MESAP/TIMES - Advanced Decision Support for Energy and Environmental Planning

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Abstract. In view of the requirements for climate and environmental protection and the increased international competition within a deregulated energy market, authorities and energy providers want to improve their competence of strategic planning in order to identify robust decisions for the upcoming threats and opportunities. This paper presents the planning tool MESAP/TIMES which integrates the TIMES optimization model and the MESAP software environment for energy and environmental planning. Questions that may be studied with MESAP/TIMES range e.g. from the planning of a local energy system, over the evaluation of energy technologies on a national scale up to the analysis of carbon permit trading strategies in the international Kyoto protocol discussion.

1 Introduction

TIMES (**T**he **I**ntegrated **M**ARKAL-**E**FOM **S**ystem) is a mathematical modelling scheme for representing, optimizing and analyzing energy systems on a flexible time and regional scale. The TIMES model has been developed under the auspices of the International Energy Agency (IEA) within the Energy Technology Systems Analysis Programme (ETSAP) [2]. The TIMES development pursues the goals of merging the advantages of existing energy system models like MARKAL [3] and EFOM [7], of eliminating some shortcomings in these models and of creating a modelling environment being readily adaptable to new ideas and methodologies. It has been implemented in the equation-based modelling language GAMS. The model has been designed for the long-term analysis of energy, environmental and economic (E3) issues over a time-horizon ranging from several years to decades. Typical questions analyzed with such a model are for example the assessment of greenhouse gas abatement strategies or capacity expansion planning in the electricity sector.

MESAP, the **M**odular **E**nergy **S**ystem **A**nalysis and **P**lanning toolbox developed at IER since 1984, was designed to analyze strengths and weaknesses of energy systems, to validate possible future strategies using computer based energy system models and to monitor the effectiveness of the implemented

strategies [5]. MESAP uses a flexible process-engineering oriented technique for modelling energy systems and a user friendly relational database management system to integrate different operations research methodologies with one single database. The MESAP shell for TIMES supports the user in the process of building an energy system and facilitates a structured analysis of the results.

This paper is divided in two sections. The first section describes the TIMES methodology. In the second part the MESAP system and the integration of TIMES as new module within the MESAP environment are presented.

2 The Energy System Model TIMES

TIMES follows a so-called bottom-up systems engineering approach that allows a detailed technical description and economic evaluation of the energy technologies. The energy system modelling approach used by TIMES can be divided into the four parts model topology, numerical data, mathematical structure and scenarios. Due to this separation and the generic formulation of the model equations, the TIMES methodology can be easily applied to different case studies ranging from a local energy system of a municipality over the national energy system of a country to the analysis of multinational energy system. Therefore, TIMES can be considered as a model generator.

2.1 Model topology and time dimension

Reference energy system (RES) The mathematical description within TIMES is based on the concept of a reference energy system (RES). The RES models the energy system as a network of processes and commodities being connected by commodity flows. Depending on the analyzed energy system, the RES may cover the entire energy system of a country from the primary energy supply over conversion, transport and distribution to the end-use sectors as shown simplified in Fig. 1.

By doing this, competition and interaction between different parts of the system may be studied, e.g. competition between increased usage of energy efficient or conservation technologies in the end-use sectors and fuel-switching to less carbon intensive energy carriers in the conversion sector to reduce CO_2 emissions. One characteristic aspect of an RES is, that in most cases a process does not depict a single plant, but rather an entire technology type being available in the energy system. The commodities being produced or consumed by the processes may be energy carriers, energy services, materials, emissions or money. Another feature of an RES is, that besides the existing stock of technologies used today it also contains a portfolio of new technologies that are still under research or too expensive today, but might become competitive in the future.

