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Selected models of energy systems

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One of the most important sector of the national economy is the energy sector. A number of changes in the sector depends on a number of factors, not only technical and economic, but also social and political. At present Polish energy sector faces serious challenges. High demand on final energy , inadequate level of manufacturing and industrial infrastructure, dependence on the external supply of natural gas and oil, climate protection commitments, give rise to the need to take decisive actions. To achieve the objectives of the proper functioning of the energy system an essential element of the process is continuous observation and prediction of changes in the system in different timeframes. The complexity of the problems of the fuel economy and energy causes computer models to be an essential tool for their analysis. No decision about the introduction of regulations in the field of energy and ecology can do without previous studies of the effects which can be therefore estimated by using models.

KEYWORDS: energy systems, modeling, energy technologies

1. Introduction

For several years the subject connected with the future of energy is one of the most important problems in national politics. The current state of energy security in different sectors of Polish energy sector is very diverse. In electrical power engineering and heat engineering which are based on their own resources of coal and lignite, Poland is self-sufficient. In the sector of gas and liquid fuels, it is largely dependent on imports, mainly from Russia. Poland has a lot of renewable energy resources, but so far their use is small. On the basis of the fuel-energy balance, it is necessary to develop a long-term energy strategy that will take into account the growing needs of consumers and industry, and at the same time will provide energy security. Therefore, for several years, efforts have been made to determine the new model of energy strategy which on the one hand, would take into account the demands of the consumers and on the other hand, would correspond to the challenges imposed by the European Union. Feasible energy strategy should take into account our natural resources whose main source is coal and to a large extent will ensure high self-sufficiency. It is also possible to increase the extraction of gas from domestic resources, including perhaps, shale gas deposits. Of great importance will be the use of renewable sources, it is even more important that the increased share of renewable energy, in the energy balance of the Member States, is supported by the European Union. The construction of nuclear power plants is also taken into consideration.

Fuel energy System is a complex system of dependency existing between different constituents. Relations taking place between individual subsystems are the main criteria for conducting research on the prognosis of the development of the energy system. Modeling of energy systems is a time-consuming task, requiring multidisciplinary knowledge (including mathematics, computer science, energy, energy policy) and a very good knowledge of the sector being modeled. This is a complex operation, requiring the application of an appropriate methodology in order to avoid errors that can occur on every stage of the construction [4, 5, 6].

2. Methodology of modeling of energy systems

Modeling development of energy system has important limitations. Along with the progress of the processes of liberalization of energy sectors, new factors determining the selection of manufacturing technology have occurred. Due to the risks associated with the business in a competitive market, investors began to favor technologies with a short payback period and the short period of construction. Politics will to a great extend affect the energy sector in terms of environmental protection, including the need to reduce CO_2 emissions. This forces a dramatic change in direction for the development of the manufacturing sector, particularly in favour of clean coal technologies and nuclear energy, as well as for the benefit of renewable energy sources (including decentralized systems). The choice of future technologies will depend on many factors. The summary of the basic characteristics of the manufacturing technology is shown in Table 1.

The complex nature of the relationship occurring in energy systems, makes it necessary to apply a number of simplifications in the process of modeling the system (Fig. 1). In addition, a major impact on the reliability of the predictions has the statistical material, which very often is insufficient. In energy projections three basic modeling methods are applied:

- econometric – this is a method that is based on statistical analysis of historical data and the construction of models that describe the economic processes for the purposes of prognosing,
- optimization, which uses a mathematical programming method for the determination of the optimal structure of the system,
- simulation, where the system is represented by a set of formulas that describe a single, interrelated processes and the forecast of its development is calculated as a result of the interaction of these processes at the time [15].

Analytical tools that are created for the development of energy systems use two basic techniques of modeling: bottom-up and top-down. Bottom-up models take into account both the supply, that is acquiring energy media and energy conversion technologies, as well as the demand side which is characterized by the need for different types of final energy. A feature of these models is the lack of energy system links with the rest of the economy, while a decision - taking criterion is the minimization of direct costs. Top-down models, i.e. models of general equilibrium include the supply side and the demand side. They are based on the assumptions of perfect market and balance between production and demand. These models assume the need to take into account the external costs in the decisions of the energy producers, for example, the cost of emissions [4, 5, 6, 13].

