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APPLICATION OF MARKAL MODEL GENERATOR IN OPTIMIZING ENERGY SYSTEMS

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Abstract
The main objectives of European energy policy include: security of energy supply, reduction of greenhouse gas emissions and the development of efficient and clean energy technologies. The obligation to fulfil these objectives is connected, among others, with the optimization of the development of all energy system i.e. a group of facilities and equipment for the collection, transmission, processing, distribution and use of energy in all its forms. Computer programs such as MARKAL, TIMES, ENPEP, MIDAS are the basic tools for modelling different energy systems. Various simulation, optimization and macro models are created with them. Multi-criteria methods are also used. In this paper the use of MARKAL as a tool for the optimization of an energy system was the matter of research. The article presents the characteristics of MARKAL. Additionally, it includes an example of the use of the program to create a model of the supply of heat for the province of Silesia together with its results.

Keywords
MARKAL, energy modelling, optimization, energy system

1. INTRODUCTION

One of the main elements supporting a decision making process is optimization; a process of determining the best possible solution according to certain criteria. As a result of optimizing a certain system we obtain the desired effect and choose the best possible scenario which ensures it is carried out efficiently.

The most often used criteria include: an economic effect, an environmental effect and a social effect. The criterion is referred to as an objective function. The function is one of the basic elements of a mathematical optimization model. Other elements include, among others, decision making variables, other parameters describing the system and constraints (Pikoń 2011).

The objective function describes the desired target; decision making variables are tools at our disposal to help us reach these targets. In turn, constraints are logical and physical associations which may come into play while reaching the target. If a model has two variables, finding a solution is easy. When calculations are more complex, computer programs are applied.

The article was devoted to optimizing energy systems directly linked with other branches of national economy.

The basic aim of an energy system is to meet the demand, both quantitative and qualitative, of energy consumers. Energy needs should be met in a continuous and uninterrupted fashion. An energy system includes facilities for: obtaining energy, its processing, transmissions, distribution and usage. An energy system consists of the following subsystems:

- electricity
- heat – power
- gas energy
- solid fuels
- liquid fuels

The above mentioned subsystems form the national fuel energy industry (Ziębik, Szargut 1995).

The tools to model energy systems are e.g.:

- EFOM-ENV/GAMS – Energy Flow Optimization Model – Environmental, developed in Belgium for the European Commission (Kruijn 1994)
- TIMES – The Integrated MARKAL-EFOM System, developed by The Energy Technology Systems Programme (ETSAP), The International Energy Agency (IEA), France[1]
- MARKAL – MARKet ALlocation, developed by The Energy Technology Systems Programme (ETSAP), The International Energy Agency (IEA), France (Loulou, Goldstein, Noble 2004)
- MESSAGE III – Model of Energy Supply Systems Alternatives and General Environmental Impacts, developed by The International Institute for Applied Systems Analysis, Austria[2]
- ENPEP – Energy and Power Evaluation Program, developed by The International Atomic Energy Agency (IAEA), Austria, with several technical modules e.g. MACRO-E, MAED, BALANCE, LOAD, WASP-IV (IAEA 2001)

[1] http://www.iea-etsap.org/web/applicationGlobal.asp
[2] http://webarchive.iiasa.ac.at/Research/ECS/docs/models.html

- MIDAS – Mobile Integrated Dynamic Analysis System, developed at The National Technical University of Athens, Greece (Capros et al. 1995)

This article concentrates on modelling with the MARKAL package, which uses the ANSWER system supporting the work of the MARKAL generator in model analyses.

2. CHARACTERISTICS OF THE MARKAL PROGRAM

MARKAL is a dynamic program with a wide range of possible applications used for energy and environment planning in various areas of activity. The characteristics of the MARKAL program are presented in **Table** .

