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Models of Coal Industry in Poland

Introduction

Poland is one of the countries which are abundant in hard coal and lignite reserves, which in total supplies 64% of primary energy and 98% of fuels for electricity production. Coal suppliers and users have passed substantial changes since the beginning of economy transition; environmental regulation, liberalisation and deregulation of fuels and energy markets fostered restructuring of energy sectors. Various analyses have been undertaken to solve the problems ensuing from new conditions of industry operation. Many of them are models of energy and environmental systems on various levels, including coal industry models. They are relevant as supply and costs of coal are important not only for energy sectors but also for the entire economy. Models task is generally to balance coal supplies and demand with respect to environmental and economic conditions. None of the models is able to consider in detail entire energy-economy-environment system in its complexity and variety, and models are constructed to fulfil specific tasks. The paper is concentrated on models used for supporting decisions in the area of hard coal supply and use. Three models are described: coal supply model, coal market model and model of coal supplies to power sector.

1. Model of coal supply

Hard coal mining was one of the most important sectors under the command and control system, providing primary energy and convertible currencies from exported coal. The

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beginning of transition period was characterized by substantial overcapacity and over employment. Productivity was an order of magnitude lower than in the world developed mining. Sector's restructuring started practically in 1990, and was based on closing of unprofitable mines and lowering redundant employment. Initially it was a kind of voluntary program, but soon formal framework in the form of governmental restructuring program was established. Polish coal mining had more than seventy mines and the employment was nearly four hundred thousand people. Such sector needed some support in restructuring efforts and a mid-term model for coal mining restructuring was constructed (Suwala 1995; Suwala et al. 2003). The task of the model was to support the policy of mines closing in order to achieve viable industry. The model used particular mines data on production and costs. Binary variables represented individual mines and the year of their closing. Such attitude is different from one which seems to be obvious, i.e. value one of binary variable means that the mine is producing, zero it is not working. But such attitude makes it difficult to consider time schedule of closing – production is gradually diminishing during few years. In the used scheme binary variables vector, for each mine, was multiplied by the matrix in which each row represented data on mine closed in a particular year. The product was a vector of values for a selected year of closure, i.e. for variable of value 1. Main constraints were related to coal demand, funds available to support closing and operation of mines, employment balances and emissions limits from coal consumers. Minimisation of total costs of coal supplies allowed to select optimal time of mines' closing.

The model, quite simple at first, was gradually developed to help solve emerging problems. Mines could be developed in one of few variants, new mines would be necessary to balance the demand, and those problems were solved in a way similar to mines closing scheme. The governmental employment reduction program had a few forms of support for dismissed miners. The total and average amount of support as well as number of potential beneficiaries allowed to estimate plausible employment reduction, which on the other hand was restricted by labour market capacity to employ miners. One of the most important environmental problems of mining was discharge of salinated waters. Available technologies of mitigating this problem were considered and those most economical ones were selected, concerning constraints given by local circumstances. Other environmental problems are related to coal users, emissions limits on power sector required better quality of coal supplied. Coal grades balances and estimated emissions gave indication on the possibility of fulfilment of environmental constraints by fuel adjustment as well as required investments in emissions reduction installations. Low production of good quality coal could force model to select variant of mine development with coal beneficiation plant. Finally, mines' production which was initially fixed in the considered years was allowed to be flexible. The use of additional variable representing production level as well as linear cost functions was necessary. The latter was constructed as a sum of fixed costs which were dependent on binary variable related to mine closing and variable costs dependent on production level.

