e t e r s   f o r   s u r f a c e / u n d e r g r o u n d   m i n i n g
-----------------------------------------------------------------------------------------------------

number of operating units    :2                      operating units
# of operating units (coal)  :2                      operating units
# of operating units (overb.):2                      operating units
average output from unit     :2500                   metric tons per day
working days/yr: coal winning:252                    days
working days/yr: overburden  :252                    days
# of shifts/day: coal winning:3                      shifts per day
# of shifts/day: overburden  :3                      shifts per day
number of hours per shift    :8                      hours
method of mining             :stripbw                stripping:bucket wheel excavator
necessity of rock blasting   :no
necessity of coal blasting   :no
overburden to coal ratio     :4.45                   cu meters per metric ton
```

```
e q u i p m e n t   f i l e
---------------------------

equipn(um) = number of equipment items
manufact   = equipment manufacturing company
weightons  = weight of all items in metric tons

:equipuse:equipn:item                  :model        :manufact         :weightons :
:-------------------------------------------------------------------------------:
:others  :      1:car                  :lada taiga   :LADA             :     1.000:
:others  :      1:diesel generator     :-1           :-1               :     5.000:
:others  :      5:transporter          :VW pritsche  :Volkswagen       :     5.000:
:product :      1:belt-conv.system/co  :-1           :VOEST ALPINE     :   359.000:
:product :      1:belt-conv.system/ov  :-1           :VOEST ALPINE     :  3858.000:
:product :      1:belt-moving dozer    :D 155 C      :KOMATSU          :    40.000:
:product :      1:bulldozer            :D 65 E       :UNIMOG           :    20.000:
:product :      1:hydr. crane          :-1           :UNIMOG           :     4.000:
:product :      1:stacker              :ARS 1600     :VOEST ALPINE     :   308.000:
:product :      1:supporting car       :-1           :VOEST ALPINE     :     7.000.
:product :      1:track-type loader    :D 65 S       :KOMATSU          :    20.000:
:product :      1:tripper car          :-1           :VOEST ALPINE     :    41.000:
:product :      2:belt car             :BRS 1400     :VOEST ALPINE     :   460.000:
:product :      2:bucket wheel exc.    :SRS 400      :Lauchh./TAKRAF   :   928.000:
:product :      2:hopper & cable car   :-1           :VOEST ALPINE     :    50.000:
:product :      4:bulldozers           :D 155 A      :KOMATSU          :   140.000:
:-------------------------------------------------------------------------------:
```

```
s p e c i f i c   w e l m m   r e q u i r e m e n t s   f o r   c o n s t r u c t i o n
=========================================================================================
perrom  = specific welmm requirements per metric ton run of mine coal
persale = specific welmm requirements per metric ton saleable coal

note : if no coal preparation perrom = persale          -1.000 means data not available !
¦name                                        ¦perrom    ¦persale   ¦unit                          ¦
¦-----------------------------------------------------------------------------------------------¦
¦water inflow during construction            ¦     0.505¦     0.505¦m3 per t ann capacity         ¦
¦water used during construction              ¦     0.000¦     0.000¦m3 per t ann capacity         ¦
¦electricity                                 ¦    40.000¦    40.000¦kwh per t ann capacity        ¦
¦motor fuel                                  ¦     1.228¦     1.228¦liters per t ann capacity     ¦
¦land affected by construction               ¦     0.080¦     0.080¦ha per 10e3 t ann capacity    ¦
¦total land leased incl waste rock piles     ¦     0.160¦     0.160¦ha per 10e3 t ann capacity    ¦
¦land occupied by mine buildings             ¦     0.160¦     0.160¦ha per 10e3 t ann capacity    ¦
