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IEA OECD ETSAP news

ANNEX X: GLOBAL ENERGY SYSTEMS AND COMMON ANALYSES

1. MARKAL: recent enhancement

Over the past several years ETSAP has continued to provide support for and enhancements to the GAMS MARKAL model generator and report writer as well as the ANSWER database management system that oversees the use of the model.

The most important of these enhancements have been motivated by the need to provide MARKAL with enhanced capabilities to meet the needs of several major modeling undertakings including:

- The International Energy Agency's (IEA) Energy Technology Perspectives (ETP) project;
- The US Energy Information Administration (EIA)System for the Analysis of Global Energy Markets (SAGE) model; The US Environment Protection Agency Office of Research and Development (EPA-ORD) development of a 9-region US national model (US9r);
- The Northeast States for Coordinated Air Use Management (NESCAUM) 12-state regional model, and
- The US Agency of International Development (USAID) 9-country Southeast Europe Regional Energy Demand Planning (SEE-REDP) capacity building undertaking.

and these institutions have provided significant funding to make these enhancements possible. In general these enhancements have then become available to the global community of MARKAL users.

1.1. Major enhancements that have been added to the MARKAL model to meet the needs of the IEA-ETP model include:

- The ability to associate emissions directly with commodities via a new ENV_ENT parameter, rather than having to enumerate each technology/emission instance;
- The (partial) "vintaging" of demand devices – two new efficiency parameters (IEFF for new investments, and REFF for residuals) have been added that allow the modeler to specify efficiencies for demand devices based upon the year that an investment actually occurs, rather than the current model year as had previously been the case. This "vintaging" reduces the database size and simplifies the management of the input data and analysis of the model results as compared with the previously needed approach of manually introducing "cloned" technologies whose efficiencies were based upon the year that investment actually occurred;
- Cross-region emission constraints for multi-region models – these are emission constraints that allow the user to specify a region-independent emission limit that applies to the sum across regions of emissions in each region. For a given emission, either a single value that applies over the entire modeling horizon, or period-by-period values may be specified;
- Cross-region user-defined (ADRATIO) constraints for multi-region models – these are ADRATIO constraints that allow the user to specify a RHS that is region-independent and that applies to the sum across regions of the LHS of the ADRATIO in each region in which said user constraint entries are provided;
- Resource and technology capacity decay constraints that limit the rate at which resources and capacity can be abandoned; and
- n-period (partial) look-ahead (where n > 1) for time-stepped MARKAL so that a number of periods can be examined

This issue of the ETSAP Newsletter summarizes recent updates and new capabilities of the MARKAL model generator and report writer, along with the ANSWER user "shell" for MARKAL, of interest to ETSAP and other users of the methodology (Figure 1). These enhancements include:

- Permitting an open ended number of time-slices to be specified by the user;
- Refinement of the SAGE Market Share Algorithm;
- Enhancement of the MARKAL-TS time-stepped formulation to allow n-period look ahead;
- Report writer enhancements to report electricity/heat generation by time-slices and calculate the expenditure on fuel by technology;
- Rule-based user constraints and tech-filters in ANSWER; and
- ANSWER 'smart' load templates that load models from Excel spreadsheets.

This newsletter also summarizes recent work in Switzerland and the United Kingdom with MARKAL and MARKAL-MACRO. A summary of an analysis conducted with the Swiss MARKAL model to evaluate possibilities for evolving to a 2000-Watt society in Switzerland, undertaken by the Paul Scherrer Institute (PSI) is presented. This is followed by an overview of the UK Energy Research Center (UK-ERC) and a discussion of the Energy System Modelling (ESM) activities being undertaken by the Policy Studies Institute (UK-PSI) and the Cambridge Centre for Climate Change Mitigation Research (4CMR) at the University of Cambridge.