Table 1. The collation of features of energy technologies [1, 2]

Technology	**Quantity of unit**	**Period of design and implementation**	**Capital costs/kW**	**Operational costs**	**Fuel costs**	**CO_2 emission**
CCGT	medium	short	low	low	high	medium
Fossil fuel power plant	big	long	high	medium	medium	high
Nuclear power plant	very big	long	high	medium	low	lack
Hydroelectric power plant	big	long	very high	very low	lack	lack
Wind power plant	small	short	high	very low	lack	lack
Piston engine power plant	small	very short	low	low	high	medium
Fuel cells	small	very short	very high	medium	high	medium
PV plant	very small	very short	very high	very low	lack	lack

Models used for forecasting the development of energy-fuel systems can be divided into:

- models of energy systems,
- energy-economic models,
- integrated energy - economic-environmental models.

Models of energy systems use engineering approach (bottom-up), where there is no need to analyze the behavior of the other markets not related to energy production. Therefore, the necessary data about the demand for primary energy carriers and the final energy is derived from macro-economic forecasts. The models of energy systems fuels compete with each other on the market of the supply of primary energy and production technologies in terms of their processing. The most important variables in this model are: the amount of primary energy carriers consumption, the amount of production of electricity and heat, the level of investment, the emission of gaseous pollutants, etc. The most famous models of this type include MARKAL and MESSAGE.

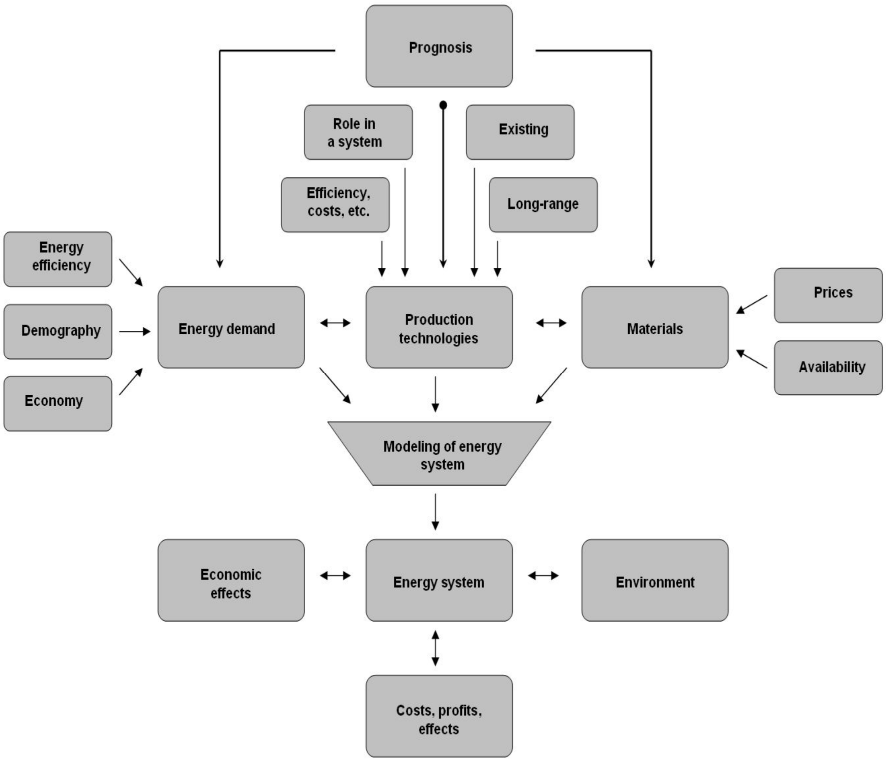

Fig. 1. Schematic model of the strategy for the development of energy system (own research paper)

Energy-economic models are used to analyze the links between the energy system with the economy. There are macro-economic models, with more extensive economy dependent structure, in comparison to the previous ones. These models use the so-called top-down approach, based on the theory of general equilibrium. They specify the supply side and the demand side of the market dependencies. The examples of models used in the study of the energy sectors are: GLOBAL 2100, GREEN, Dynamic General Equilibrium Model and PRIMES.