The model was evolving, gaining and losing some segments, and actually it had never been applied in the complete form, having all mentioned properties. Firstly, there was no

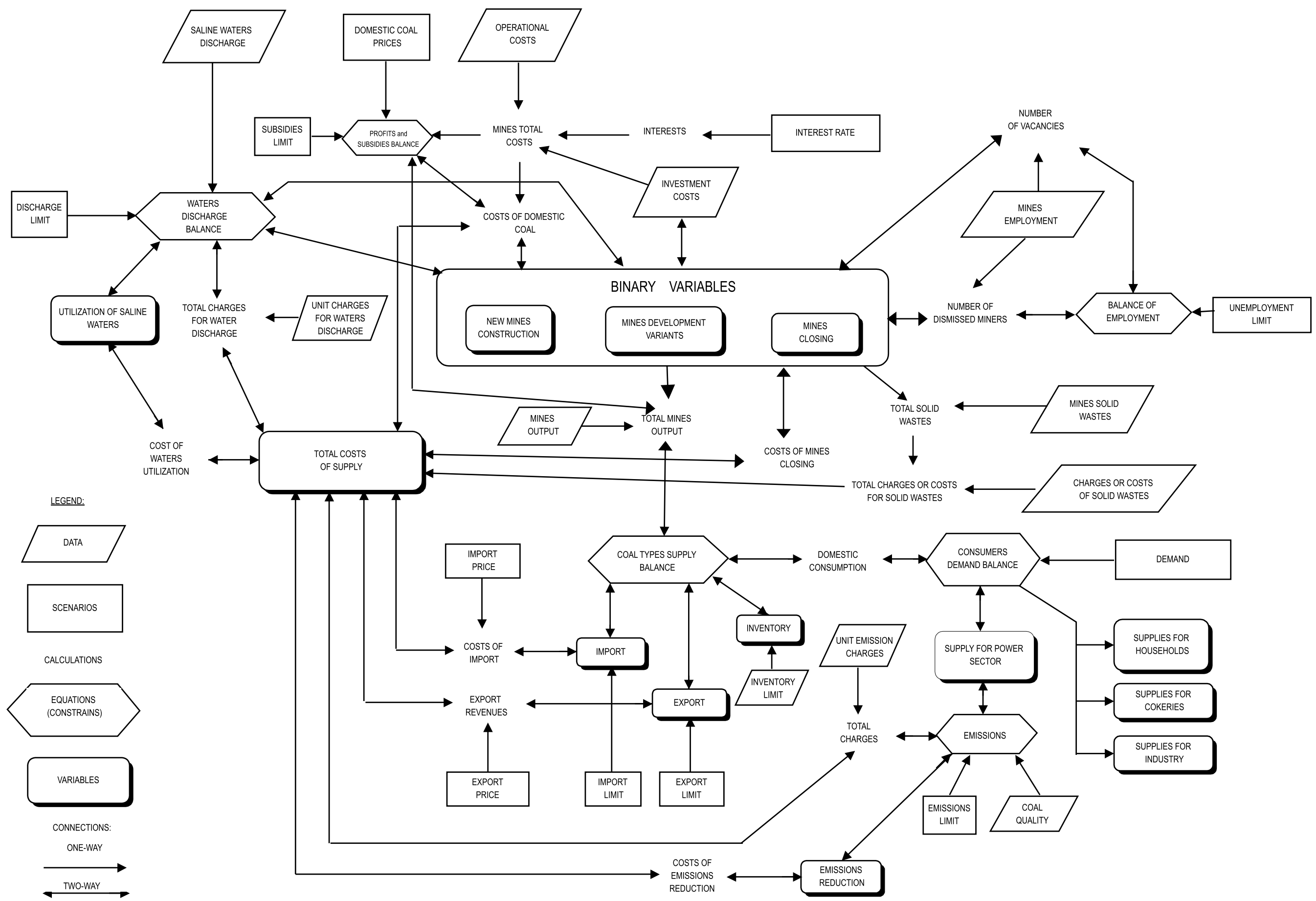

Fig. 1. Structure of the coal supply model

Rys. 1. Struktura modelu podaży węgla

need to consider all of them simultaneously, secondly the model would be very complex, what would cause problems not with finding solutions but interpreting them. The interwoven mechanisms which simulated real decisions are linked more indirectly than directly, and finding explanation for some results is quite tough. Fig. 1 presents general scheme of the model in one of its early forms.

