XA9745303

COAL SECTOR MODEL: SOURCE DATA ON COAL FOR THE ENERGY AND POWER EVALUATION PROGRAM (ENPEP)

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Abstract

Coal is the major primary energy source in Poland and this circumstance requires that the data on coal supply for use in energy planning models should be prepared properly. Economic sectors' development depends on many factors which are usually considered in energy planning models. Thus, data on the development of such sectors as coal mining should be consistent with the economic assumptions made in the energy planning model. Otherwise, coal data could bias the results of the energy planning model. The coal mining and coal distribution models which have been developed at the Polish Academy of Sciences could provide proper coal data for use in ENPEP and other energy planning models.

The coal mining model optimizes the most important decisions related to coal production, such as coal mines development, retirement of non-profitable mines, and construction of new mines. The model uses basic data forecasts of coal mine costs and coal production. Other factors such as demand for coal, world coal prices, etc., are parameters which constitute constraints and requirements for the coal mining development. The output of the model is the amount of coal produced and supply curves for different coal types. Such data are necessary for the coal distribution model and could also be used by ENPEP.

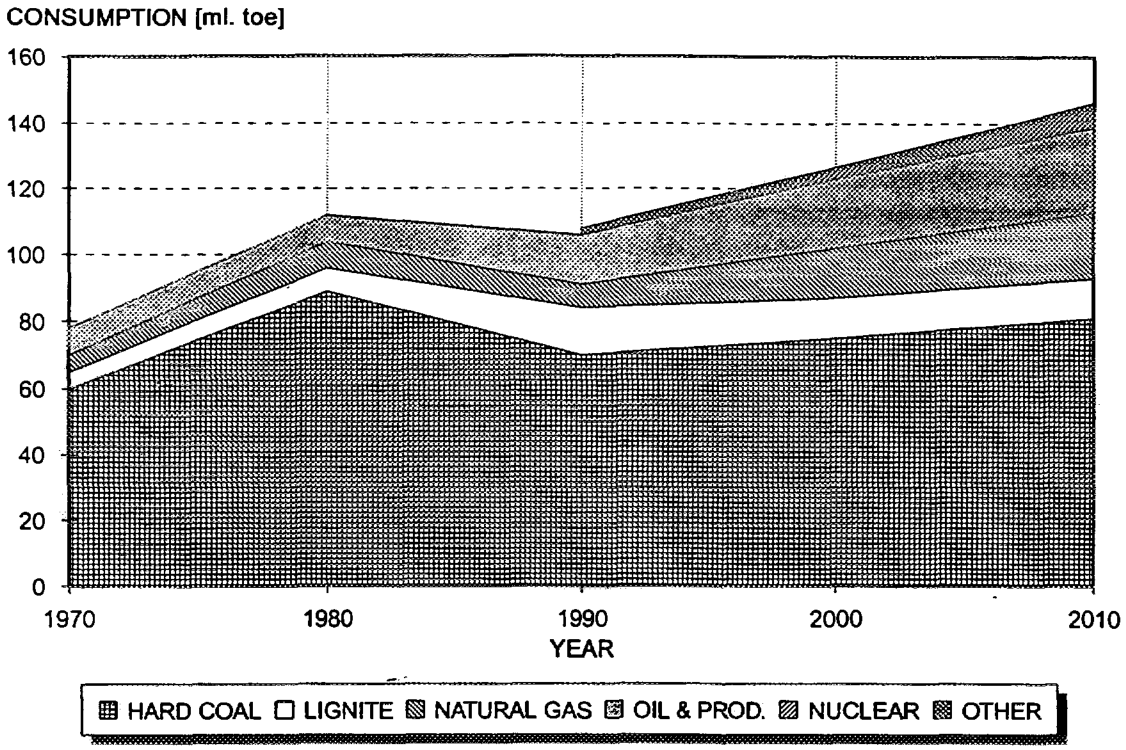
This paper describes the model, its structure and how the results of the model could serve as coal-related data for ENPEP. Improvement of some input data forms of the BALANCE module of ENPEP are also suggested in order to facilitate data preparation.

1. INTRODUCTION

Hard coal is the major component of the Polish primary energy supply and presently represents about 67% of the total primary energy. This share should diminish in the future (Fig. 1), although the amount of coal consumed is expected to increase.

Research on the future of large systems such as the energy supply/demand system requires considerable amount of data of various kind. Models, like ENPEP which deals with integrated systems, need to be provided with data on primary energy supply. The data on coal supply to be used by energy systems models, need to be elaborated carefully since minor distortions could lead to improper results. The wide range of data are required. These range from the characteristics of primary energy supply technologies (the SPSEK system used in Poland) through costs and production of specific fuels (IPM for power generation planning) or supply curves (ENPEP).

