IMPLEMENTATION OF STRATEGIC ENERGY PLANNING TOOLS FOR THE BIH ENERGY SYSTEM

Marko Ikić, *Faculty of Electrical Engineering in East Sarajevo*
markoikic@yahoo.com
Semir Hadžimuratović, *Faculty of Electrical Engineering in Sarajevo*
semir.hadzimuratovic@gmail.com
Boško Kenjić, *Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina*
bosko.kenjic@mvteo.gov.ba
Gary A. Goldstein, *International Resources Group*
Gary.A.Goldstein@gmail.com
Evelyn L. Wright, *International Resources Group*
Evelyn.L.Wright@gmail.com
Bruno Merven, *University of Cape Town*
brunomerven@gmail.com

Abstract – This paper describes the implementation of a widely used, bottom-up, linear programming energy systems analysis modeling framework (MARKAL) in energy sector. The definition and overview of a standard Reference Energy System (RES) structure, that illustrates how all available energy sources, energy-transforming technologies, and energy-using technologies may be utilized and combined to meet a country's energy service demands is given. The RES built for the SYNENERGY Strategic Planning Southeast Europe and Caucuses national energy models is described in detail.
Keywords: MARKAL, Technology energy modeling, Energy system analysis.

1. INTRODUCTION

MARKAL is a widely used, bottom-up, linear programming energy systems analysis modeling framework. This modeling paradigm has been in use for more than 30 years at more than 200 institutions worldwide, and, along with its successor framework, TIMES, it has become one of the leading energy systems modeling frameworks. MARKAL/TIMES is currently in use for several major international and global applications, and in dozens of developed and developing countries for national strategic planning. [1, 2, 3, 4, 5]

A MARKAL/TIMES model represents all energy producing and consuming sectors in a Reference Energy System (RES) network that links resource supplies, energy conversion and processing technologies, and end-use demands and the devices that meet them, tracking the flows of energy and associated emissions. The network is established at model construction time according to a user-specified level of end-use, technology, and pollutant detail. The model finds the least-cost path through the RES network to meet all end-use demands, subject to constraints that enforce network integrity as well as any user-imposed policy and market constraints by performing a perfect foresight, perfect information minimization of the net present value of total energy system costs, including the capital and operating costs of all devices, fuel costs built up from stepped resource supply curves, and any taxes and subsidies the user imposes.

A MARKAL/TIMES model for BiH has been developed under the US Agency for International Development and Hellenic Aid-funded SYNENERGY Strategic Planning (SSP) project, and its predecessor, the Regional Energy Demand Planning (REDP) project, which have led to the development of MARKAL/TIMES models in eleven countries in the Southeast Europe, Black Sea, and Caucusus regions. [6] The projects' goal is to develop national energy modeling capacity in each of the participating countries, and to develop a common technical “language” for regional energy strategy dialog.

This paper describes the model organization and data requirements for the SSP MARKAL/TIMES models. A MARKAL/TIMES model is structured using a Reference Energy System (RES) network structure that illustrates how all available energy sources, energy-transforming technologies, and energy-using technologies may be utilized and combined to meet a country's energy service demands. The model data is organized within a set of "Smart" Excel workbooks, or templates, that guide the analyst in specifying the data needed to characterize each component of the RES. For the SSP undertaking a complete set of workbooks have been provided to each country team, representing a typical SSP situation, which have then been adjusted appropriately by each team to properly reflect their country's situation. [7]

The starting point of the data development procedure within the templates is the Energy Balance, which is available in most countries. The Energy Balance provides primary energy supply, transformation sector input/output, and final energy consumption by fuel for each sector. Various shares and assumptions are then used to establish a detailed picture of how this final energy consumption is being used in the base year (a process called *calibration*) and a structured approach is taken to projecting the demands for energy services and characterizing the options available to meet them in the future.

2. OVERVIEW OF THE SSP REFERENCE ENERGY SYSTEM

A MARKAL/TIMES model is built upon a Reference Energy System (RES) structure. The RES is a network that links resource supplies, energy conversion and processing technologies, and end-use demands and the devices that meet them, tracking the flows of energy and the associated emissions. The figure below shows a summary diagram of the RES. The model finds the least-cost path through the network to meet all end-use demands, subject to constraints that enforce network integrity as well as any user-imposed (policy) constraints. Figure 1 shows an overview of a generic RES, providing examples of fuels that could be included and general categories of technologies and end use sectors.