Models were implemented in GAMS system (Brooke et al. 1992), and used mixed integer programming algorithms as solver.

2. Coal market model

Economy transition initiates problems which are not recognizable for producers and consumers. In case of coal these were related to coal prices, and possible impact of fuels market liberalisation. Low international coal prices for the consumers located far from domestic sources could make imported coal competitive in relation to the domestic one. Thus, the model of coal market was needed to estimate distribution of coal produced or imported, and related coal prices (Suwala, Labys 1998, 2002). The model was based on spatial equilibrium scheme, and used coal supply model results to form supply curves (Fig. 2).

Again the model evolved, from the coal distribution one, with fixed demands and minimisation of total costs as objective function, to that of partial equilibriums for local

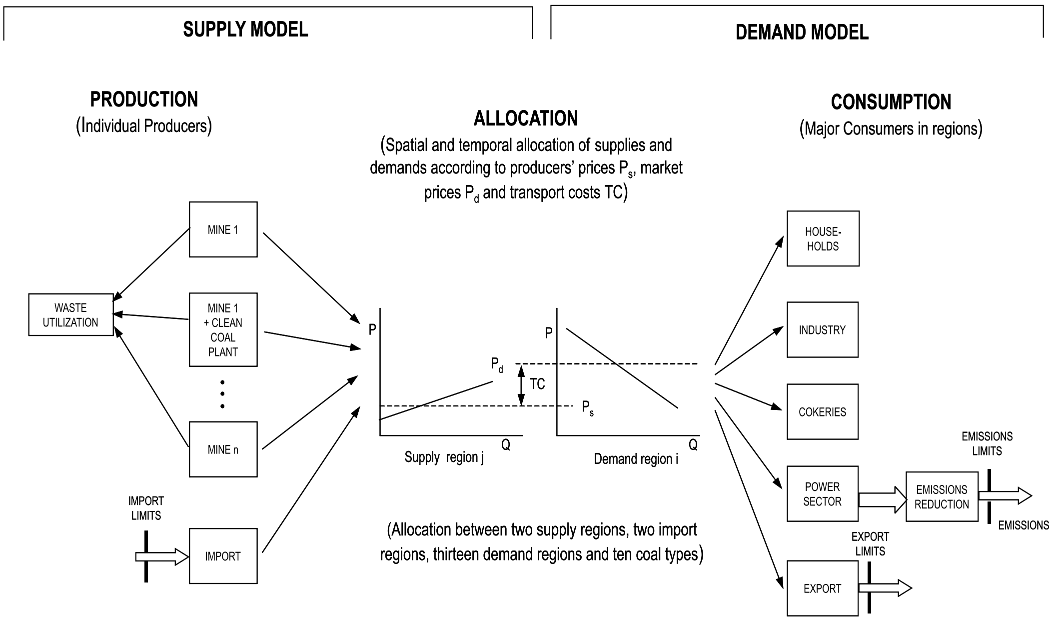

Fig. 2. Framework of coal supply and coal market models

Rys. 2. Schemat współpracy modeli podaży i rynku węgla markets and groups of consumers. The lack of data to estimate econometrically demand curves forced to use substitutes. Demand curves were formed for four groups of consumers on each local market. Representative data on coal consumption and prices gave one point on a curve and assumed price elasticity of demand allowed to calculate parameters of the linear demand curve.

The core model (Fig. 3) has a typical structure of spatial equilibrium model (Takayama, Judge 1971), with maximization of net social payoff as an objective function forming local equlibria. Additional conditions were emissions limits for power sector consumers. The issue of emissions was also addressed in the form of emission charges included into the objective function. They are a kind of external cost which shifts the supply curve and changes the equilibrium point. However, the level of charges is far from covering the environmental damages and actually they are a fund rising instrument.