Fig. 1 PRIMARY ENERGY SUPPLY in POLAND



Data on fuel supply sectors are usually prepared under different projects and constitute one fixed set of data. The underlying assumption is that the sectors will be relatively stable and therefore the data associated to these sectors will not need any modification. This might be the case for small and not very relevant supplies or stable sources such as coal imported from major coal exporting countries. Any other supply sector should be considered as variable with possible modifications of its structure, level of production, costs, etc. The different factors which cause these changes are usually considered within the energy planning models (by means of scenarios). The data on primary energy supply required for such models should be coherent with the values of these factors.

On the other hand, there are other factors which are not considered in the energy planning models, but which are specific to the fuel supply sectors. In case they are considered as relevant factors, the modeler should try to establish a link between the corresponding factor and the other known factors considered in the energy planning model in order to establish consistent scenarios. For example, in the case of Poland, the extent of coal mines' saline waters utilization programme could be associated with an appropriate environmental protection scenario in the energy planning models.

Another way of preparing consistent data on primary energy supply is to use separate (satellite) models which focus on the analysis of the problems specific to these sectors. Such models became more important since the transformation of the economy and the restructuring of the sectors stimulate significant structural changes.

The system for coal sector modelling is being developed to analyze coal industry perspectives. It consists of databases and three groups of models (Fig. 2). These models are the coal mining model (supply model), the coal consumption model (demand model) and the market equilibrium models. Presently, the system comprises databases and two models: coal mining and coal distribution (an early version of market equilibrium model). These are sufficient for the present research on energy and economy systems. Currently, the development of demand models is limited by the lack of the data required, especially on coal demand and prices. The future development of the system is directed towards demand modelling and improvement of the links with models of energy system, electricity generation and national economy models.

2. COAL MINING MODEL

During the period of centrally planned economy, coal mining was exploited to produce as much as possible, regardless of efficiency and costs. The result is that no single coal mine was profitable at the beginning of the economic reforms in 1990. Presently, with a low demand for coal, mines remain with problems of economic efficiency. This situation could change if demand for coal raises because of an increasing industry production or/and heavy winters. The coal quality, not quantity, would then become a major issue. The problem of coal mining viability for the long term is therefore crucial for the prospects of the Polish energy system.

The coal sector (Fig. 3) is represented by a set of mines producing different types of coal, and by major consumers divided into four groups: households, industry, coke ovens and power generation. Some mines continue to operate as usual; others might benefit from the construction of fines beneficiation or desulphurization plant. Supply could be supported by construction of new mines and imported sources. However, both imports and exports are limited. Coal production and consumption are one of the major sources of pollution. The protection of the environment is implemented thanks to technologies of salinated waters utilization and emission reduction.

The coal mining model (Fig. 4) has to consider major economical and environmental issues of the present and future development of coal mining and coal consumption. Those coal mines which remain after some others have been shut down are expected to be profitable without being subsidized. Therefore one should establish plans for restructuring of mines within the next twenty years. The basic data needed are estimates of mines production and economic factors for the period 1993-2010.

The model involves several stages. The first step is to forecast costs and revenues of the mines. There is a need to adjust costs to the changes in price structure. The major component of operating costs, e.g., labor, materials and energy costs, are expected to rise to the world market level. Prices of energy (electricity, natural gas) which are controlled by the state, have risen more than five times since January 1990. Other prices should not rise as much; labor costs could increase proportionally to consumption, which in turn depends on the gross national product (GNP) increase. Costs of supporting materials and equipment have already reached the world market prices. The differences in expected increments of the operating costs require the adjustment of the forecasts which are estimated at present market prices. The model performs this adjustment on the basis of mining cost structure and assumed price increases. Capital and investment costs are calculated considering mines' own funds and loans as the source of investments funds. The sum of operating and capital costs gives a primary estimation of the cost of coal production. The revenues of coal mines are calculated on the basis of prices which are expected on the domestic market. There is a presumption that the prices will be equivalent to coal export prices (at the mines' mouth). Other forecasts of domestic coal prices are estimated from a coal distribution model. These sources determine the level of prices, the structure - relations for different coal quality are adjusted according to the commonly approved rules. They allow to estimate coal prices depending on their ash and sulphur content, heat value, grade.

Coal is not uniform in quality and should therefore be divided into classes (coal fuels) according to their characteristics. Quality parameters such as ash and sulphur content, heat value could be used as criteria of classification. If some of the input data are obtained from another model, the classification criteria and the number of coal categories should be established according to the requirements and properties of the recipient model. For example, for the analysis of power station supply, other measures like emissions of particulates and SO_2 are recommended.

The calculation of both costs and revenues allows to make a first assessment of coal costs. The final assessment requires solution by the model, as it includes costs of mine waters desalination and investment of coal fines beneficiation or coal desulphurization.

Coal mines in the east region of Upper Silesia Coal Basin discharge a lot of saline waters to rivers. Presently, only a small fraction is neutralized. The model was prepared to select technologies of water desalination, taking into account the economic and limited possibilities of application of these technologies. For example, the cheapest re-injection technology requires particular geological conditions of surrounding rocks. The results of the model provide the capacities for each technology and the schedule of construction.