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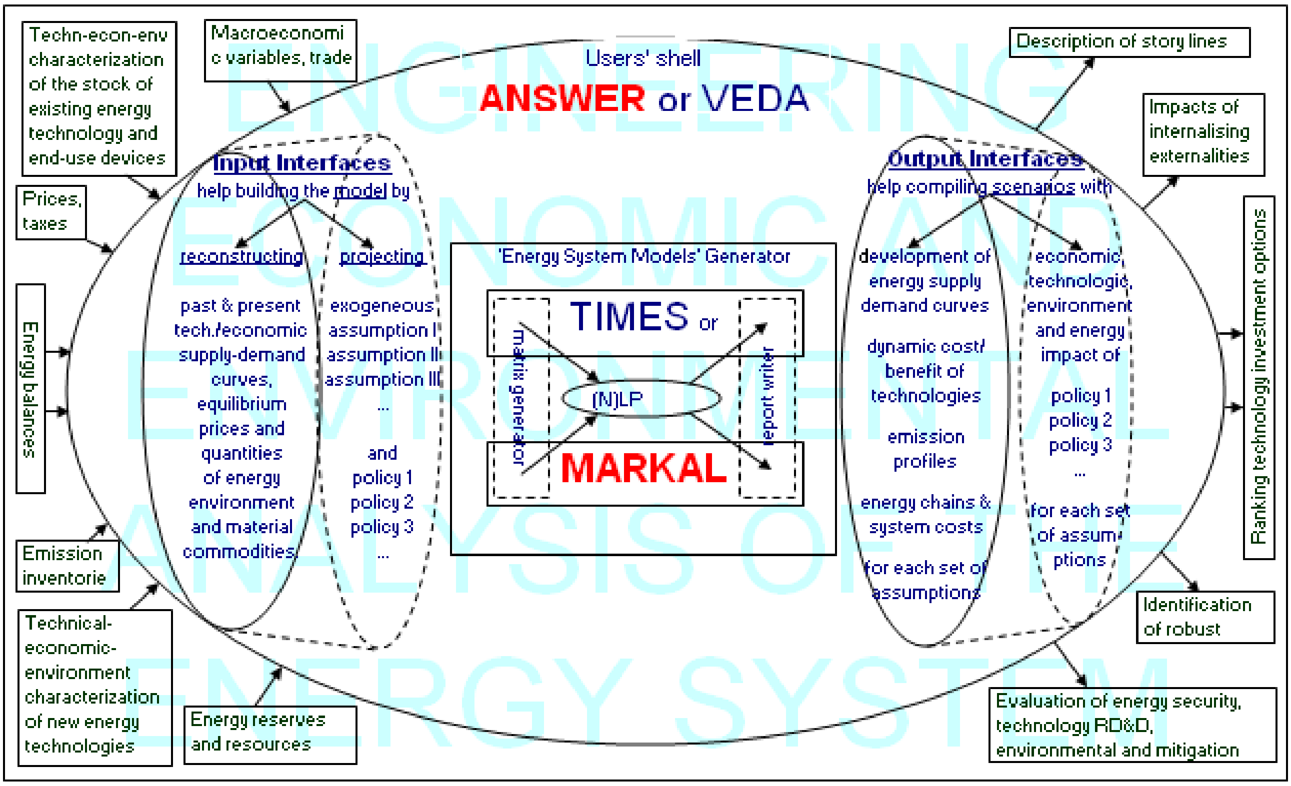

Figure 1: ETSAP tools and typical applications
[Acronyms: MARKAL = MARKet Allocation; TIMES = The Integrated MARKAL - EFOM System; LP = Linear Programming; NLP = Non Linear Programming; VEDA = VErsatile Data Analyst; RD&D = Research, Development & Deployment]

simultaneously, stepping through one period at a time to solve for the next n-periods; the 1st period in each solve is then fixed prior to stepping forward.

1.2. Major enhancements that have been added to the MARKAL model to meet the needs of the EIA-SAGE model include:

- The ability to run MARKAL in a time-stepped manner, meaning investment decisions are made in each period without knowledge of future events (often referred to as myopic or without foresight), whereas standard MARKAL is run in a clairvoyant manner; and
- The initial development and subsequent refinement of the SAGE MarKeT SHaRe (MKTSHR) algorithm. The basis of this facility is to identify market segments or “groups of competing technologies” (e.g., all alternative fueled passenger vehicles), then accumulate the level of all the technologies in the market segment and redistribute to each technology in the group according to weighted shares as the relative cost.

1.3. Major enhancements that have been added to the MARKAL model to meet the needs of the US Environment Protection Agency include:

- The development of a Goal Programming formulation that permits the user to explore the trade-off between conflicting goals (e.g., least-cost and air quality) by assigning preferences to the various objectives being considered; and
- The introduction of flexible time-slicing and thereby the removal of a long-standing MARKAL restriction that imposed a fixed segmentation of the electricity load curve by dividing the annual demand for and production of electricity into six distinct time-slices (3 seasons x 2 diurnal divisions), and three seasonal time-slices for heat. With flexible time-slicing, the user is able to control the number of seasons and the number of diurnal divisions.

1.4. Other significant enhancements that have been added to MARKAL over the past several years include:

- The development of a facility to model Lumpy Investment. This facility permits more sophisticated modeling in respect of lumpy investments (such as the construction of gas pipelines) by using mixed integer programming (MIP) techniques to model the all-or-nothing building of new capacity;
- The development of a new Benefit/Cost report employing a new GAMS UnitB/C utility;
- The development of a “RAT_FLO” facility that enables the user to associate commodity flows in/out of technologies with ADRATIO constraints; and
- The provision of improved

reporting of results details in the standard MARKAL tables, so that electricity/heat generation and consumption are reported by time-slice, the expenditure on fuel is calculated by technology, and the split of demand devices output to multiple sectors is provided.