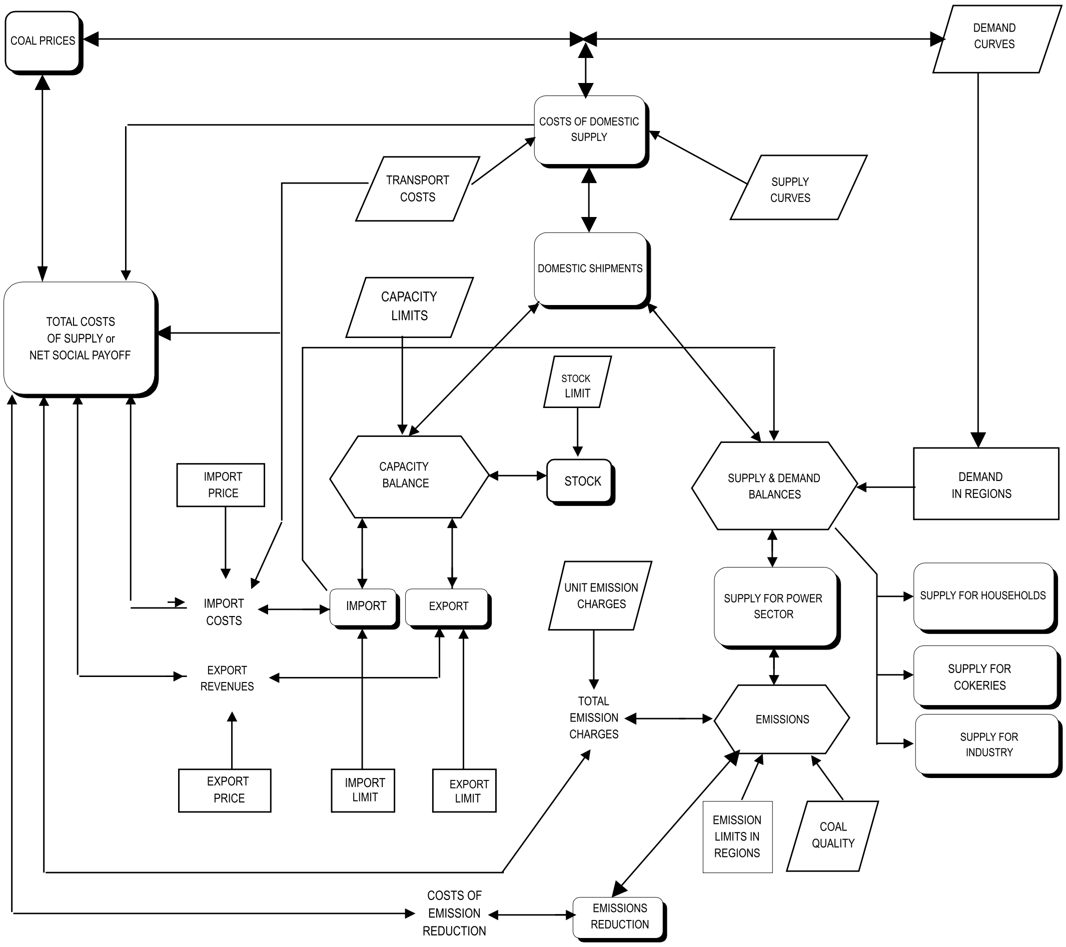

Fig. 3. Structure of the coal market model

Rys. 3. Struktura modelu rynku węgla

Coal prices, demand and coal shipments for each region and group of consumers are main outcomes from the model. The model proved that the import is not a real threat for the domestic producers, in case of assumed level of international coal prices.

3. Models of coal supplies to power sector

The most useful models were constructed for the mid-term balancing of coal supplies for power generation and used for the planning of its development at a country or company level. More than 60% of Polish electricity is produced from hard coal. The role of coal as fuel supplier will not diminish in next two decades. However, the environmental regulations would foster generators to switch fuel. Such situation would arise in case of limited domestic production of coal of the quality assuring emissions below limits. Sulphur content seems to be the most important coal feature in the light of LCP Directive (2001/80/EC), which imposes low sulphur dioxide emission level for power plants. Global limits for the country's emissions have also been established, and as fuel and energy sectors have major share in emissions, they are expected to reduce emissions further than the regulations for the individual plants.