Table 1. Characteristics of the MARKAL program (Seebregts, Goldstein, Smekens 2000)

MARKAL (MARKet ALlocation)	
origin	ETSAP, IEA, France
aim	integrated energy analysis and planning through minimizing costs
approach	bottom-up
methodology	optimization
structure	linear programming
area of activity	national, regional
area of research	energy industry
time horizon	long-term

MARKAL is an optimization tool based on linear programming. Its aim is to find the optimum value of a linear objective function for one or many variables while taking into consideration the assumed constraints. The objective function is the discounted total of the updated values of yearly costs generated by an energy system taking into account all the years of the considered time horizon and regions (Jaskólski 2005). The flow of yearly costs includes incurred investment costs, fixed maintenance costs, variables (the cost of materials, purchasing energy carriers, supply costs), as well as the costs of using the environment. Income from sales of e.g. energy and goods beyond the researched area is deducted from the determined yearly costs.

The use of MARKAL is associated with a necessity to become familiar with the different markings of symbols: parameters used in the program, the names of different technologies, energy carriers, etc., which are defined with abbreviations, making the structure of the model unclear, especially during initial contact with the software. The symbols are presented in **Table** .

Table 2. Description of symbols used in the model

IMP	supply source: import
RNW	supply source: renewable
BIO	biomass
HCO	hard coal
NGA	methane-rich natural gas
OLL	fuel oil (light, heavy)
OTH	other fuels
ELC	electricity
LTH	heat (public power stations and CHP stations, public heating plants)
L2H	heat (industrial CHP stations, non-public heating plants)
L3H	heat (local boiler houses and individual installations)
RIB	heat demand – industry and construction
RRES	heat demand – households
RTRN	heat demand – transport and storage
RCOM	heat demand – other users
RRES1, RCOM1, RTRN1, RIB1	technologies appropriate for heat demand in given sectors (LTH)
RRES2, RCOM2, RTRN2, RIB2	technologies appropriate for heat demand in given sectors (L2H)
RRES3	technologies appropriate for heat demand in given sectors (L3H)
RELC	electric heating plants (decentralised)
RLIQ	liquid fuel heating plants (decentralised)
RGAZ	gas fuel heating plants (decentralised)
RSOL	solid fuel heating plants (decentralised)
RBIO	biomass fuel heating plants (decentralised)
H10	public power stations and public CHP stations (+ public heating boilers)
H20	industrial CHP stations
H30	public heating plants
H40	non-public heating plants

MARKAL does not contain an in-built database. That is why the user is obliged to enter a number of input parameters. The program contains qualitative information (e.g. the energy carrier types, technology types) and quantitative information (parameters characteristic of the technologies used etc.). In MARKAL, apart from conversion Technologies, there are also demand technologies and a group of technologies referred to as processes. The model chooses the combination of technologies which minimizes the total costs of the energy system. In each case, the model finds the cheapest mix of technologies and energy carriers to meet the energy demand. The energy demand can be divided into sectors e.g. services, industry, household, agriculture, transport; or according to the type of energy used i.e. central heating, hot water, cooling. There is also a so-called, non-energy demand.

MARKAL provides the possibility of using it to:

- identify the least costly energy systems and cost-efficient methods for limiting the emission of substances harmful for the natural environment
- prepare long-term analyses of energy balance for various scenarios
- evaluate new technologies and identify priorities for further research and development works
- evaluate the consequences of introduced regulations, tax system, subsidies and other payments
- evaluate projects associated with greenhouse gas emissions
- estimate the value of regional cooperation (Answer… 2004)

3. REFERENCE ENERGY SYSTEM (RES)

One of the first steps associated with building a model with the MARKAL program is preparing so-called Reference Energy System (RES). The RES may be described as a network of energy resources and energy demand. In other words, it is a graphic scheme reflecting a model, its elements and complexity. The RES presents the flow of energy, starting from the energy contained in fuels, through its conversion with selected Technologies, to fulfilling energy needs. A block diagram of the Reference Energy System is presented in Figure 1.

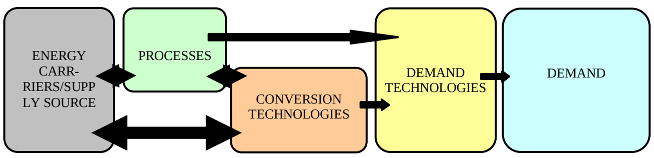

Fig. 1. A block diagram of the Reference Energy System