The first step in developing a MARKAL/TIMES model is then to customize this generic RES for the situation at hand. The sectors, fuels, and end-use demands to be included are defined at the desired level of detail, and the technological options for each are enumerated. "Dummy" process devices are also often included, which do not represent real technologies but rather modeling techniques to make the analyst's job easier.

The resulting RES is too large and detailed to picture as a whole. However, one may depict it in pieces or in summary or example fashion and one may step through it in the ANSWER data handling shell. Figure 2 provides a snapshot overview of the structure of the SSP RES, selecting natural gas as a sample fuel and apartment space heating as an example demand. [7]

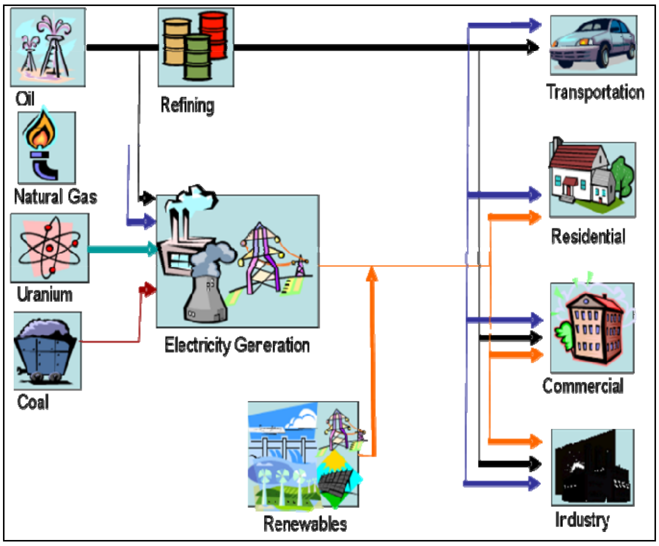

Figure 1: MARKAL Reference Energy System Overview

The fuel supply chains for natural gas and for electricity are shown in Figure 2, along with sample devices to generate electricity from natural gas and to provide apartment heating from electricity and gas. This general structure is repeated for many other fuels, devices, and demands throughout the SSP RES.