There are many options to keep the emissions on low level, two most frequently applied methods are fuel adjustment and construction of emissions reduction installations. The former is the cheapest one, but could be applied only in cases of emissions standards that could be complied without any additional installations. Polish emission standards made this solution plausible for low capacity boilers, and the fired coal should have less than 0.6% of sulphur. Therefore arises the question of availability of such coal, taking into account requirements of all consumers, which in case of small ones usually use best quality coal. Emission reduction installations are costly and also require physical space. Both conditions constitute severe constraint for such investment, which is unjustified for small boilers.

The power generation models deal generally with mentioned problems, suggesting solutions for each group of generators. However the validity of their results depends on the appropriate data on coal supplies for power generation. Such data require consideration of all coal consumers, their demand and quality requirements and supply structure on the other side. It would be impractical to include such calculation into the power generation model making it complex and difficult to operate. The problem of coal producers response to various levels of coal demand, especially in case of Polish hard coal mining which undergoes restructuring, would remain unsolved. High demand generally means higher production costs, but in case of large overcapacity, as in Poland, it could rather give lower production costs. Therefore the appropriate tool was needed to answer the question of balancing supply and demand for coal of the quality required by the Polish electricity and heat production.

The models which have been developed are based on earlier works on coal mining modelling. Two models were worked out, one for the planning of particular plant development, the second one for the whole power sector considerations. The principle of the models is to minimise costs of coal supply to the units producing electricity, balancing supplies with demand of all coal consumers and taking into account limits on quality demanded and emissions.

3.1. Model for the planning of coal supplies to a power and heat generation company

Power plants will face the problem of stringent emission standards in the next years. Their problem is whether there are available coal grades which allow to comply with emission standards with present emissions reduction installations and whether the demand for such coal will not exceed the supply leading to higher prices or shortages. Otherwise investments would be needed: fuel switch (to natural gas) or construction of more efficient emission reduction installation. The model should give answers to the questions related to the balance of coal supplies, but it could be easily extended to consider investment options.

The general framework of the model is presented on the Fig. 4. Coal supplies data are provided with respect to the amount of possible supplies, lower heat value, ash and sulphur content – all related to coal grades. The number of grades depends on the purpose of the research and could reach more than one hundred. Low sulphur coals are considered with more details by increasing the number of respective grades. The coal supply data are usually outcomes of coal supply model. Demand data refer to different groups of consumers. Non power sector consumers are only two, one for coking coal the other one for steam coal. The latter encompasses households and small industry. Their demand is expressed as an amount and coal grades which they accept. Power sector consumers form groups depending on options for their future emission limits and emission reduction installations which could be built for them. The considered single company is represented by individual boilers, each having specific demand characteristics and development options, for example various emission reduction installations. The model adjusts coal supplies to consumers and gives suggestions on rationality of investment in installations. The latter could be considered within a model as zero-one variables or as exogenous decisions which are evaluated within the model.

Main equations of the model are supply-demand balances, coal grades production and consumption balances and emission limits. The objective function is generally total cost of coal supplies to all consumers, based on coal production economic costs or coal prices. Variations of this function, in which costs are limited to the considered company or power sector only, represent company's or sector activities to purchase low costs coals and gives suggestions on lowest possible costs of supplies. Other important information is coal grades balances, especially of low sulphur ones. Relatively big gap between domestic supplies and demand (actually representing export) means high certainty of uninterrupted and low cost supplies. The increase of demand on domestic market could be easily met by decrease of coal exported.