All the enhancements mentioned above are fully documented in a series of MARKAL information notes, MARKAL_v5.3-7_EnhancementsUpdates, available in the ANSWERv6\DOC folder.

In addition, as is discussed in the next section, there have been numerous enhancements to the ANSWER data management system for MARKAL, notably the introduction of "smart" Excel workbooks to facilitate the assembling and loading of the MARKAL data into ANSWER. These workbooks are heavily employed in the US9r, NE-12, and SEE-REDP undertakings, as well as new capacity building activities with the state of Ohio and in Nepal.

1.5. Recent ANSWER Enhancements

Over the past several years Noble-Soft Systems has continued to enhance the ANSWER-MARKAL software interface so that it supports the majority of enhancements that have been incorporated into the MARKAL model generator and report writer. (While ANSWER supports running SAGE time-stepped solve, it does not support the SAGE Market Share algorithm.) In addition the ANSWER-MARKAL software interface has been enhanced to provide improved power and convenience to the ANSWER user in a number of areas.

The most important of these enhancements have been motivated by the needs of:

- The International Energy Agency's Energy Technology Perspectives (IEA-ETP) model, and
- The US Environmental Protection Agency's US 9-region model.

Briefly, the major enhancements added to the ANSWER interface (with ETSAP funding support) to meet the needs of the IEA-ETP 15 region MARKAL model involved the creation of a special ETP version of ANSWER with the following main characteristics:

- The use of a special Library Region within an ANSWER database to store information and data associated with technologies and commodities that are common to each of the 15 regions;
- The provision of extensive bulk copying and bulk updating facilities, such as from the Library Region to each of the 15 regions, to expedite the task of ensuring commonality of information and data across the 15 regions, and
- The creation of an "Operator Parameter" mechanism that allows the user to specify regional multiplier/adder to be applied to Library Region parameter numeric values.

The special ETP version of ANSWER is not generally available to ANSWER users.

More recently, the following major enhancements have been added to the ANSWER interface (with US EPA funding support) to meet the needs of the US Environment Protection Agency's US 9-region model:

- Support for the newly introduced MARKAL flexible time-slicing facility – in particular to simplify using this facility for multi-region modeling;
- The introduction of a new Technology Items Filter (TechFilter) facility that allows the user to define powerful filters based on Name and/or Description and/or Set Membership and/or Input/Output Commodity (topology,). Once defined by the user, these TechFilters may be "dialed up" either to filter the Technologies that are displayed to those of immediate interest, or as part of the process of defining "rule-based" user constraints – see immediately below. For example, the Technology Items Filter form shown i Figure 2 defines a filter that specifies all industrial demand devices (DMDs) that consume natural gas (NGA); and
- The introduction of a new "rule-based" user constraint (ADRATIO) facility overcoming the previously cumbersome and error prone process whereby each individual technology had to be explicitly enumerated as part of the constraint specification. By use of the TechFilter facility to specify a set of like technologies to be involved in the user constraint, the specification of many user constraints can be greatly simplified. Another important benefit is that "rule-based" constraints are resolved at run time, so all qualifying candidates are picked up and the user does not have to remember, when adding new technologies, to augment old ADRATIOs. For example the screen snapshot shown in Figure 3 indicates how two TechFilters ALL-ELE and RENEW-ELE (to select all electric technologies and all renewable electric technologies respectively) may be used to define a "rule-based" user constraint named RENEWELC that specifies that production by renewable electric technologies must comprise at least 5% of total electricity production:

The above flexible time-slicing, TechFilter and "rule-based" user constraint facilities are now available to all ANSWER6 users. This includes a "Resolve Rule-based Constraint" option that enables the user to cross-check the fully enumerated entries associated with the constraint via a right-mouse menu option for a highlighted ADRATIO.