¦land for railways & worker villages         ¦    -1.000¦    -1.000¦ha per 10e3 t ann capacity    ¦
¦manual technical manpower                   ¦   292.000¦   292.000¦manyears per 10e6 t ann cap.  ¦
¦workers with mining qualifications          ¦    -1.000¦    -1.000¦manyears per 10e6 t ann cap.  ¦
¦manual non technical manpower               ¦   452.000¦   452.000¦manyears per 10e6 t ann cap.  ¦
¦non manual technical manpower               ¦   104.000¦   104.000¦manyears per 10e6 t ann cap.  ¦
¦foremen                                     ¦    84.000¦    84.000¦manyears per 10e6 t ann cap.  ¦
¦engineers                                   ¦    20.000¦    20.000¦manyears per 10e6 t ann cap.  ¦
¦non manual non technical manpower           ¦    12.000¦    12.000¦manyears per 10e6 t ann cap.  ¦
¦total manpower                              ¦   876.000¦   876.000¦manyears per 10e6 t ann cap.  ¦
¦underground manpower                        ¦     0.000¦     0.000¦manyears per 10e6 t ann cap.  ¦
¦manpower in preparation plant               ¦    -1.000¦    -1.000¦manyears per 10e6 t ann cap.  ¦
¦wood                                        ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦field metals                                ¦    -1.000¦    -1.000¦t per 10e3 t ann capacity     ¦
¦concrete                                    ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦cement                                      ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦ferro concrete                              ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦soft roof materials                         ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦oil,bitumen                                 ¦    -1.000¦    -1.000¦t per 10e3 t ann capacity     ¦
¦bricks                                      ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦glass                                       ¦    -1.000¦    -1.000¦m2 per 10e3 t ann capacity    ¦
¦sand                                        ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦ceramic plates                              ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦gravel,stone                                ¦    -1.000¦    -1.000¦m3 per 10e3 t ann capacity    ¦
¦explosives                                  ¦    -1.000¦    -1.000¦t per 10e3 t ann capacity     ¦
¦metals in buildings and equipment           ¦    -1.000¦    -1.000¦t per 10e3 t ann capacity     ¦
¦waste rock mined & stored during constr.    ¦  9600.000¦  9600.000¦m3 per 10e3 t ann capacity    ¦
¦waste rock mined & stored during constr.    ¦ 18720.000¦ 18720.000¦t per 10e3 t ann capacity     ¦
¦total working weight of equipment           ¦     4.997¦     4.997¦t per 10e3 t ann capacity     ¦
¦specific capital investment                 ¦    -1.000¦    -1.000¦us $ 1975 per t ann capacity  ¦
¦investment during construction              ¦    26.641¦    26.641¦us $ 1975 per t ann capacity  ¦
¦infrastructure investment                   ¦     1.675¦     1.675¦us $ 1975 per t ann capacity  ¦
¦indirect investment incl interests          ¦     1.066¦     1.066¦us $ 1975 per t ann capacity  ¦
¦direct investment total                     ¦    23.900¦    23.900¦us $ 1975 per t ann capacity  ¦
¦mine buildings a o facilities               ¦    10.999¦    10.999¦us $ 1975 per t ann capacity  ¦
¦mine equipment                              ¦    12.902¦    12.902¦us $ 1975 per t ann capacity  ¦
¦preparation facility                        ¦    -1.000¦    -1.000¦us $ 1975 per t ann capacity  ¦
¦mine opening and development                ¦     9.629¦     9.629¦us $ 1975 per t ann capacity  ¦
¦mine surface facilities                     ¦    -1.000¦    -1.000¦us $ 1975 per t ann capacity  ¦
¦-----------------------------------------------------------------------------------------------¦
```

specific welmm requirements for operation

perrom = specific welmm requirements per metric ton run of mine coal
persale = specific welmm requirements per metric ton saleable coal

note : if no coal preparation perrom = persale   -1.000 means data not available !