Another factor which could affect coal mines efficiency is the program of coal desulphurization and fines washing. Coal from the Upper Silesia basin has a relatively high sulphur content. Burning of this coal for electricity production causes large emissions of SO_2. The model considers construction of abatement plants for specific mines. Data needed are the expected costs and quality of raw and produced coal for two variants of mine development, namely with or without additional preparation plant (coal fines' washing or desulphurization). The economic performances of these abatement technologies are added to the values of costs and revenues previously obtained. The model considers environmental constraints, i.e., emission limits for power stations. The costs of emission reduction are compared with the costs of coal beneficiation which improves coal quality and therefore lowers emissions. This segment was established in order to consider new regulations that reduce substantially emission limits. Therefore the model is able to analyze the influence of the regulations on the demand for coals of different quality.

FIG.2. STRUCTURE OF THE COAL SECTOR MODEL.

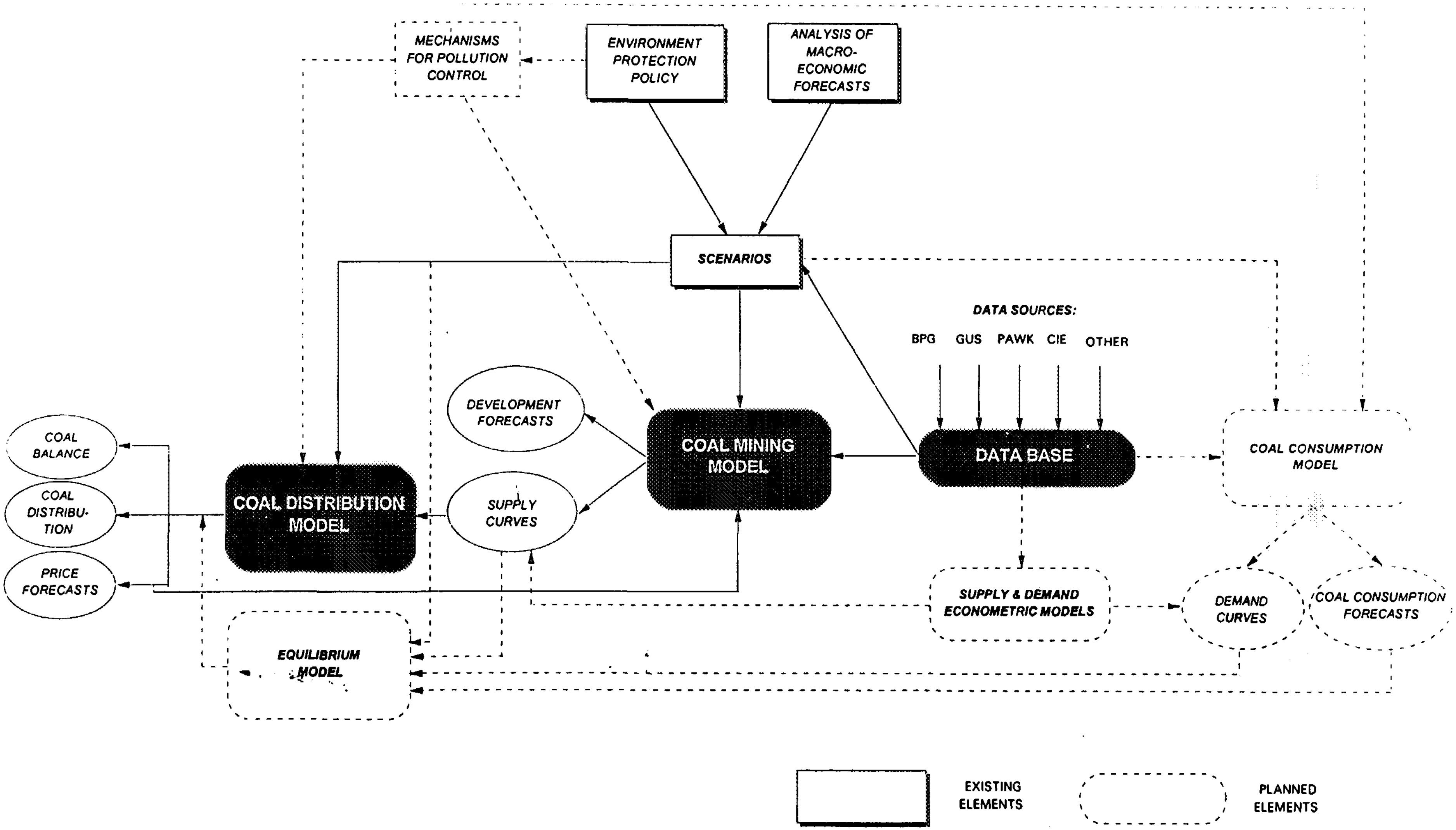


FIG.3. REPRESENTATION OF COAL PRODUCTION AND CONSUMPTION IN COAL MINING MODEL.