Other significant enhancements that have been added to the ANSWER interface over recent years include:

- Strengthening of the Export Scenario facility to allow the specification of the start and end periods for time-series data that will be exported, and related strengthening of the Import Scenario facility;
- The recoding of various parts of

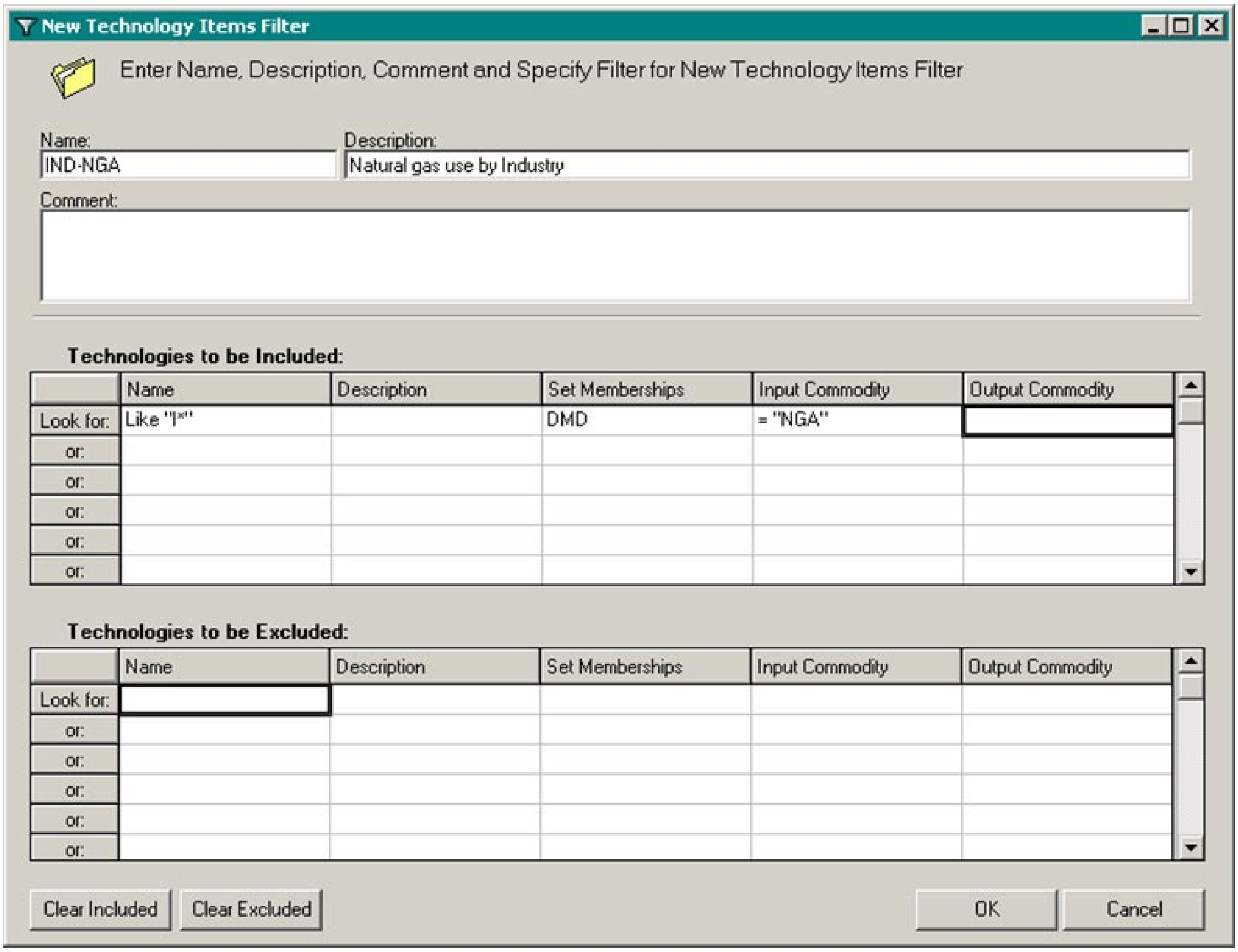

Figure 2: Example of new technology items filter

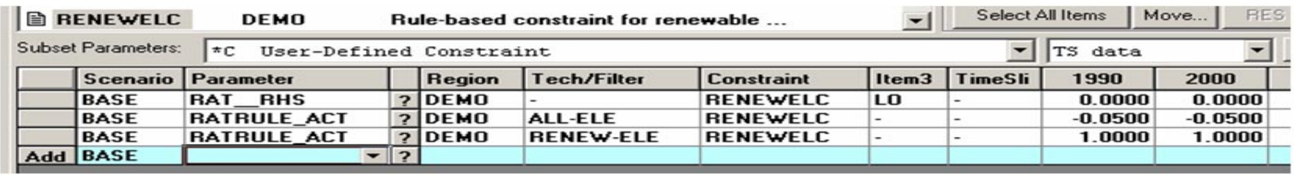

Figure 3: of rule-based constraints

the ANSWER code to significantly speed up areas that were running slowly, for example the Run Model code has been sped up by a factor of about 25;

- Improving user-friendliness by allowing multi-select in various places (such as selection of Scenarios for Run Model) where previously only single select was possible;
- The introduction of a "Remember Case Definition" option when deleting a Case, so that the Scenarios involved and other settings are retained online, while all the actual results for the Case are deleted; and
- A revised Batch Run facility that allows the user to readily specify a set of runs to be carried out one after the other, further enhanced by a new Batch Management facility allowing the user to create, copy, delete and edit named Batches of Cases inside an ANSWER Database. This facility is used in conjunction with new [Load Batch] and [Save Batch] buttons on the Batch Run form to allow the user to store and hence easily recall a Batch of Cases to be re-run.