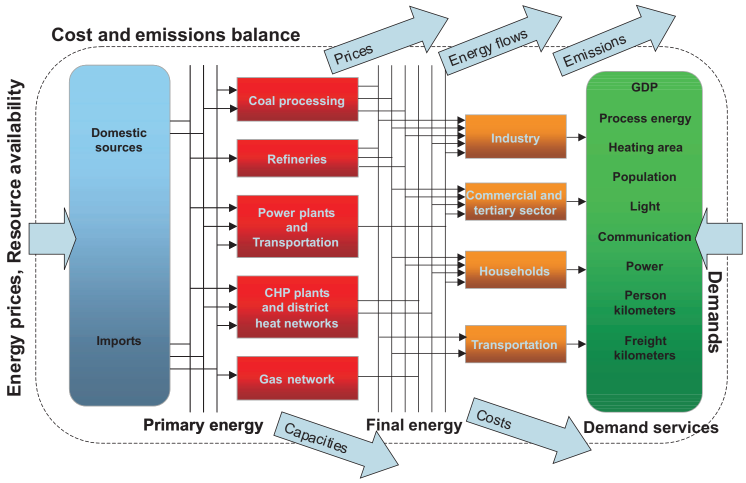

Fig. 1. Concept of a reference energy system (RES).

Regions A model in TIMES can consist of a variable number of regions (Fig. 2). The regions are connected by inter-regional exchange processes describing the trade activities between the internal model regions. The exchange processes might represent abstract trade flows but can also model physical transport processes like electricity grids or pipelines. A multi-regional model might for example be useful to study the benefits of international cooperation in greenhouse gas abatement by carbon permit trading or to analyze the trade of energy intensive products and the development of electrical or natural gas grid capacity in liberalized energy markets.

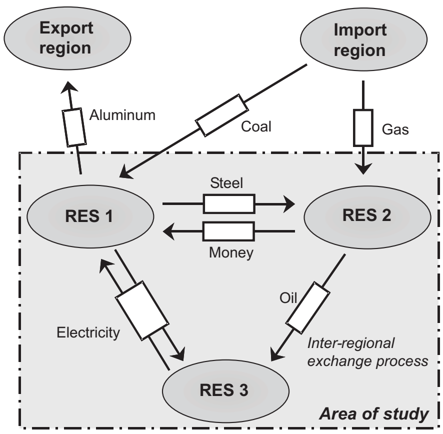

Fig. 2. Building multi-regional models by exchange processes.

Time horizon and time segments In order to describe dynamic aspects over time, the time horizon is divided into periods which may have durations from one to several years. The number of periods and their durations are completely under user-control. Assigning existing capacities to their installation year (in contrast to the usage of residual curves) makes changes in the starting year of the model horizon relatively easy. The average year of a period can again be divided in different subannual time-segments on up to four levels (annual, seasonal, weekly, daily) to model seasonal, weekly or daily variations of e.g. the electricity and heat demand. TIMES uses a load curve and not a load duration curve, so that for example the concurrent production of heat and electricity in combined heat and power plants can be captured in the model.

2.2 Numerical data

The numerical data required by the model as inputs are either global or are assigned to a process, a commodity or a commodity flow. Typical input data comprise technical and economic description of the processes (e.g. efficiencies, availabilities, investment costs, existing capacities), end-use demands, resource availability, import prices of energy carriers and policy measures (e.g. subsidies or taxes) or targets (e.g. greenhouse gas reduction goal).

2.3 Mathematical structure

Using the RES abstraction, the energy system is described by a generic system of linear equations including for example mass and energy balances, transformation equations for the processes relating the input to the output flows, capacity constraints limiting the activity of a process by its available capacity and capacity transfer constraints between successive time periods. In an addition to the standard set of equation types, TIMES offers the user a generic equation framework to add non-standard, user-specific constraints to the model without having to write an equation in GAMS code, for example to put a lower bound on the electricity produced from renewables. The decision variables of the model are the commodity flows between the processes (e.g. the choice of energy carriers), the production or activity of the processes and new installation of technologies. The objective function of TIMES is expressed as the discounted sum of annual costs minus revenues, so as to provide year-by-year reporting of net costs. The model accepts technology-specific discount rates as well as a general discount rate. It is also possible to distinguish between the technical and economic lifetime of a technology. The capacity whose technical life has not expired at the end of the modelling horizon is salvaged in the objective function. This means, that all investment related costs taking place after the last model year are compensated and thus do not effect optimization. Further features of the TIMES methodology include:

- option to use price elastic demands,
- storage processes between time-slices of the load curve and between periods,
- representation of the intensity of attributes, such as sulfur content of fuel,
- vintaging of a technology allowing to describe the technical characteristics of installed capacity (e.g. its efficiency) as a function of its construction year,
- possibility to alter technical parameters of an installed capacity over its lifetime, e.g. decline of the availability of a power plant at the end of its lifetime due to aging,
- flexible process description giving the option to let the model determine the optimal ratio of input/output flows for processes with several inputs/outputs.