name	perrom	persale	unit
water inflow during operation	0.252	0.252	m3 per t produced
additional water supply	0.000	0.000	m3 per t produced
water used by the mine (total)	0.000	0.000	m3 per t produced
water used by the preparation plant	0.000	0.000	m3 per t ann output
water pumped out, total	0.252	0.252	m3 per t produced
water inflow per year	315360.000	315360.000	m3 per year
electricity	21.356	21.356	kwh per t produced
motor fuel	0.534	0.534	liters per t produced
process heat fuel	-1.000	-1.000	tce per 10e3 t produced
land undermined (underground mining)	0.000	0.000	m2 per t ann output
land disturbed by mining	0.057	0.057	m2 per t ann output
height of topsoil	0.300	0.300	meters
land area reclaimed	0.057	0.057	m2 per t of output
reclamation cost	30.000	30.000	us $ 1975 per t produced
reclamation cost	0.133	0.133	us $ per m2
disturbance duration	-1.000	-1.000	years
land area disturbed over lifetime	-1.000	-1.000	km2
land area reclaimed over lifetime	-1.000	-1.000	km2
manual technical manpower	0.039	0.039	manshifts per t produced
workers with mining qualifications	-1.000	-1.000	manshifts per t produced
manual non technical manpower	0.016	0.016	manshifts per t produced
non manual technical manpower	0.007	0.006	manshifts per t produced
foremen	0.005	0.005	manshifts per t produced
engineers	0.001	0.001	manshifts per t produced
non manual non technical manpower	0.002	0.002	manshifts per t produced
total manpower	0.088	0.088	manshifts per t produced
underground manpower	0.000	0.000	manshifts per t produced
personnel of mine on books	318.000	318.000	persons
manual technical manpower	156.000	156.000	manyears per 10e6 t produced
workers with mining qualifications	-1.000	-1.000	manyears per 10e6 t produced
manual non technical manpower	64.800	64.800	manyears per 10e6 t produced
non manual technical manpower	25.600	25.600	manyears per 10e6 t produced
foremen	21.600	21.600	manyears per 10e6 t produced
engineers	4.000	4.000	manyears per 10e6 t produced
non manual non technical manpower	8.000	8.000	manyears per 10e6 t produced
total manpower	254.400	254.400	manyears per 10e6 t produced
underground manpower	0.000	0.000	manyears per 10e6 t produced
auxiliary manp. of other companies	21.600	21.600	manyears per 10e6 t produced

labor productivity	-1.000	-1.000	t per manshift
productivity: coalface	17.857	17.857	t per manshift
productivity: mine	16.667	16.667	t per manshift
productivity: mine complex	-1.000	-1.000	t per manshift
shift losses	-1.000	-1.000	manshifts per t produced
shift losses	20.000	20.000	percent
manpower in preparation plant	0.008	0.008	manshifts per t produced
manpower in preparation plant	33.600	33.600	manyears per 10e6 t produced
wood	0.000	0.000	m3 per t produced
explosives	-1.000	-1.000	kg per t produced
metal(supports wo hydraulic)	0.011	0.011	t per t produced
other metals	-1.000	-1.000	t per t produced
other materials	-1.000	-1.000	us $ 1975 per t produced
total materials excl. fuel	-1.000	-1.000	us $ 1975 per t produced
solid waste to be disposed of at surface	2.035	2.035	t per t produced
solid waste from the preparation plant	-1.000	-1.000	t per t produced
solid waste used as stowing material	0.000	0.000	t per t produced
total operational costs of mining	-1.000	-1.000	us $ 1975 per t produced
wages and salaries	-1.000	-1.000	us $ 1975 per t produced
social costs	-1.000	-1.000	us $ 1975 per t produced
depreciation	-1.000	-1.000	us $ 1975 per t produced
other costs	-1.000	-1.000	us $ 1975 per t produced

Footnote: Oberdorf mine (s-eb-vkk01)

references: **WELMM** - questionnaire filled out by mining company

field trip to mine and meeting with mine engineers

reference A : Kuckenberger,Walter: Oberdorf opencast mine,
an Alpine brown coal project in Austria.
10th WORLD MINING CONGRESS,Istanbul,Sept.1979
I-5/p1-13

contact persons: Bergdir.Dipl.-Ing. Kuckenberger
Berginsp.Dipl.-Ing. Kornberger
Dipl.-Ing. Magele
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1) GENERAL CHARACTERISTICS OF MINE

cminesa: general data

cminesb: coal in place

cminesc: conditions of seams to be mined (genesis)

(reference A)

The coal deposits in the southeast of Austria were formed in the Miocene period as freshwater deposits. The structure of the coal is lignitic. The ranges of basement rocks subdivide the Tertiary coal basin into several partial synclines up to 350 m deep.

The Oberdorf coal syncline : The Oberdorf mining area is in the form of a circular field with an area of about 2 km2. There are built-up areas adjoining the mining area to the west and south. Although coal has been mined for over 200 years there, the yield has been only 11 million metric tons. There was some opencast mining of seam outcrops. From 1967 to the end of 1978 mining was underground with mechanized longwall working. This underground mining led to subsidence and splitting of the covering layers , producing large faults and dips on the surface, which filled with water.

The coal bed consists of sandy clay of layers up to 30 m thick resting on a Mesozoic (Gosau) and Paleozoic (Devonian Dolomite) base. The coal formation has a mild to moderate inclination, with thicknesses of up to 40 m at the lowest part of the syncline. The formation is divided by a ridge of foundation rocks penetrating from the north and faults into eastern and western sections. There is also a sub-bed of up to 30 m thickness, similar to the facies of the upper bed, diverging from the seams, and here the sandy-clay intermediate layers are up to 50 m thick. The layers covering the coal, which have a maximum thickness of 160 m, mainly consist of blue-grey sands and clays. Towards the top of the mountain these layers are covered by gravel and alluvium, and on the mountainside by brown loam. There is considerable variation in the quality of the coal.