Finally, and importantly, a completely new facility – ANSWER "smart" load templates – has been created to be used in conjunction with the ANSWER interface's "File, Import Model Data from Excel" facility to load single-region or multi-region model data from an

Excel workbook into an ANSWER database. The main features of the "smart" load templates include:

- The new ANSWER "smart" load templates comprise an Excel workbook in which the worksheets have a very flexible and user-friendly format and where associated "smart" buttons (with underlying macros) allow linking to the user's ANSWER database enabling the user to do such things as selecting an Item's Set Memberships/Units from the ANSWER database, as well as the other "smart" sheets in the workbook;
- To specify declaration information (Name, Description, Units, Set Memberships, optional Comment), there are three declaration worksheets, one for each of Commodities, Technologies and Constraints;
- To specify data information, there are three data worksheets used for each of Commodity, Technology and Constraint data respectively, and
- The format of the ANSWER "smart" load templates simplifies the specification of declarations and data for multi-region models that have common naming conventions across regions.

The "File, Import Model Data from Excel" facility has been enhanced to enable the import into ANSWER of the 6 types of worksheets in the new ANSWER "smart" load templates. In addition, the options that are available on the "Import Model Data from Excel" form have been extended in a number of ways to allow the user additional control over the Import process.

2. Intermediate steps towards the 2000-Watt society in Switzerland: An energy-economic scenario analysis 2000-Watt

The Energy Economics Group, Laboratory for Energy Systems Analysis, Paul Scherrer Institute, CH-5232, Villigen, in Switzerland (CH-PSI) – Thorsten F. Schulz, Leonardo Barreto, Socrates Kypreos, Alexander Wokaun – has been using the Swiss energy-system MARKAL model for the examination of intermediate steps towards the 2000-Watt society in Switzerland (Schulz, 2007) in the context of the Swiss National Centre of Competence in Research on Climate (NCCR-Climate) funded by the Swiss National Science Foundation (SNSF).

The 2000-Watt society, i.e. a Swiss energy system with a yearly per-capita primary-energy consumption of 2000-Watts, has been proposed as an alternative path to achieve long-term sustainability goals. Although ambitious from today's perspective, a 2000-Watt society could bring benefits in terms of climate change and security of energy supply, among others.

An analysis of intermediate steps towards the 2000-Watt society has been conducted. Scenarios were developed of the evolution of the Swiss energy system up to the year 2050 and the effect of combined targets on primary energy consumption per capita and energy-related CO_2 emissions were examined.

This analysis has been conducted with the Swiss energy-system MARKAL model, a perfect-foresight, optimisation, "bottom-up" energy-systems model that provides a detailed representation of energy supply and end-use technologies for Switzerland.

This modelling and scenario analysis suggests that a 2000-Watt society should be seen as a long-term goal. During the first half of the 21st century, only intermediate steps towards this goal are possible. Feasible intermediate steps would reduce the primary energy consumption per capita in Switzerland to approximately 3.5 kW/capita in the year 2050 and simultaneously reduce energy-related CO_2 emissions by 10% per decade up to the year 2050 (see Figure 4).

These intermediate steps are associated with a considerable transformation of the Swiss energy system and sizeable costs. Among others, advanced passenger cars, energy conservation measures in the residential and industrial sectors and biomass-based energy carriers would need to be key contributors to these intermediate goals.

The combined scenarios also show that as the constraint on primary energy consumption becomes more stringent the contribution of several of the energy-supply technologies that could play a role in fulfilling CO2 reduction targets, such as nuclear energy and new renewable energies, is reduced (see Figure 4). This behaviour is due to two reasons: on the one hand, a more stringent constraint implies lower energy consumption, while on the other hand, these technologies have comparatively low conversion efficiencies between primary-energy and secondary-energy levels. This fact makes their contribution to the constraint on primary energy per capita less attractive although they could be important contributors to the fulfilment of a CO2 reduction target imposed in isolation. This does of course raise the question of whether such sources, particularly the renewable, should perhaps be accounted for with an efficiency of 100% instead of a fossil fuel equivalent, as done in this study, but that awaits future studies.