Energy-economic-environment integrated models, combine a few specialized and complementing each other models due to the multidimensional nature of the analysis, therefore studies of this type tend to a detailed representation of the major technological, economic and environmental relation and due to calculative difficulties it is not performed in one model, but through the use of previously created tools [4, 5, 6, 13].

3. Characteristics of the selected models

MARKAL model (MARKet ALlocation) is a tool used to programming models for the development of energy systems, with a particular focus on manufacturing structure, on the basis of the balance of power [3]. MARKAL Model allows for solving problems with linear programming based on the minimization of the net updated value cost of energy supply to the end user. Decision variables are, among others: the size of the installed power and the quantity of annual production in the processing technologies of various forms of energy. Schematic model of the inputs and the results obtained by using MARKAL model is shown in Fig. 2. Optimization criterion applied in the MARKAL is to minimize the discounted sum of the updated value of the stream of annual costs generated by energy system in all the years of time horizon.

The basic components in a MARKAL model are specific types of energy or emission control technology. Each is represented quantitatively by a set of performance and cost characteristics. A menu of both existing and future technologies is input to the model. Both the supply and demand sides are integrated, so that one side responds automatically to changes in the other. The model selects that combination of technologies that minimizes total energy system cost.

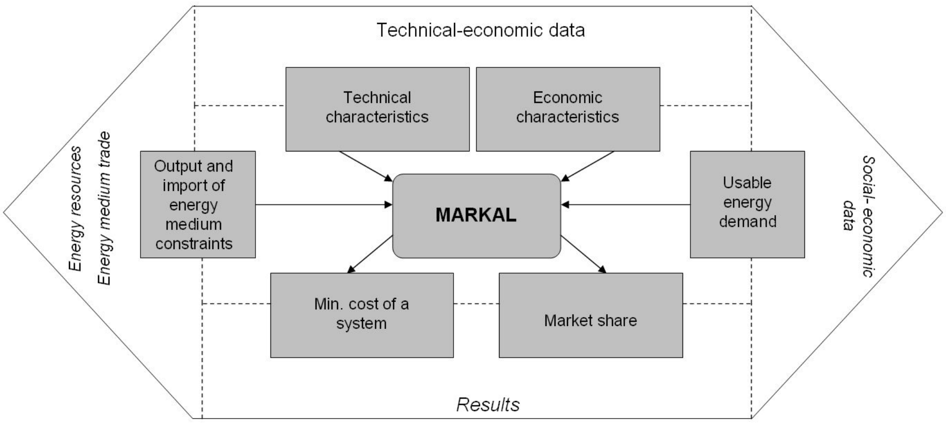

Fig. 2. Schematic model of a structure of a model built with the use of MARKAL [3]

Some uses of MARKAL:

- to identify least-cost energy systems,
- to identify cost-effective responses to restrictions on emissions,
- to perform prospective analysis of long-term energy balances under different scenarios,

– to evaluate new technologies and priorities for R&D,
– to evaluate the effects of regulations, taxes, and subsidies,
– to project inventories of greenhouse gas emissions.

POLES Model (Prospective Outlook on Long-term Energy Systems) belongs to a group of five global models of energy-ecology-economics type (3E). The model enables the simultaneous assessment of supply and demand options along with different constraints, in particular, the availability of resources and the objectives of the emission. POLES model takes into account two main factors, determining the power requirement: demographic potential and growth of gross domestic product (GDP) per capita. The model provides a complete system for the simulation and economic analysis of the world's energy sector up to 2050. The model simulates the energy demand and supply for 32 countries and 18 world regions. There are 15 energy demand sectors (main industrial branches, transport modes, residential and service sectors), about 40 technologies of power and hydrogen production. For the demand, behavioral equations take into account the combination of price and revenue effects, techno-economic constraints and technological trends [7, 13].