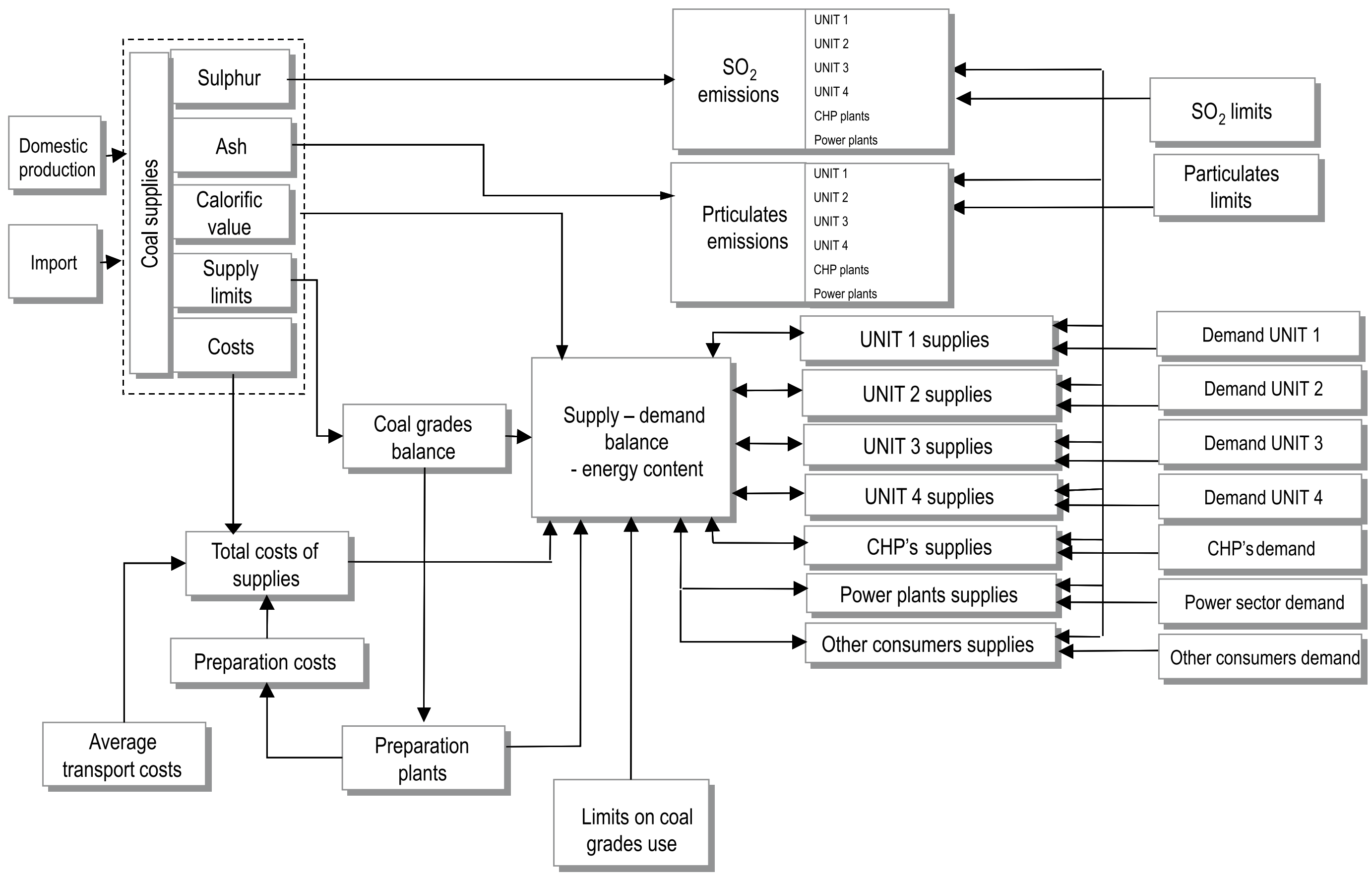

Fig. 4. Model for the planning of coal supplies to a generation company

Rys. 4. Model planowania dostaw węgla do producenta energii

Total costs of the company, assigned to emission reduction options (fuel adjustment or investments), give the suggestions on rational choices. Recent results point that investment in medium efficient sulphur dioxide reduction installation (dry method) is little more expensive than fuel adjustment and should be preferred as provides more security in complying with emission standards.