Reference

Schulz, T.F., 2007: Intermediate steps towards the 2000-Watt society in Switzerland: An energy-economic scenario analysis. PhD Thesis in preparation. ETH Zürich. Zürich, Switzerland.

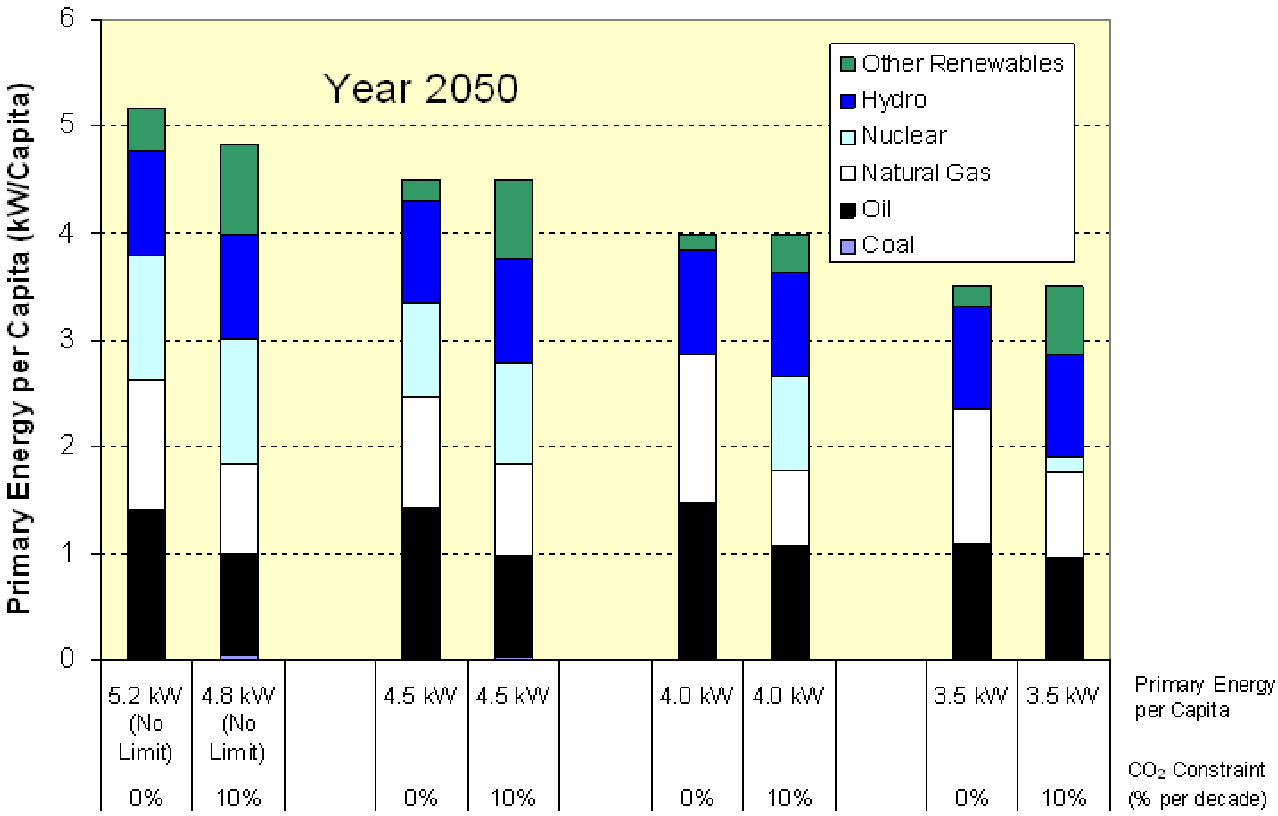

Figure 4: Primary energy per capita mix in Switzerland in the year 2050 for scenarios with an increasingly stringent constraint on primary energy per capita (labelled "no limit" to "3.5 kW") imposed in isolation and in combination with a reduction on CO_2 emissions of 10% per decade up to the year 2050.

3. Overview of the UK Energy Research Centre (UK-ERC) and Recent Energy System Modelling (ESM) Activities

The UK Energy Research Centre's mission is to be the UK's pre-eminent centre of research, and source of authoritative information and leadership, on sustainable energy systems. The Centre was established in 2004 and is a central part of the £28 million UK cross-Research Councils programme "Towards a Sustainable Energy Economy" (TSEC)

UK-ERC's Energy Systems and Modelling (ESM) research activities are being undertaken by the Policy Studies Institute (UK-PSI) and the Cambridge Centre for Climate Change Mitigation Research (4CMR) at the University of Cambridge. UK-PSI's core UK-ERC staff are Professor Paul Ekins, Dr. Neil Strachan –strachan@psi.org.uk –, Ramachandran Kannan, and Dr. Nazmiye Ozkan. 4CMR's core UK-ERC staff are Dr. Terry Barker, Dr. Tim Foxon and Cathy Goss.