cminesd: coal resources and reserves in reference year

cminese: geotechnical conditions

Coal is very tough with compression strength of 2000 N/cm2, cutting against the grain will entail cutting forces of up to 3500 N/cm (Newtons per cm of cutting edge)

cminesf: coal quality 1

The average values of moisture content, ash content of raw coal, ash content of dry coal and calorific value of raw coal (which is the lower calorific value) are calculated from 11 analysis values.

cminesg: coal quality 2

cminesh: landscape and hydrology data

The future land use will be for a recreation center and for forestry.

cminesi: **climate, population & infrastructure**

data

The value for annual precipitation is an average value for the last 78 years.

In 1978 the coal production of this basin, done by 3 coal-mining undertakings in opencast and underground mining, was 1750000 metric tons. Of the coal sold, 15% went to industry, 22% for domestic consumption, and 63% to power stations. The coal of Oberdorf will provide 1.25 million tons per year over 25 years for the power plants (330 MW, which are under construction at present time).

The difficulty is the smallness of the field and the resultant short and irregular faces, mostly requiring relatively small, powerful and mobile mining equipment.

A permanent problem in future will be the expensive noise reduction measures.

The realization of this opencast project was not only of particular regional relevance - mining has a not inconsiderable influence on the prosperity of this region - but also of national relevance, since the extraction of domestic coal also makes a small contribution to Austria's energy supply (ref.A).

cminesj: **mine capacity and lifetime**

cminesk: **evolution and mine capacity over lifetime**

METHOD OF MINING: In view of all the special features of Alpine deposits, as well as the need to start producing coal in 1980 the mining plans are as follows: The mountain col up to a height of 484 m a.s.l. will be removed in four blocks and four phases. Work on block 1 started in September 1977. Work should finish by the beginning of 1980. The height difference in block 1 is 90 m, so that the conveyors have to be lowered at short intervals. Since this removal work showed that there was less undermined and solider ground than expected, the carriages of the larger vehicles were modified in accordance with the ground conditions. Below 484 m a.s.l. an anticlockwise swivel is used to remove the overburden. The swivel point for the first unit was selected near the Oberdorf shaft. Work towards exposing the coal is being carried out in the south part of the west syncline and will be completed in 1980-1981. Before the coal is reached at the end of 1980 some 12 million tons of overburden will have to be removed.

Both mining areas are working with blocks of 20 m width, each group working to a cutting height of 34 m, divided into five sections of 12, 5, 5, 7 and 5 m height respectively.

The excavator and, if necessary, the conveyor belt vehicle move after each cut to the next section, and after reaching the lowest section drive up an interior ramp back to the top. The stoping conveyor unit is always in the third section.After the coal has been removed from the west syncline. the first internal tip can be started, this having a capacity of 24 million m3. The remaining 30 million m3 will be tipped on the flat southern part of the east syncline of the opencast area (ref.A).

The overburden to coal ratio is calculated from:
139000000 m3 of overburden (total) / 31225000 t of coal mined (total)

cminesn: equipment file

Values concerning working weight for the D 65 E, D 65 S, the UNIMOG and the cars are estimated values.

Additional information on equipment:
bucket wheel excavator SRS 400.14/1.0 (500 kW)
belt car BRS 1400/23+24x12.5 (250 kW)
stacker ARS 1600/20+30x12.5 (900 kW)
bulldozer D 155 A (320 hp)
bulldozer D 65 E (155 hp)
track-type loader D 65 S (155 hp)

preparation and loading facility

The material to be transported is brought from the point of extraction by the face belts to the main belts at a central transfer point. Transfer is by means of swiveling belts that pass the overburden or coal to the appropriate conveyors. As preliminary investigations have shown, the coal will be extracted with edge lengths of up to 700 m. For this reason a continuous crusher will be installed at the central transfer point to break the coal down to a maximum lump size of 250 mm. Subsequently the coal will be moved by belts 1000 mm wide and moving at 3.5 m/s in its raw state to a sieving and breaking plant still to be built. It is planned to use a hammer crusher with rotating cylinders for crushing mud coal, instead of impact plates.