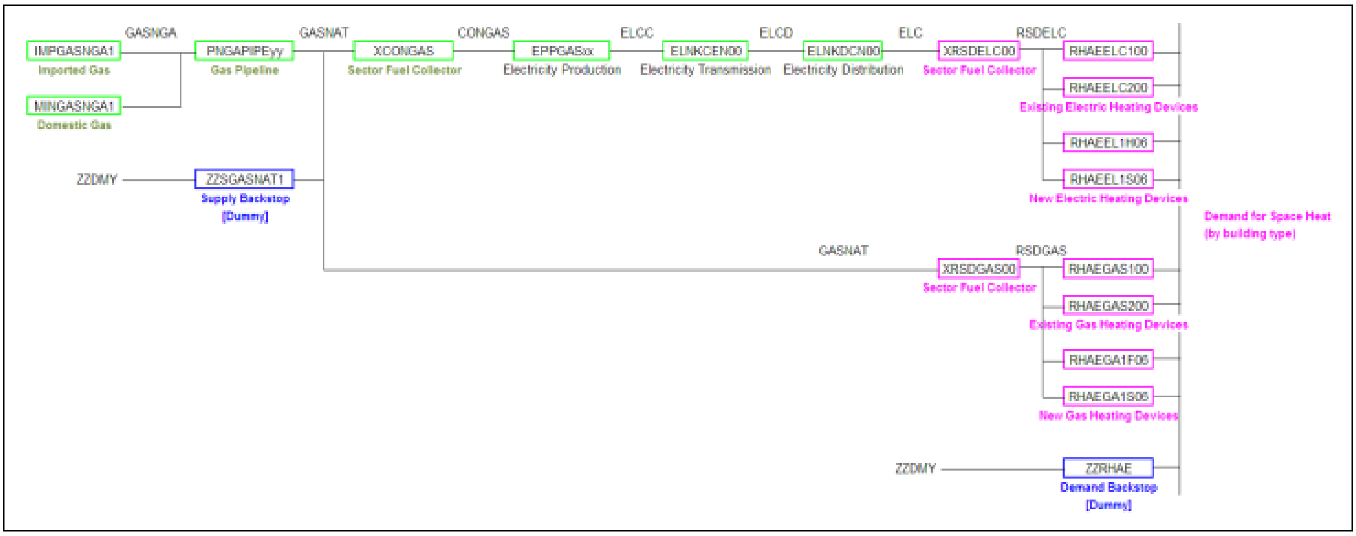

Figure 2: SSP RES Snapshot Using Natural Gas, Electricity, and Apartment Space Heating as Examples

The boxes in the RES represent fuel supplies and/or technologies, while the lines represent energy carriers (fuels). The names of the supplies/technologies are shown within the boxes, while the names of the energy carriers are shown above the lines. These "short" names or codes are defined using strict naming conventions that, once learned, make identifying and working with model components much easier.

Working from the right hand side of the RES in Figure 2, the rightmost item is the demand for energy service, in this case Apartment Space Heating. An important distinction is made between energy services demand (often called useful energy demand or end-use demand) and the final energy consumed to enable technologies to meet these end-use demands. Energy services are what users actually need – the light, heat, travel, or industrial process drive provided by energy consuming devices. Final energy is the last time that physical energy forms (e.g., electricity, gasoline, distillate) can be explicitly recognized in the model, before the demand service devices (e.g., cars, light bulb, heater, air conditioners, industrial heat) convert said energy into services (e.g., passenger travel, lighting, heating, cooling, preparing pulp for making paper). **A MARKAL/TIMES model is *driven by* energy service demands and *computes* final energy consumption**.

The demands for energy services in the SSP models are categorized into five main sectors: Agriculture, Commercial (Services), Industry (including mining and construction), Residential (Households) and Transport. Each sector is then split into a number of sub-sectors. For example, Households may have demands for heating, cooling, hot water, lighting, refrigeration, washing and drying clothes, washing dishes, other electrical appliances. Some demands, like space heating, are further broken down by building type.

These demands are calculated for the base year in the templates through the calibration process. Then a key aspect of developing a model to assist with future energy demand planning becomes the development of projections for useful energy demand services, which MARKAL will then be required to meet by choosing the **least-cost** set of fuels and technologies within the various constraints imposed. The demand projection process systematically relates the specific demands identified in a model to the corresponding social, economic and technical factors that affects this demand. [3]

Moving leftward in the RES depicted in Figure 2, we find a sample of the technologies available to meet the specified demand, in this case a small subset of the electricity and natural gas powered heating devices. The characteristics of the existing devices are specified in the template for each end use sector and the base year stocks are calculated therein. A library of new devices available to purchase with complete cost and performance characteristics is made available to the model in the NEWTCH-DMD template.

Below the end use devices is a so-called "dummy" backstop technology, named ZZRHARE. This device is a modeler's tool, a nonphysical device that consumes an inexhaustible, nonphysical fuel named ZZDMY and that can meet any amount of apartment space heating demand at very high cost. This device, and similar devices for each demand, prevents infeasibilities during the model run. Infeasibilities are cases where the model cannot meet all the demands and thereby terminates a run without producing the usual reports, making it very difficult to locate the problem area. These backstop processes allow one to trace back where the infeasibilities would otherwise occur and are thus a key diagnostic tool for the modeler. Each time the modeler makes a significant change to the model and creates a new run, the first result to check is for any consumption of ZZDMY. In a working model run, these devices should never be used. (A similar set of devices exists to supply every resource in the model. The example ZZGASNAT is shown in Figure 2.)