In the first 2 years of UK-ERC, the ESM theme has built comprehensive UK capacity in E4 (energy-economic-engineering-environment) modelling. Full and updated working versions of major UK modelling tools are in place, notably the technology focused energy systems MARKAL and MARKAL-MACRO models, and the macro-econometric MDM-E3 model – Multi-sectoral Dynamic Energy-Environment-Economic Model. These models have been used to address a range of UK energy policy issues including long-term carbon reductions, the role of innovation in the future energy system, the development of hydrogen infrastructures, and the uptake of energy efficiency technologies and measures. Ongoing development work is underway to link these "bottom-up" and "top-down" energy modelling frameworks in a hybrid modelling approach.

ESM is focused on the following three principal activities:

- Modelling the UK energy-environment-economy-engineering (E4) system. A principal focus of ESM is its original research focusing on academically rigorous and policy relevant quantification of the drivers and interactions within the UK energy-economic system. This research effort adopts a "whole-systems", multidisciplinary approach, concentrating on bottom-up/top-down integration of models. Additional research focuses on analytical underpinnings of future energy scenarios, the role of innovation, and the systematic treatment of uncertainty. The principal modelling tools are the energy systems MARKAL and MARKAL-MACRO models and the macro-econometric MDM-E3 model.

- Mapping UK energy modelling expertise. A regularly updated inventory of UK modelling research has been constructed, to feed into the UK-ERC Research Atlas. The aim is to make UK energy modelling expertise more accessible to potential users, and allow knowledge gaps to be identified and addressed.
- Networking and co-ordination. The goal is to develop the coherence and capacity of UK energy research modelling, and deepen the interactions within the UK and with major international energy modelling groups. A range of joint projects, meetings and conferences aim to develop, assess and evaluate different modelling approaches across the whole range of energy system issues.

3.1. Selected ESM activities through March 2007

UK-PSI is coordinating the construction, calibration and use of the revised UK MARKAL model. This is a technology focused dynamic cost optimization model of the entire UK energy system from resources through process, conversion and demand technologies to sectoral energy service demands. The subsequent development of the UK MARKAL-MACRO model has been a major analytical underpinning of the 2007 Energy White Paper, published in May 2007 (see section below).

Selected highlights:

- A collaborative work programme was developed between UK-PSI and AEA to build upon existing UK modelling expertise and to build a new version of the UK MARKAL model.
- Following intensive data collection, programming, calibration and review processes the extended and fully revised new MARKAL model is now complete.
  - o Major updates include resource supply curves, full depiction of energy processes and fuel carriers, nuclear fuel, biomass and hydrogen energy chains, remote and decentralized electricity grids, substantially greater detail in end-use sectors (industry, transport, residential, services and agriculture).
  - o Three working papers to explain the assumptions, scope and results of the new model with the aim to increase transparency were completed and are now available under the UK-ERC/ESM working paper series at: http://www.UK-ERC.ac.uk/content/view/295/592.
  - o An ongoing and stakeholder exercise involving a range of bilateral reviews and three dedicated sectoral workshops was undertaken.
  - o A major documentation effort is being undertaken with all data sources, assumptions, etc. being made publicly available, and a major stakeholder data workshop is scheduled for 21 June 2007.
  - o A major methodological extension to incorporate a neoclassical macro-economic module (the MARKAL-MACRO model; Figure 5) was successfully completed.
- A major analytical input into policy has been to quantify a range of low carbon scenarios as a key input and ongoing analysis for the UK 2007 Energy White Paper. This has involved both the MARKAL and MARKAL-MACRO models.
- A further application has been to quantify hydrogen infrastructure development via the SuperGen UKSHEC programme – UK Sustainable Hydrogen Energy Consortium.
- Further, the UK model is contributing in an international modelling effort on low carbon societies (LCS) under a joint Japan-UK research programme designed to report to the 2008 Japanese G8 presidency.

3.2. 4CMR is coordinating the use and improvement of the MDM-E3 model

This is a top-down macro-econometric model with bottom-up sub-models of the energy sector, the electricity supply industry (ESI), the household sector and the transport sector.