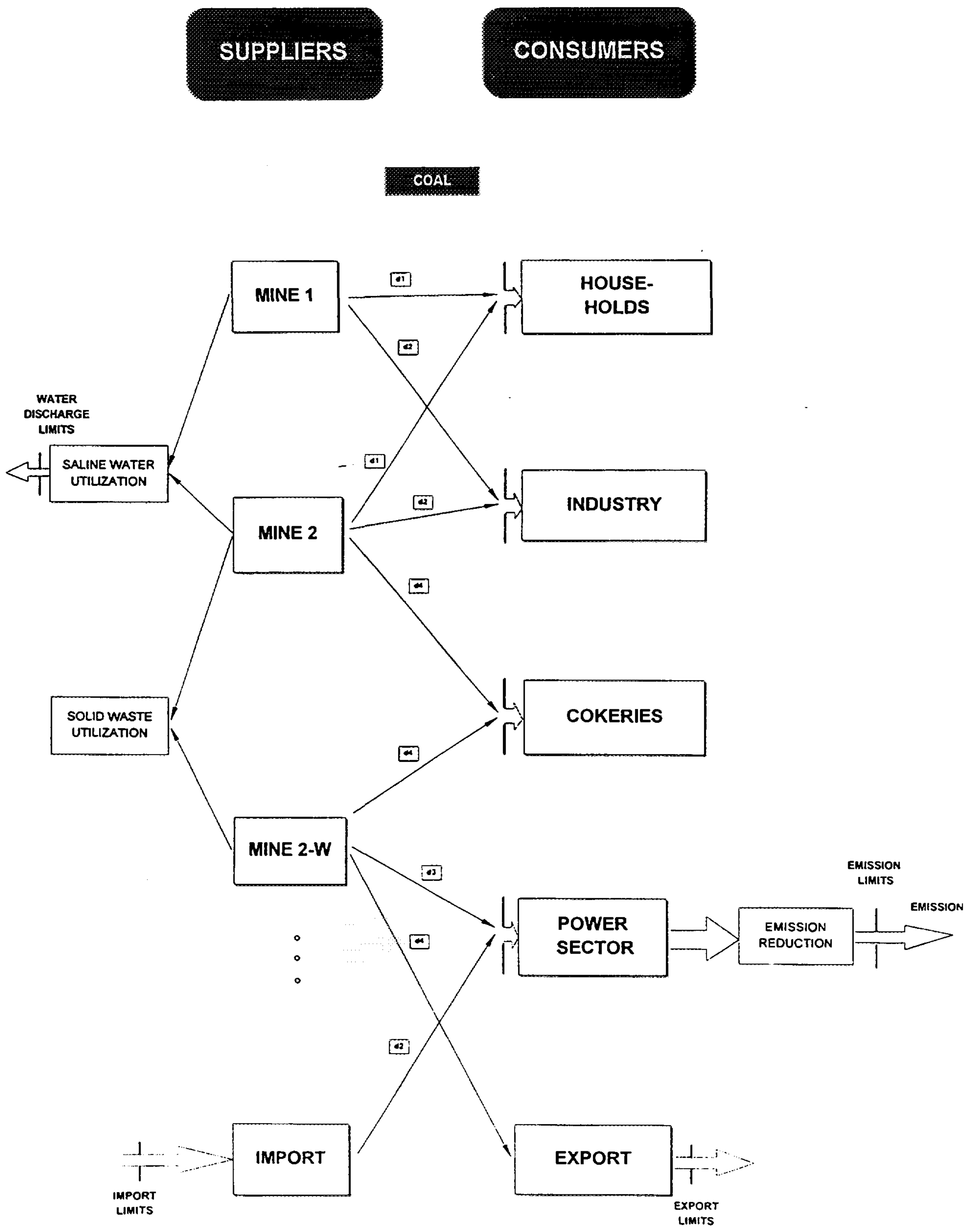
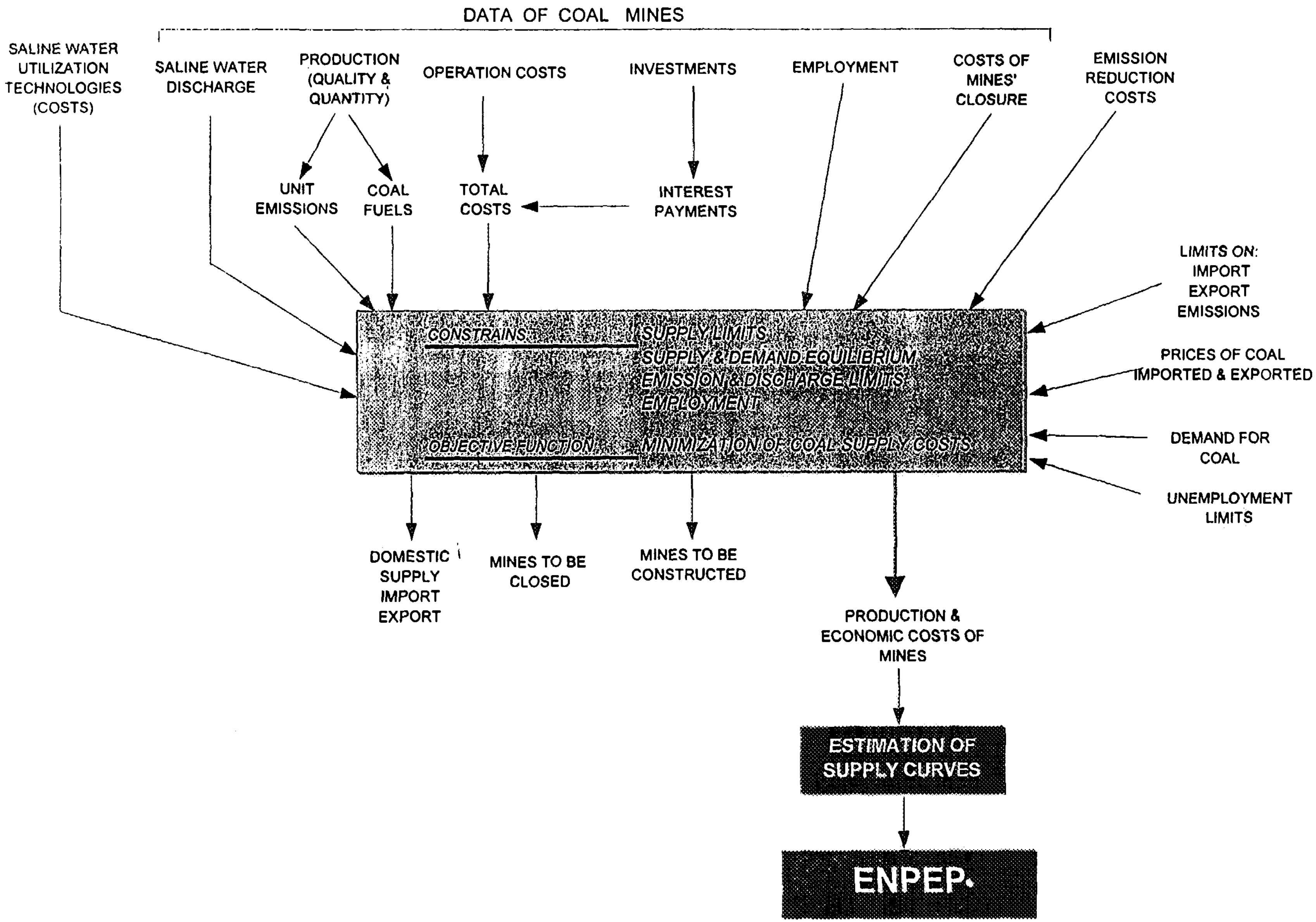