Just to the left of the end use technologies, for each demand sector there are a set of dummy technologies whose names always begin with X. Like the ZZ dummy devices, these X processes are nonphysical devices that are inserted into the model to make the modeler's job easier. The X processes change the name of each fuel as it moves from the supply side to where it is consumed (for example, from GASNAT to CONGAS, for the conversion (power) sector or RSDGAS, for the residential sector). This nomenclature makes it easy to quickly track, for example, how much natural gas is consumed in each sector. The delivery markup for sector fuels, which tends to vary by sector, is also charged at these devices. In some cases, these devices are used to collect several upstream fuels into a single demand fuel when this simplicity is warranted (e.g., hard coal, briquettes, and lignite coal are all combined into <sect>COA for the demands). In a few cases where fuel distribution infrastructure is limited and costly, such as for natural gas, these devices are also used to represent the capacity of the existing infrastructure and to charge the model a cost to extend it. [4]

Moving further leftward from XCONGAS and XRSDGAS in Figure 2, the gas supply RES is straightforward. Gas is delivered to the sectors through a transmission pipeline that represents total national transmission capacity (where base year capacity and options for investing in increased capacity may be specified). Gas is supplied to the pipeline through imports and/or domestic production, as applicable to the country-specific situation. The electricity sector warrants additional description. Shown here is one example of a centralized gas-fired power plant. Electricity only and combined heat and power plants (as well as heat only plants) may be described for a number of fuels, in both centralized and decentralized option. The data for describing existing power plants is organized in the PP template, and a library of options for new plants is characterized in the NewtchPP template. Electricity transmission and distribution grids (conceived as national aggregates) are represented separately as interconnection (LNK) technologies (ELNKCEN00 and ELNKDCN00), each with its losses. Once electricity has traveled through these grids, it is ready to be fed to the end use sectors by the relevant X<sector>ELC processes. The heat distribution grid is modeled similarly.

A consistent set of units must be employed for each component of the RES. The basic units employed throughout the SSP models are:

- Capacity - Gigawatts (GW) for electricity generating facilities; Petajoules/year (PJ/a) everywhere else
- Demands - Petajoules (PJ);
- Energy and Process Activity - Petajoules (PJ); and
- Monetary - Million EUR2006.

Frequently data will be available in other units. The templates provide a structure for performing the necessary unit conversions.

3. ORGANIZATION OF THE SECTORS

This section works through the RES described above sector by sector, elaborating the structure, level of detail, and naming conventions. We begin with the demand sectors and work leftward through the RES, as above.

3.1. Demand Sectors

There are five main demand sectors depicted by the SSP RES:

- Residential
- Commercial
- Agriculture
- Industry

- Transportation

In the sections that follow, the organization of the sub-sectors or categories of end-use services within each sector is first presented, followed by the specifics of the RES details (technologies) associated with each sub-sector. Naming conventions for the demand sectors follow.

3.1.1. Residential

The residential sector (RSD) distinguishes 10 end-uses in 4 dwelling categories. Only space heating, water heating and space cooling are broken out by building types, owing to the variance in thermal integrity, seasonal use profile, and device and conservation options for each dwelling type. [5]

The residential sector includes the following end-uses:

- space heating;
- water heating;
- space cooling;
- cooking;
- lighting;
- refrigeration and freezing;
- clothes washing;
- clothes drying;
- dish washing, and
- all other consumption of electricity in households (includes TV, computers, radios, etc).

The heating, cooling, and water heating demands are divided into the following dwelling categories:

- single houses in rural area with local space and water heating;
- single houses in urban area with local space and water heating;
- single houses in urban area with central space and water heating, and
- all apartments (urban areas) with local and central space and water heating.

"Local" in this context means heating systems that heat a single room, while "central" refers to dwellings with central heating systems. Thus a single urban house may move from the local to urban category by installing a central heating system. For apartments, this distinction was not made because the difference is smaller.

3.1.2. Commercial (or Services)

In terms of energy consumption, the commercial (or services) sector in transition economies does not generally exceed 25% of the final energy consumption in the residential sector. Because of the relatively low energy consumption in relation to other sectors, the energy balances show the commercial sector only as one economic sector, not split into sub-sectors (like industry). However, the service sector is expected to grow, both in economic and energy consumption terms. Therefore, it will be increasingly important to improve upon the statistical records regarding energy consumption in the service sector, and the SSP depiction of the commercial sector has been structured with this in mind.

The service sector can be classified by sector activities into public services and market services. Public services include: health care, education and other public services (culture, sport, public administration and civil service). Market services include: commerce, hospitality industry (catering and tourism), banking, consulting services, etc.