2.4 Scenarios

Due to the longevity of most of the energy technologies as well as their high capital costs, investment decisions in the energy sector usually have to take into a account a time horizon of several decades. Several key assumptions made in energy system models, like future evolution of end-use demand or energy prices, cannot be predicted over such a long horizon. To address these uncertainties, usually different scenarios describing possible future developments are created to compare their possible outcomes.

3 MESAP

Building and analyzing an energy system model is a complex task. The modeler has not only to create an abstract simplified representation of the real-world system which still accurately depicts the technical characteristics of the system. Since the optimization is driven by the cost parameters, one also has to ensure that the price relationships, e.g. the shadow prices of different energy carriers induced by import, transportation and process related cost parameters, are realistic. This situation is complicated by the fact, that energy system models usually contain a large number of technologies (up to several hundreds). In addition, the model size and the dependencies within the model are increased by the introduction of time periods, load curves and multiple regions. Furthermore, the model is usually applied for several scenarios creating a huge amount of results to be analyzed. Because of these reasons a software tool is essential to support the modeler in the tasks of building a model and analyzing its results. Moreover, such a planning tool helps to make the model - often considered as a black box from outsiders - and its results more transparent.

3.1 Philosophy of MESAP

For these purposes the integrated energy and environmental planning tool MESAP has been developed at IER. The main characteristics of MESAP are:

- a set of integrated planning models sharing the same database,
- user friendly data entry and model handling,
- powerful and flexible analysis tools,
- common language for energy system data enabling the easy data sharing between case studies and models,
- modular architecture facilitating methodological enhancements.

Fig. 3 summarizes the architecture of MESAP which consists of three parts: the calculation modules, the MESAP information system and additional tools for specific modules or purposes.

The calculation modules include INCA an investment calculation module, PlaNet an energy system simulation model, PROFAKO an operational planning model for electricity and district heat, a general XTRACTOR creating sets and parameters for GAMS models, CalQlator a general equation editor and the optimization model TIMES. The MESAP information system comprises the central database, the Explorer for building and navigating through the database and basic tools for entering data (DataSheet) and analyzing them (Analyst, DataCube). Additional tools are available for special modules, e.g. the RES Editor for the energy system models PlaNet and TIMES, or for special purposes like accessing the database via the Internet.

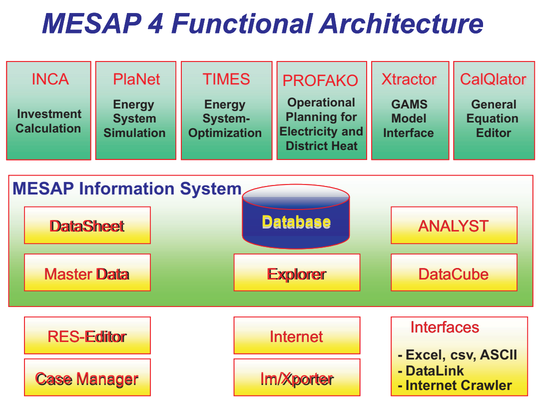

Fig. 3. The architecture of MESAP4.

3.2 Integration of TIMES in MESAP

Due to the modularity of the MESAP concept and its standardized data interface, a continuous integration of new methodologies and planning models

has been possible. Currently the integration of TIMES in MESAP is underway. The different tasks in the course of building, running and analyzing a model are:

- defining time horizon and model topology,
- specifying processes and commodities,
- entering and editing data,
- defining scenarios,
- running the model,
- analyzing the results.

A great part of these tasks can be accomplished by MESAP components. For the definition of the model topology the RES editor (Fig. 4) can be used.