FIG.4. STRUCTURE OF THE COAL MINING MODEL.



The resulting changes of the efficiency of coal mines is calculated and the values are used by the model to identify those mines that might be unprofitable and should be closed. Final values of costs are also used for the estimation of the supply curves.

Coal demand is one of the constraints of the model which distinguishes domestic coal from imported coal. The comparison of the costs for domestic and imported coal allows to identify the mines that could efficiently supply the domestic market.

The problem of closing unprofitable mines needs some explanation. Shutting down a mine requires special funds devoted to technical and social issues. The impact of a closure should be limited by the implementation of other measures, e.g., to limit the problem of unemployment, one could develop programmes for training the staff for new jobs and/or develop special retirement programmes. The costs arising from these measures are, in some cases, comparable to the subsidies granted to allow some mines to run. A rational decision in this case could be to postpone the closing of the mine. In the model, the decision criteria for shutting down a mine is the comparison between the subsidies necessary to maintain it in operation and the costs generated by its closure. One constraint could be a limit of the unemployment rate. As a result, the model is able to identify the mines to be closed and the time it should occur.

The macro- and micro-economic conditions in which the model simulates coal mining development are represented in different scenarios that take into account prices for exported and imported coal, domestic demand, costs increase, interest rate. Data are taken from other models, from programmes concerning the development of the energy sector, or from authors own judgment. The number of scenarios varies depending on the number of decision factors to be analyzed.

The discounted cost of coal supplied for domestic consumers is the objective function of the model. It uses the General Algebraic Modelling System software (GAMS) and mixed integer programming.

Results of the model are indications for retirement or construction of new mines, capacities of technologies, level of production, costs, etc. For this specific subject, coal supply curves are to be considered. Figures 5 and 6 present examples of such curves.

Figure 5 shows the differences between curves established for two scenarios, lower and upper. The lower scenario corresponds to a low GDP increase, limited imports and implementation of basic environmental protection measures. The upper scenario corresponds to a higher GDP increase, absence of import limits and strict environmental protection requirements. The largest difference between the total costs for the two scenarios is more than 10%, which is substantial for a major source of primary energy.

Figure 6 presents curves established for diverse years for the same scenario. The difference here is much more in the capacity of supply rather than in the associated costs. Both cases show that data on coal supply for ENPEP should be prepared with great care.