The basic reference used for energy intensity in the service sector is square meters of floor-space in buildings according to the individual sub-groups of services. It may be difficult, however, to find a comprehensive and public statistical analysis of space used in the commercial sector, particularly by service type. This data must be obtained by means of surveys and energy audits, and thus is costly to obtain and maintain. In 1996 in Croatia, for example, the Energy Institute Hrvoje Požar conducted an in-depth survey of floor space of the individual service sectors by regions in the country. As a result of this survey 80% of total commercial sector was analyzed. The remaining 20% was then estimated. However, since 1996 there have not been any follow-up studies to investigating the commercial sector in the country, nor have official statistics improved with respect to methods of monitoring this sector. Therefore, estimation is generally required when constructing MARKAL models [8].

Due to this sparse data, for the SSP models, the commercial sector has been divided into two broad sub-sectors: small and large buildings. Note that as with the residential sector, building type is only relevant for heating, cooling and hot water. Water heating requires this distinction because of its link to space heating through the use of furnaces that provide both space heating and hot water.

3.1.3. Agriculture

Agriculture is treated slightly differently than the Residential and Commercial sectors. For Agriculture only a single demand category is specified, with generic devices provided for each fuel type. Thus we track only final consumption, rather than actual energy services such as tractor use, greenhouse heating, and so on. Generic devices in future years allow more efficient energy use to meet the same implicit service demand.

3.1.4. Industrial

Because of differences in the evolution of the various demands for energy services (end-uses), and in the availability of technologies to meet these demands, the industrial sector (IND) distinguishes three end-uses in each of the seven industry subsector:

- chemical industry;
- food industry;
- iron and steel industry;
- non-ferrous metals industry;
- non-metallic minerals industry;
- other manufacturing industry; and
- pulp and paper industry.

The end-use categories within each industry are:

- high temperature heat;
- low temperature heat; and
- machine drive.

Energy consumption in the industrial sector includes biomass consumption (including fuel wood and other non-conventional fuels). Coke consumption includes coke oven gas and blast furnace gas.

3.1.5. Transportation and Non-energy Consumption

Because the original analysis focus for the SSP models was electricity demand growth and supply, only the electricity-powered portion of the Transport sector (public transport and rail) is currently depicted in the SSP models. This demand is met by generic devices, as in the Agriculture sector. For now, other modes of transport and consumption of oil derivates in Transport sector are not considered for the SSP.

Non-energy consumption is the natural gas consumption for fertilizers production. This consumption is added to fulfill the overall energy balance for natural gas.

4. SECTOR FUELS AND FUEL PROCESSES

Energy carrier names consist of 3-6 characters throughout the SSP Reference Energy System. Within each of the demand sectors, the energy carrier names are six characters, as follows:

- The first 3 letters describe the sector (e.g., RSD = residential, COM = Commercial, IND = Industry, TRN = Transportation, AGR=Agriculture); and
- The last 3 letters describe the fuel type:

Short Name	Energy Carrier
BIO	Biomass (wood)
COA	Coal
ELC	Electricity
GAS	Natural Gas
LTH	Low-temperature Heat
OIL	Petroleum Products

Table 1: Energy carriers

Thus coal to the residential sector would be named RSDCOA, and petroleum to the commercial sector COMOIL.

Although the physical fuels to each sector may not be physically different (e.g., COMGAS and RSDGAS represent the same physical natural gas commodity), giving them distinct names serves several purposes:

- It facilitates tracking of fuel consumption by sector in model results;
- It allows charging different delivery markups to different sectors (e.g., industrial vs. household tariffs); and
- It allows tracking of the capacity and cost of limited infrastructure (e.g., natural gas distribution networks).

Within each sector a set “dummy“ X process technologies are established to create the named sector fuels from the fuels emerging from the supply (or upstream) subsystem of the complete RES. [2]

5. CONCLUSION

Energy has always played an important role in human and economic development and in society’s well-being. That is the reason that we need to plan and strategize for the use of energy in rational and more efficient ways. In this paper we have presented a very powerful strategic energy planning tool and its implementation in the SSP energy sector models. The next steps will be to present the results of energy balance in BIH, present reference scenarios, renewable targets and energy efficiency scenarios.

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