From the sieving and crushing plant power station, coal, size 0-30 mm, will mostly be transferred to a mixing tip to even out the coal quality. However, intermediate storage is also necessary for reasons of streaming production, since in many years of operation it is expected that the total annual production required will be achieved in 5 to 6 months each year, thus permitting the extractor groups to work with optimal efficiency.

The mixing tip or intermediate storage facility will be removed using a paddlewheel device. The coal will be weighed and sampled on belts with a fixed hourly capacity,which transport the coal continuously to the power station.

2) SPECIFIC WELMM REQUIREMENTS FOR CONSTRUCTION

water

No impacts of the construction on local water resources.

energy

land

manpower

materials

investments

financial costs :
1976 - 2.30 million austrian schillings
1977 - 12.25 million austrian schillings
1978 - 24.75 million austrian schillings
1979 - 33.75 million austrian schillings
1980 - 43.25 million austrian schillings
1981 - decrease

3) SPECIFIC WELMM REQUIREMENTS FOR OPERATION

water

Pollution of water is negligible.

resnum 136 = maximum value

energy

land

Measures taken for recultivation : regrading , seeding and afforestation.
Gradients of the endslopes : 20-30 degrees
Surface area disturbed by mining over lifetime : 1977-1990 = 100 ha
1990-2008 = 87 ha

manpower

resnum 431 : calculated for 252 working days

materials

Consumption of hard metal during operation : 2 kg/1000 m3 for cutting teeth per bucket wheel excavator.

operational costs

APPENDIX B DEFINITIONS AND MINIMUM/MAXIMUM VALUES OF VARIABLES USED IN THE STATISTICAL ANALYSES (SECTIONS 4.1.2 AND 4.2.2)

APPENDIX B.1 DEFINITIONS OF VARIABLES

$R(R^2)_{\text{index}}$	the (squared) multiple correlation coefficients after introduction of the variable(s) specified by the index into the regression equation
n	number of observations
s	standard error of the estimate and of the regression coefficients

Opencast Mining

$Cdir_{\text{spec}}$	specific direct investment costs (excluding coal preparation) (US \$(1975)/t raw coal per year)
$Cequip_{\text{spec}}$	specific equipment investment costs (excluding coal preparation) (US \$(1975)/t raw coal per year)
$Ctot_{\text{spec}}$	specific total construction costs (excluding coal preparation) (US \$(1975)/t raw coal per year)
$E_{\%}$	fraction of electricity in the total energy requirements (percentage)
El_{spec}	specific electricity requirements (excluding coal preparation) (kWh/t raw coal produced)
En_{spec}	specific total energy requirements (including coal preparation) (kWh equivalent/t raw coal produced)
L_{spec}	specific land requirements (m^2/t saleable coal)
Mat_{spec}	specific material costs (including coal preparation) (US \$(1975)/t saleable coal)
Mp_{spec}	specific total manpower requirements (excluding coal preparation) (persons per 10^6 t raw coal per year)
O_{R}	annual mine output (10^6 t raw coal per year)
$R_{\text{o:c}}$	overburden to coal ratio (m^3/t)
R_{R}	size ratio, $1/O_{\text{R}}$
S_{avg}	average seam thickness mined (m)
S_{tot}	total seam thickness mined (m)
Th_{ov}	overburden thickness (m)

Underground Mining