Fig. 5 SUPPLY CURVES
coarse coal, 2005

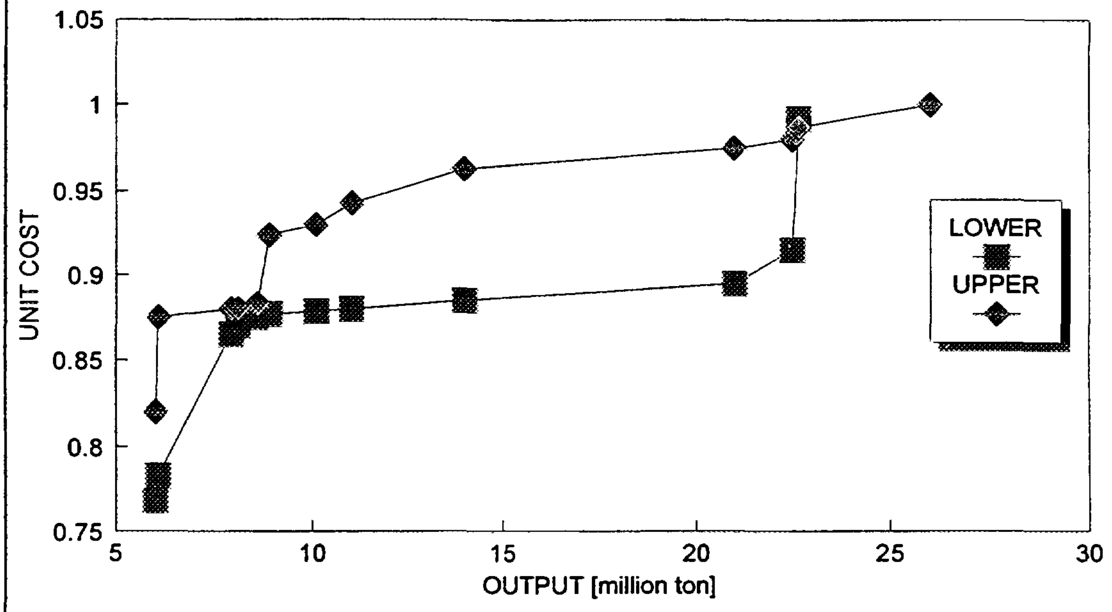
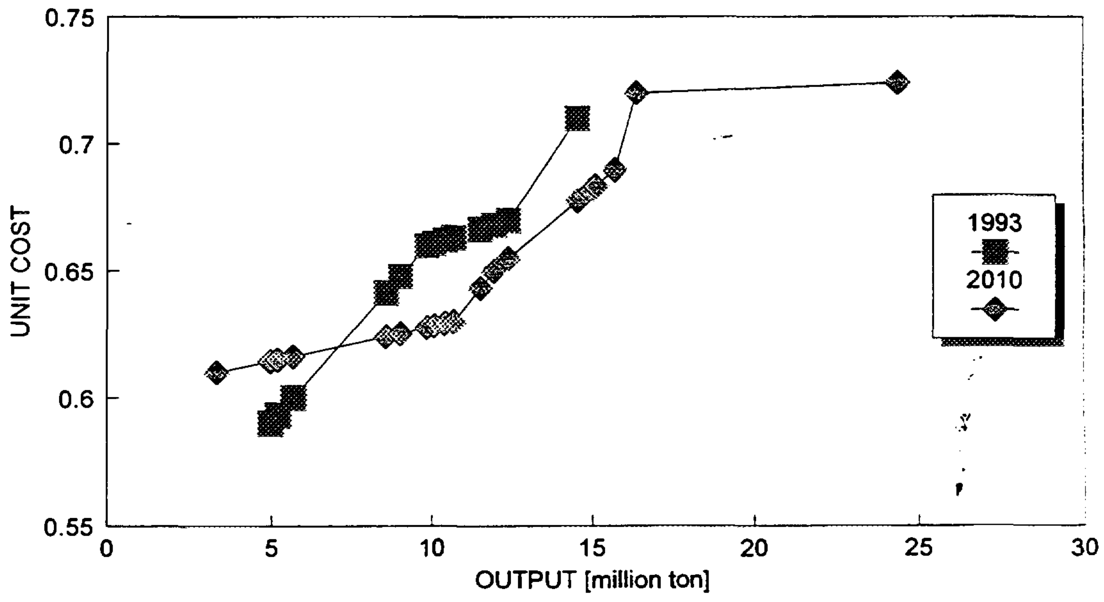


Fig. 6 SUPPLY CURVES
fine coal, UPPER Scenario



3. ESTIMATION OF DATA FOR ENPEP

The results of the coal mining model comprise data on expected production and its costs. These should be prepared according to the requirements of the ENPEP package. For coal, the depletable resource input form (B021) should be used.