LEAP Model (The Long-range Energy Alternatives Planning System) which is a tool developed by the Stockholm Environment Institute for the analysis of energy policy. It is used for integrated energy planning and analysis of climate change. It is used in many different scales, from the cities and regions to national or continental use, taking into account the emission problem. In the LEAP model was the specific energy system not implemented , but it is a tool that can be used to create models of different energy systems. LEAP also allows the use of a series of specialized optional modeling methods involving, for example, energy consumption (fuel) in the transport sector or a load of power system. LEAP offers a variety of methods of simulation, which are sufficient for modeling the electricity generating sector and planning to expand its production capacity. LEAP is intended as a medium to long-term modeling tool. Most of its calculations occur on an annual time-step, and the time horizon can extend for an unlimited number of years. LEAP is designed around the concept of long-range scenario analysis. Scenarios are self-consistent storylines of how an energy system might evolve over time. Using LEAP, policy analysts can create and then evaluate alternative scenarios by comparing their energy requirements, their social costs and benefits and their environmental impacts [8, 9].

The EnergyPLAN model is a computer model for the analysis of energy systems. This is a deterministic model that optimizes the operation of the energy system based on input and output data, as defined by the user. The main purpose of the model is to help design national or regional energy planning strategies based on technical analysis and the economic impact of different energy systems and investments. The Model covers the entire national or regional energy system, including the production of heat and electricity, as well as transport and industry. Compared to other similar models, the following characteristics of EnergyPLAN can be highlighted:

- EnergyPLAN is a deterministic model as opposed to a stochastic model or models using Monte Carlo methods. With the same input, it will always come to the same results. However the model can perform a calculation on the basis of Renewable Energy Sources (RES) data of a stochastic and intermittent nature and still provide system results that are valid for future RES data inputs.
- EnergyPLAN is an hour-simulation model as opposed to a model based on aggregated annual demands and production. Consequently, the model can analyze the influence of fluctuating RES on the system as well as weekly and seasonal differences in electricity and heat demands and water inputs to large hydropower systems.
- EnergyPLAN is aggregated in its system description as opposed to models in which each individual station and component is described. For example, in EnergyPLAN, the district heating systems are aggregated and defined as three principal groups.
- EnergyPLAN analyzes 1 year in steps of 1 hour as opposed to scenario models analyzing a series of years.
- EnergyPLAN is based on analytical programming as opposed to iterations, dynamic programming, or advanced mathematical tools. This makes the calculations direct and the model very fast when performing calculations [10].

MAED Model (Model for Analysis of Energy Demand) assesses the future energy demand on the basis of the medium-and long-term scenarios for socio-economic, technological and demographic development. Energy demand in this model is divided into a large number of the categories of the final users, corresponding to different services in various sectors. There are estimated social, economic and technological factors from a scenario and combined, give the overall picture of future growth in energy demand. MAED uses Excel macros [11]. The starting point for using the MAED model is construction of base year energy consumption patterns within the model. This requires compiling and reconciling necessary data from different sources, deriving and calculating various input parameters and adjusting them to establish a base year energy balance (Fig. 3). This helps to calibrate the model to the specific situation of the country.

The next step is developing future scenarios, specific to a country's situation and objectives. The scenarios can be sub-divided into two sub-scenarios:

- one related to the socio-economic system describing the fundamental characteristics of the social and economic evolution of the country,
- the second related to the technological factors affecting the calculation of energy demand, for example, the efficiency and market penetration potential of each alternative energy form.

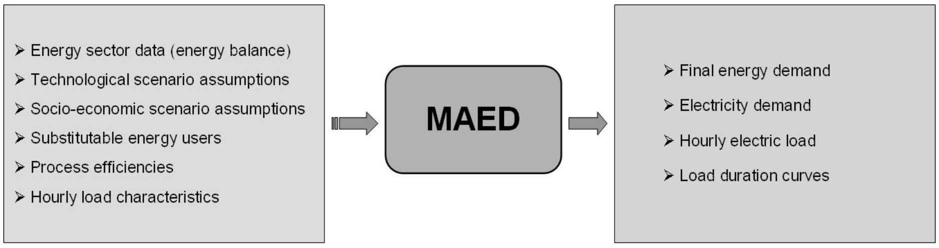

Fig. 3. Schematic model of main inputs and outputs data in MAED model [11]

This Model has been used in the preparation of prognosis demand for fuel and energy by the year 2030, annex 2 to the project "Polish energy policy by 2030".