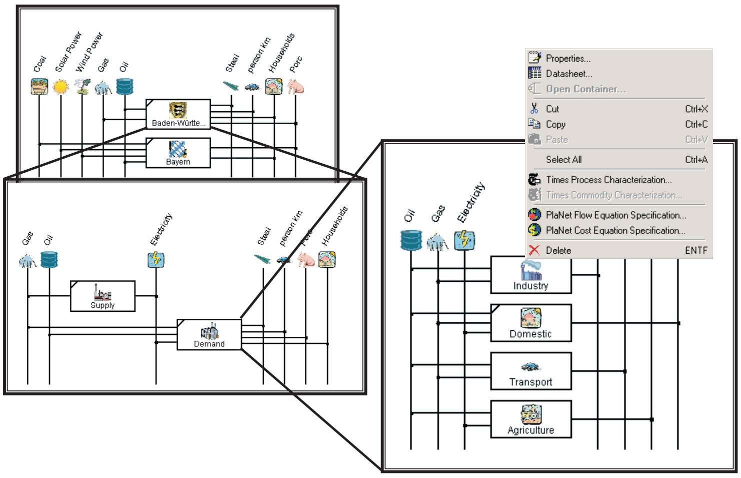

Fig. 4. RES Editor with containers for structuring the RES and direct access to further information.

Besides regions the RES editor also allows additional structuring of the RES in sector or technology containers. Within the RES editor the user can intuitively navigate through the model. The graphical process and commodity objects offer a direct link to additional forms for the specification of processes and commodities (e. g. determining the commodity type) and to the DataSheet for entering and editing data. In addition to a pure process or commodity oriented view, the user can create and save specific views on the data, e.g. investment costs of all coal power plants.

To run the model, the input information needed for TIMES is extracted out of the database in an ASCII file. In the opposite direction MESAP will allow the import of already existing TIMES models. The Analyst is developed as an COM-Add-In programme for Microsoft Excel. It offers within Excel the possibility to create tables, graphics and reports, which through a direct

reference to the database can be automatically updated, if new results are present. Another analysis tool, the DataCube, opens the opportunity to pivot rows and columns in a table or to change the sort order of rows and columns in a drag-and-drop manner providing different perspectives on the results. In the DataCube it is also possible to drill-down to the underlying values of an aggregated number, e.g. to check the individual electricity production of each coal plant constituting the total electricity generated by coal.

4 Outlook

The TIMES model has been developed with the goal to tackle some drawbacks in existing energy system models and to create a modelling platform being open to new model paradigms and ideas. Currently endogenous technology learning (ETL) [6], which allows to describe the investment costs of a technology as a function of the cumulative installed capacity, is implemented in TIMES. Another possible extension is the introduction of an uncertainty index in the parameters and sets, which will support stochastic programming or fuzzy logic. Further future enhancements may include the linkage of TIMES to other models like a general equilibrium model similar to MARKAL-MACRO [4] or the connection with an environmental impact assessment model like EcoSense [1]. In this context, the ongoing integration of MESAP into TIMES will provide powerful and flexible tools, so that the modeler or planner can spend his time on the central issues of his work not being sidetracked by cumbersome data converting and processing tasks.

References

1. European Commission DG XII, Science Research and Development, JOULE (editor): Externalities of fuel cycles - ExternE Project, Vol.7 - Methodology 1998 Update, EUR 19083 EN, Brussels-Luxemburg, 1998.
2. ETSAP, The New TIMES: a Model for the Millenium, In: Hill, D. (Editor): ETSAP News. **7**, No. 1, January, 2001, (available under `http://www.ecn.nl/unit_bs/etsap/newslet/main.html`)
3. Goldstein, G. A., Greening, L. A. (2001) Energy planning and the development of carbon mitigation strategies - Using the MARKAL family of models, (available under `http://www.ecn.nl/unit_bs/etsap/reports/markal.html`).
4. Manne, A., Wene, C.-O. (1982) MARKAL-MACRO: A linked model for energy-economy analysis, BNL-47161, Brookhaven National Laboratory.
5. Schlenzig, C., Reuter, A. (1996) An Information and Decision Support System for Energy and and Environmental Planning. In: Carraro, C., Haurie, A. (editors): Operations Research and Environmental Management, Kluwer Academic Publishers, Dordrecht, Netherlands.
6. Seebregts, A.J., Kram, T. et. al. (1998) Endogenous technological learning: Experiments with MARKAL, Report ECN-C-98-064, Petten, Netherlands.
7. Van der Voort, E., Doni, E. et. al. (1984) EFOM-12C Mark I, Energy Supply Modelling Package, Mathematical Description, Rapport8896.