Since the formula used in ENPEP for supply curves is not a straight estimation of data for a specific year and scenario, the following method should be used. It uses data on coal production and costs extracted from the coal mining model previously described. Using these data, the following procedure is performed for each scenario and type of coal separately:

1. For each year, the supply curves are estimated trough the second order polynomial function:

$$P_t = A_t + B_t \times Q_t + C_t \times Q_t^2$$

where:

$P_{t\text{-}}$	- coal price at time *t*,
Q_t	- coal production at time *t*,
A, B, C	- coefficients.

2. The intercept value is subtracted from cost data:

$$\bar{P}_t = P_t - A_t$$

3. The relative differences between intercepts of the base year and subsequent years are associated with R_t parameters (form B022),

$$R_t = \frac{A_t - A_1}{A_1}$$

4. The modified costs and the respective output for all years are gathered in one set and are used for determining the values of the coefficients B and C of the supply curves. The equation used to estimate these coefficients can be expressed as:

$$\bar{P}_t = B \times Q_t + C \times Q_t^2$$

And the final supply curve is represented by the formula:

$$P_t = A_1 \times (1 + R_t) + B \times Q_t + C \times Q_t^2$$

The above procedure allows to use the ENPEP form B021 to represent primary energy supply curves. The following example was prepared on the basis of fine coal data. ENPEP requires data (actually R_t coefficients) for every year of analysis. Therefore, the real case needs interpolation of the results of the coal mining model to obtain raw data for estimation of coefficients.

A first estimation of supply curves gives the following results:

1993: P_t=0.5234 + 0.0142*Q_t - 1.2 10^{-4} * Q^2_t R_t=0
1995: P_t=0.5555 + 0.0109*Q_t - 3.4 10^{-5} * Q^2_t R_t=0.0613
2000: P_t=0.4428 + 0.0241*Q_t - 6.1 10^{-4} * Q^2_t R_t=-0.1540
2005: P_t=0.5284 + 0.0116*Q_t - 1.6 10^{-4} * Q^2_t R_t=0.0096
2010: P_t=0.5741 + 0.0082*Q_t - 7.4 10^{-5} * Q^2_t R_t=0.0967

The R_t factors were calculated using ENPEP form B022.

The supply curve has the following form:

$$P_t = 0.5235*(1+R_t) + 0.01632*Q_t - 3.7\cdot10^{-4}*Q^2$$

Figures 7.1 and 7.2 show the results of the procedure for this sample case, i.e., supply curves for the different years. The last supply curve does not fit precisely into the data, but generally follows the trends of the detailed supply curves. In some cases, it could not be used as input data for ENPEP.

In order to facilitate input of the supply curves, introduction of new BALANCE forms (or improvement of the current form B021) is suggested. The form should allow to input coefficients of supply curves (possibly third order polynomial) for each year of the analysis (or certain years with interpolation performed by BALANCE). The annual capacity (available amount) of fuel supply should be additional data in this form. These two elements (supply curve coefficients and capacity) give the possibility to input any kind of data of fuel or other energy supply processes.

Another possibility that does not require estimation of supply curves, is to use the BALANCE form B023 which was actually prepared for renewable sources. The data to be supplied in this form are the capacities and costs of coal mines. Since these data do not change over the time, they could be applied only in case of coal supply that does not change costs and has a stable capacity.