D_{max}	maximum mining depth (km)
El_{pred}	value of the specific electricity requirements predicted from eqn. (16) (kWh/t raw coal produced)
El_{raw}	specific electricity requirements (excluding coal preparation) (kWh/t raw coal produced)
L_{tot}	total number of mine personnel employed (persons)
L_{und}	total number of underground personnel employed (persons)
M_{Ptot}	specific total mine personnel employed (persons/10^3 t raw coal produced)
Mat_{spec}	specific material costs (roubles (1977)/t raw coal produced)
Mat_W	amount of waste rock produced (t/t raw coal mined)
O_{MPtot}	annual raw coal output per unit of mine personnel employed (including social and related services but excluding coal preparation) (10^3 t per year per person)
O_{MPund}	annual raw coal output per unit of underground personnel employed (10^3 t per year per person)
O_{raw}	annual mine output (10^6 t raw coal per year)
P_{und}	underground labor productivity (t raw coal per shift worked)
S_{avg}	average seam thickness mined (m)
W	water inflow (m^3/t raw coal produced)

APPENDIX B.2 MINIMUM AND MAXIMUM VALUES OF VARIABLES

The type of relationship described may be valid only within the interval described by these minimum/maximum values. No extrapolation beyond these limits should be attempted. Where a linear relationship is presented, this does not imply that the relationship under consideration is of linear form in general, *but rather that the relationship is approximated* within the intervals considered *by a linear form.*

Equation/ Figure	Variable	Unit	Minimum	Maximum
			value considered in analysis	
Eqn. (3)	O_R	10^6 t/yr	0.14	60.00
Fig. 6 (f_1)	$R_{o:c}$	m^3/t	0.29	15.05
Fig. 7	Mp_{spec}	persons/10^6 t/yr	17.30	97.90
	$R_{o:c}$	m^3/t	1.11	15.05
Eqn. (4)	En_{spec}	kWh_{equiv}/t	18.54	60.45
Fig. 8	R_R	$(10^6\ t/yr)^{-1}$	0.02	7.10
Eqn. (5)	$R_{o:c}$	m^3/t	1.50	15.05
	$E_{\%}$	percent	16.24	90.68
Fig. 9	El_{spec}	kWh/t	1.55	29.30
	$R_{o:c}$	m^3/t	1.77	15.05
Fig. 10	For comparison only			
Fig. 11	From Academy of Sciences of the USSR (1979)			
Fig. 12	L_{spec}	m^2/t	0.012	0.78
	$R_{o:c}$	m^3/t	0.29	15.05
Eqn. (6)	L_{spec}	m^2/t	0.018	0.78
	S_{avg}	m	1.17	55.00
	Th_{ov}	m	13.00	95.00
Eqn. (7)	L_{spec}	m^2/t	0.012	1.45
	S_{tot}	m	1.22	60.00
	Th_{ov}	m	13.00	95.00
Fig. 13 (f_1)	L_{spec}	m^2/t	0.014	0.78
	S_{avg}	m	1.17	55.00
Fig. 13 (f_2)	L_{spec}	m^2/t	0.012	1.45
	S_{tot}	m	1.22	130.00
Fig. 14	$Ctot_{spec}$	US \$(1975)/t/yr	4.71	30.97
	$R_{o:c}$	m^3/t	1.77	15.05
Eqn. (8)	$Cdir_{spec}$	US \$(1975)/t/yr	3.27	30.91
Fig. 15	$R_{o:c}$	m^3/t	1.30	15.05
	R_R	$(10^6\ t/yr)^{-1}$	0.017	0.80
Fig. 16	$Cequip_{spec}$	US \$(1975)/t/yr	3.01	23.41
	$R_{o:c}$	m^3/t	1.30	15.05

Equation/ Figure	Variable	Unit	Minimum	Maximum
			value considered in analysis	
Eqn. (9)	From Ivanov and Yevdokimov (1973)			
Eqn. (10)	From Alymov *et al.* (1972)			
Eqn. (11)	D_{max}	km	0.16	1.37
	S_{avg}	m	1.06	3.31
Eqn. (12)	O_{raw}	10^6 t/yr	0.43	9.77
Eqn. (13)	P_{und}	t/man-shift	2.68	9.00
Fig. 17 (f_1)	S_{avg}	m	1.09	3.31
	D_{max}	km	0.16	1.26
	O_{raw}	10^6 t/yr	0.61	9.77
	W	m^3/t	0.07	8.50
Eqn. (14)	O_{MPund}	10^3 t/yr/person	0.64	2.21
	S_{avg}	m	1.09	3.31
	D_{max}	km	0.16	1.26
	O_{raw}	10^6 t/yr	0.61	9.77
	W	m^3/t	0.07	8.50