MESSAGE Optimization Model (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) allows the designation of prognosis of demand for electricity and network heat as well as prognosis of sources development created on a national scale. The principle of operation of the MESSAGE model is based on minimizing the discounted overall system cost in the whole examined time, using a linear programming methods. MESSAGE allows you to build a model energy system in an arbitrary complexity, containing manufacturing and transit of fuel and energy technologies, taking into account most of the technical and environmental constraints in the real system. This gives you a wide range of simulation of the system behaviour under various conditions and study the impact of various factors on the choice of the optimal structure of technology [10, 12]. MESSAGE is a systems engineering optimization model used for the planning medium to long-term energy systems, analysing climate change policies, and developing scenario, for national or global regions. The model uses a 5 or 10 year time-step to simulate a maximum of 120 years. All thermal generation, renewable, storage and conversion, and transport technologies can be simulated by MESSAGE as well as carbon sequestration. Inputs for the model are very detailed on the supply side but the demand inputs are more aggregated. MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations and market penetration rates for new technologies. Environmental aspects can be analyzed by accounting, and if necessary limiting, the amounts of pollutants emitted by various technologies at various steps in energy supplies. This helps to evaluate the impact of environmental regulations on energy system development.

Many elements of this model were used during the creation of the "model of the optimal energy mix for Poland by 2060".

The PRIMES Model simulates the solutions for the market balance of supply and demand. The model algorithms search prices for each form of energy, which best satisfy quantitative consumer demand by a quantitative offer of producers. PRIMES is modular system with individual sub-models for several demand sectors and energy supply system, including a detailed electricity, CHP, gas, RES and biomass models (Fig. 4). The integrating module of PRIMES simulates simultaneous market equilibrium. The model projects dynamically to the future energy balances, investment costs, prices and emissions per country. The Model captures the behavior of market participants and uses available supply and demand technologies and emission control technologies. The Model distinguishes supply subsystems (petroleum products, gas, coal, electricity, heat and other) and final use sectors (housing, services, transport, nine industry sectors), where it is possible to combine the function of a producer and consumer (for example in cogeneration processes) [14].

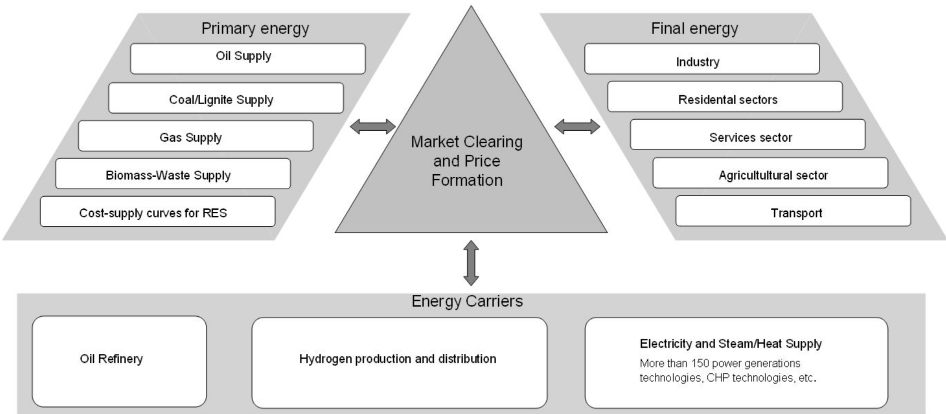

Fig. 4. Modular structure of the PRIMES model [16]

4. Conclusions

One of the conditions to ensure the security of supply of electricity to customers is to maintain a balance between the demand for electricity and peak power and the availability of generation capacities in the national energy system (KSE). A comparison of the current state and structure of the power generating sources in the KSE and the demand for electricity and peak power, as well as the anticipated growth in the coming years, indicates that in the Polish electrical power engineering new investments generating sources are urgently needed. The selection of technology for new generating sources in the long term must, however, be based only on economic criterion, which is based on knowledge of the expected total cost of production of electricity, including environmental costs.

Getting up to a proper model of energy is going to be a long and difficult process. Currently, it is necessary to take actions to protect Polish energy security in the undisturbed supplies of conventional energy sources, mainly oil and gas through their diversification. The prospect of energy deficit means that today one has to wonder whether and what to build. It seems that in the current situation you need to put on the mining of coal and lignite and on renewable sources of energy and nuclear energy-in fact any form of energy in our energy system will be increasingly needed.

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