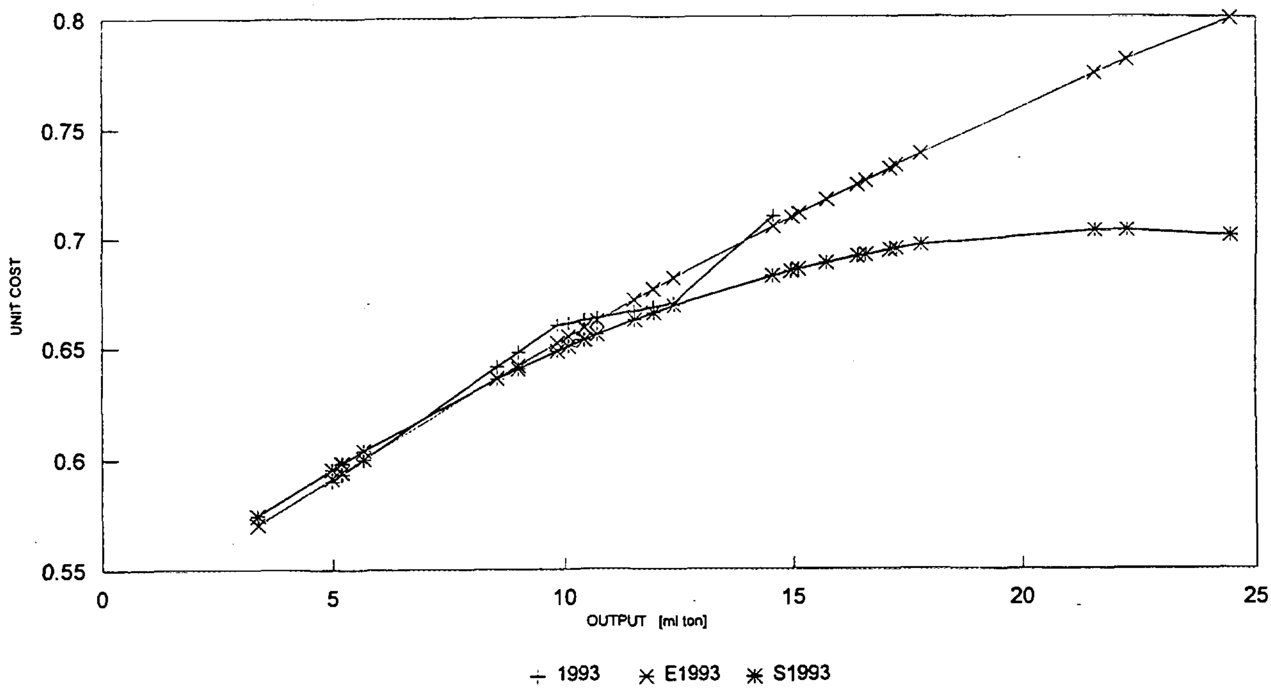
5. SUMMARY

The paper presents the coal mining model developed in Poland and which can be used to provide data associated to the coal sector that are consistent with the ENPEP requirements and the scenarios applied in ENPEP studies.

The coal model considers the principal problems related to coal mining development and therefore the results represent possible variation in coal prices and production. These data are used to estimate coal supply curves as required as input to ENPEP.

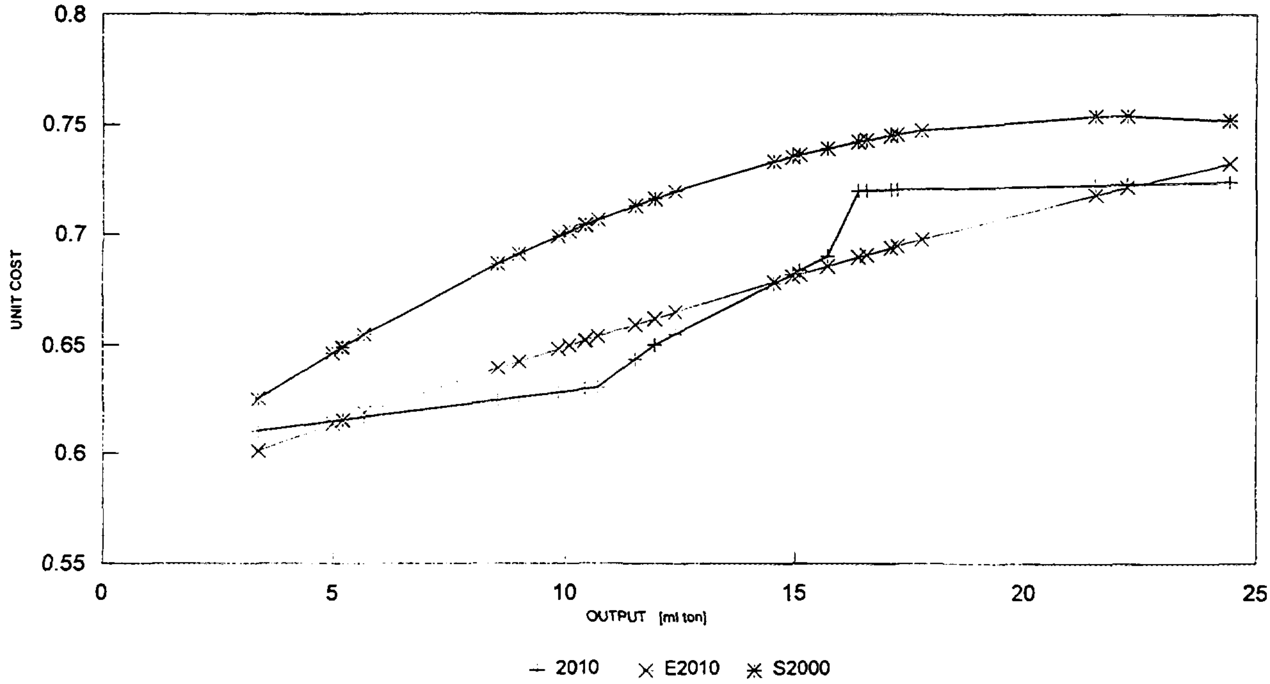
Because the procedure of data preparation would not be satisfactory in some cases, it is suggested to add new data entry forms in the ENPEP package.

Fig. 7.1 SUPPLY CURVES
fine coal, 1993, UPPER scenario



1993 - DATA oF 1993; E1993 - ESTIMATED CURVE of 1993
S1993 - SUPPLY CURVE for ENPEP

Fig. 7.2 SUPPLY CURVES
fine coal, 2010, UPPER scenario



2010 - DATA of 2010; E2010 - ESTIMATED CURVE of 2010
S2010 - SUPPLY CURVE for ENPEP