Fig. 17 (f_2)	L_{und}	persons	481.29	5,982.00
	O_{raw}	10^6 t/yr	0.61	9.77
Eqn. (15)	O_{MPtot}	10^3 t/yr/person	0.42	1.57
	S_{avg}	m	1.09	3.31
	O_{raw}	10^6 t/yr	0.61	9.77
	W	m^3/t	0.07	8.50
Fig. 18	M_{Ptot}	persons/10^3 t	0.64	2.39
	L_{tot}	persons	734.34	7,432.00
	O_{raw}	10^6 t/yr	0.61	9.77
Eqn. (16)	El_{raw}	kWh/t	10.69	87.33
Fig. 19	D_{max}	km	0.16	1.07
	O_{raw}	10^6 t/yr	0.61	4.13
Eqn. (17)	El_{pred}	kWh/t	13.41	65.91
	W	m^3/t	0.10	8.50
Eqn. (18)	El_{raw}	kWh/t	10.69	87.33
Fig. 19 (predicted values)	D_{max}	km	0.16	1.07
	O_{raw}	10^6 t/yr	0.61	4.13
	W	m^3/t	0.10	8.50
Fig. 20	Mat_{spec}	roubles/t	0.61	2.18
	S_{avg}	m	1.15	3.20
Fig. 21	From Astakhov (1977b)			
Eqn. (19)	Mat_W	t/t	0.02	0.563
	S_{avg}	m	1.06	3.08
	D_{max}	km	0.16	1.37
	O_{raw}	10^6 t/yr	0.43	9.77

APPENDIX C CONVERSION TABLE

From:	**Conversion factor: multiply with**	*Into:*
Length		
mile, US	**1.609**	*km*
yard	**0.9144**	*meter*
foot	**0.3048**	*meter*
inch	**0.0254**	*meter*
Area		
square mile	**2.59**	km^2
acre	**0.004047**	km^2
	4,046.87	m^2
square yard	**0.836**	m^2
Volume		
acre-foot	**1,233.374**	m^3
	$1.233 \cdot 10^6$	*liters*
cubic yard	**764.55**	*liters*
	0.7645	m^3
cubic foot	**28.317**	*liters*
barrel, US	**158.987**	*liters*
gallon, US	**3.7854**	*liters*
gallon, Imperial	**4.546**	*liters*
Mass		
long ton	**1.016**	*metric ton*
short ton	**0.9072**	*metric ton*
pound	**0.4536**	*kg*
Others		
Stripping ratio:		Overburden to coal ratio:
yd^3/short ton	**0.843**	m^3/*metric ton*
Density:		
lb/yd^3	**0.59333**	kg/m^3
	0.00059333	*metric ton*/m^3
Calorific value:		
Btu/lb	**2.3241**	*kJ/kg*
kcal/kg	**4.1876**	*kJ/kg*
360° (degrees)	**1**	400^g *(gon)*

APPENDIX D ESCALATION AND EXCHANGE RATES FOR SELECTED COUNTRIES, 1965 TO 1983

Year	Australian dollar ($A)	Austrian schilling (AS)	Canadian dollar (CAN$)	French franc (FF)	German mark (DM)	UK pound (£)	US dollar ($)	USSR rouble (R)
1965	52.7	59.9	58.1	52.8	65.9	43.3	58.6	
1970	61.4	70.3	70.2	65.4	74.2	54.2	72.1	
1971	65.1	73.6	72.2	69.0	78.1	59.3	75.2	
1972	69.0	78.2	75.7	73.3	82.5	63.6	77.7	
1973	75.5	84.2	81.4	78.7	88.2	69.4	82.6	
1974	86.9	92.2	90.3	89.5	94.4	80.5	91.6	
1975	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1976	113.5	107.3	107.5	109.6	104.3	116.5	105.8	105.0[a]
1977	127.5	113.2	116.1	119.9	108.1	135.0	112.7	110.3[a]
1978	137.6	117.3	126.5	130.8	111.1	146.2	121.2	
1979	150.1	121.6	138.1	144.8	115.6	165.8	134.9	
1980	165.4	129.3	152.1	164.1	122.0	195.6	153.1	
1981	181.3	138.1	171.0	186.0	129.2	218.8	169.0	
1982	201.6	145.6	189.5	208.6	136.0	237.7	179.3	
1983[b]	215.4[c]	149.2	199.1	226.0	139.4	247.4	184.2	
1975 exchange rate:[d]								
1 US $ =	0.763	17.43	1.017	4.81	2.463	0.452	1	0.7[a]

[a] Rates used in this report. The official exchange rates in 1975 ranged from 100 US $ = 69 to 75.5R. Escalation of 5% per year is assumed.

[b] Average of second quartal, 1983.

[c] Average of first quartal, 1983.

[d] From C. Manthy (ed.) (1980) *Energy Technology Data Handbook*, vol. 1 *Conversion Technology*, Jül-Spec 70/vol. 1 (Kernforschungsanlage Jülich, FRG).

Source: International Monetary Fund, *International Financial Statistics*, vol. 35 (Yearbook 1982) and vol. 36/9 (September 1983).

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