3.2. Model of coal supplies to power sector on the country level

The country level model was prepared to work with the model of coal supplies as well as with the power sector integrated planning model (Suwala, Kudelko 1999) (Fig. 5). Complexities of supply and consumption systems development do not allow to consider them in a single model. Coal supply or coal mining model considers decisions on about forty mines,

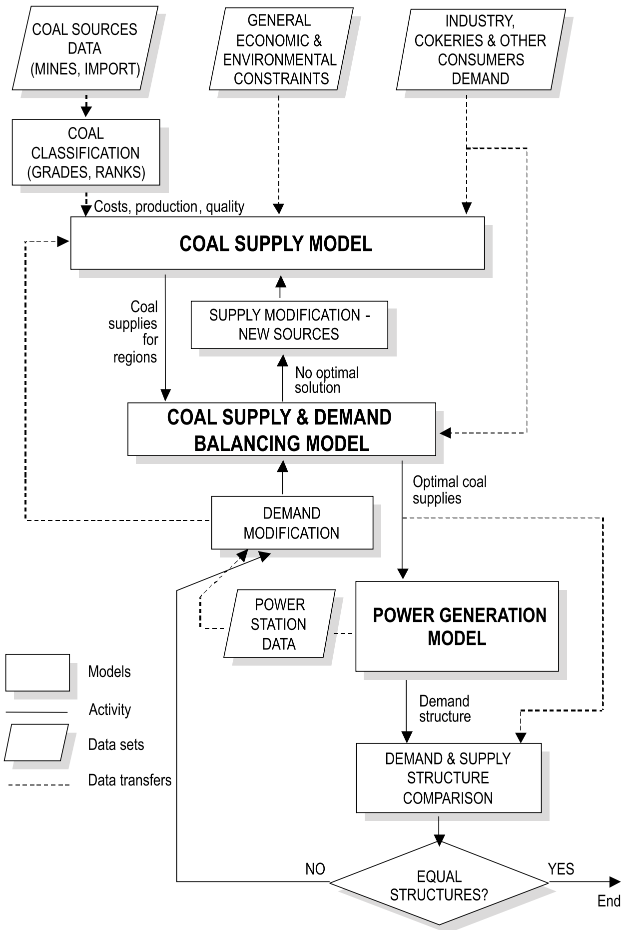

Fig. 5. General framework of models co-operation within coal balancing system for the country level

Rys. 5. Ogólny schemat współpracy modeli w systemie bilansowania węgla na poziomie krajowym power sector model refers to more than three hundred units representing single boilers or groups of similar ones. However it is imaginable to have all of mines and units in a single model, but it would be difficult to operate, of large calculation time and the results would not be easy to interpret.

The supply side was represented by all operating hard coal and lignite mines. In case of hard coal mines their location was considered in the form of coal transport costs added to costs of coal supplied. Three import sources were allowed in the model – two of them for sea borne transport and one for railway from Ukraine or Russia. More than sixty grades of coal were distinguished to assure the appropriate level of coal quality representation. The producers were described by supplied grades and their amounts, coal quality and prices based on the production costs.

The demand side was represented by the following groups of purchasers: more than 330 units of electricity generators (operating or prospective), other power sector coal consumers (autoproducers), coking plants, other consumers and export. Most of the units referred to single boiler-turbine-generator systems, remaining were represented by "aggregates" of units of the same properties. Each unit has strictly specified individual demand for the coal of particular quality:

— the amount of demanded energy in fuel,
— coal quality (calorific value, sulphur content, ash content),
— emissions limits,
— emission reductions factors for each pollutant,
— distances from the suppliers to the unit.

The objective function was the total cost of the coal supply sector, all the costs related to coal production and transport were included. Scenarios established for the model calculations considered different levels of demand for electricity and coal, price developments, environmental regulations and import or export limits.

The main result of the calculations is that domestic supplies would balance coal demand of the necessary quality up to 2020. The demand was easier to meet because of the target of 7.5% of electricity production from renewables in 2010, decreases the demand for steam coal for power generation. Additionally a systematically decreasing demand from other consumers releases coal of good quality for power generation purposes.

Power sector demand for coal derived from power sector model could be different from supplies calculated in coal supply model. The latter uses some preliminary estimations of demand. Deviation between supply and demand could be substantial with respect to particular coal grades. Such relations form interwoven supplies and demand which require iterative process to balance them. The coal supply and power sector models co-operate in the mode that outcomes of one of them are inputs of another one. The iterative process uses procedure that leads to similar structure of coal supplies and coal demand by altering coal demand used as input in coal supply model. It is changed at each iteration according to relation of coal demand to supplies calculated in both models in their previous runs. Only a few iterations are required to come to low differences between supplies and demand.

An important feature of power sector model is a possibility of inputting data on consumed fuels in the form of supply curves. Such curves are constructed basing on the coal supply model results. They allow to simulate fuels market by adjustment of fuels prices to quantity demanded.

The model is implemented in GAMS system and is very flexible tool and allows to recalculate effortlessly all the scenarios and add new emerging constraints and factors.

Conclusions

The analyses of the development of the Polish fuel and energy sectors development are widely supported by models on different levels. Sectoral models, discussed in this paper, were applied for the analysis of coal mining restructuring, coal market and supplies to power generations. The models provide data indispensable for the reliable decision making process for the economy and fuels consumers. Repeated application leads to the improvement of models structure and their usefulness. However, they are still far from being completed. Markets development, liberalisation of fuels and energy markets require further development of the models.

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MODELE SEKTORA WĘGLOWEGO DLA POLSKI

Słowa kluczowe

Przemysł węglowy, modele sektorowe, programowanie matematycze

Streszczenie

Podejmowanie decyzji w zakresie rozwoju systemów paliwowo-energetycznych jest szeroko wspierane przez modele o rożnej skali agregacji. Najbardziej popularne są modele poziomu kraju oraz sektorowe. Polski system energetyczny jest zależny od zasilania w węgiel kamienny i stąd potrzeba budowy modeli dla uzyskania wiarygodnych prognoz do optymalnego rozwoju systemu energetycznego. Artykuł opisuje trzy typy modeli dla węgla kamiennego: podaży węgla, rynku węgla i zasilania elektroenergetyki. Pierwszy z modeli podejmuje problemy restrukturyzacji i rozwoju górnictwa węgla kamiennego – sektora, który przechodził zasadnicze zmiany w okresie transformacji gospodarczej. Model rynku węgla buduje równowagę przestrzenną dla oszacowania cen węgla i jego dystrybucji. Elektroenergetyka, produkująca ponad 60% energii elektrycznej z węgla kamiennego, potrzebuje szczegółowych analiz i danych o perspektywach zasilania w węgiel dla podjęcia pozbawionych ryzyka decyzji inwestycyjnych, zwłaszcza podczas zaostrzania regulacji w zakresie emisji. Opracowano odpowiednie modele dostarczające wymaganych danych.

MODELS OF COAL INDUSTRY IN POLAND

Key words

Coal industry, sectoral models, mathematical programming

Abstract

Development of fuels and energy systems is widely supported by models on different levels. Most common are global or country level as well as sectoral ones. Polish energy system depends on hard coal supplies and coal sector models are required to make valid provisions of energy system development. The paper describes briefly three such models: of coal supplies, coal market and coal supplies for power generation. The first model is devoted to the analysis of coal mining restructuring and development, the sector facing substantial changes in transformation period. The coal market model is of spatial equilibrium type and is used for forecasting coal prices and distribution. Power sector, which produces more than 60% of electricity from hard coal, needs detailed data on supplies perspectives in order to take devoid of risk decisions on investments forced by stringent emissions regulations. The model has been worked out to provide such data.