Selected highlights:

- The MDM-E3 model was extended to include policies identified as contributing to the Government's energy efficiency policies as components in its Climate Change Programme so that the model could incorporate "bottom-up" estimates of the effects of the policies.
- A major research report was completed for DEFRA – Department for Environment, Food and Rural Affairs – on "Macroeconomic rebound effects

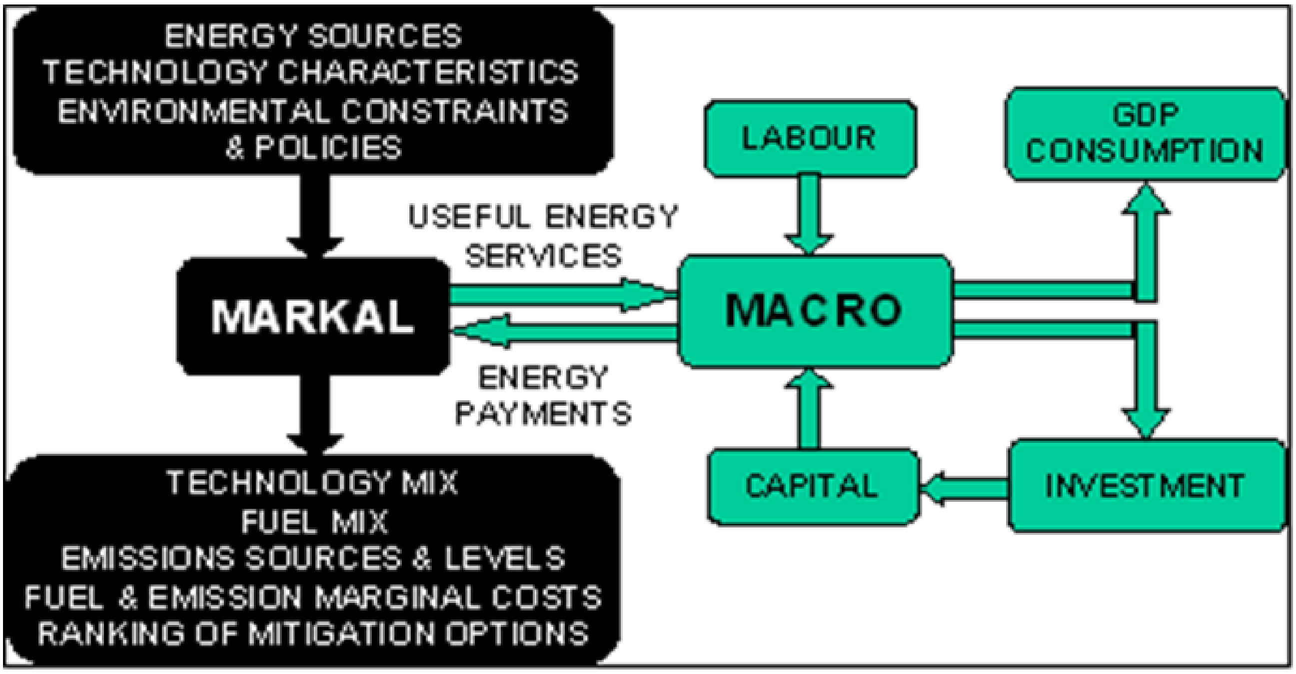

Figure 5: MARKAL-MACRO (M-M) model integration

for energy efficiency in the UK" using the extended MDM-E3 model

- Work is progressing on model development within MDM-E3, notably the energy demand sub-model, the existing household energy sub-model and a transport energy sub-model.
- Work is ongoing to incorporate endogenous technological change into MDM-E3, based on energy learning curve modelling developed under the Tyndall Centre ETech+ project.

3.3 UK-PSI and 4CMR are undertaking additional modelling and complementary activities

Selected highlights:

- ESM is the core organizer of an international energy modelling collaborative effort designed to quantify scenarios of low carbon societies (LCS). This involves 12 international modelling teams, with a heavy developing country focus. The output of this project will feed into the G8 Gleneagles dialogue when Japan holds the presidency in 2008, as well as in a special journal issue of Climate Policy.
- ESM is a core participant and is providing analytical support for the UK-ERC integrating scenarios research project.

3.4. Networking and Coordination

The goal is to develop the coherence and capacity of UK energy research modelling, and deepen the interactions within the UK and with major international energy modelling groups.

Selected highlights:

- The 1st ESM Annual Energy Modelling Conference (AECM) in December 2006 focused on long-term modelling of low carbon societies. This will be integrated into the UK-Japan LCS research project. A conference report and summary were produced and are available on the UK-ERC ESM website at http://www.UK-ERC.ac.uk/content/view/297/792
- Two major international workshops on innovation in energy systems took place at the UK-ERC Meeting Place in Oxford in March and September 2006. A conference proceeding was produced, and is available on the UK-ERC ESM website.
- ESM hosted a major international conference on MARKAL modelling via the International Energy Agency's ETSAP network. This was held in Oxford in November 2005, and focused on state-of-the-art international energy technology modelling, as well as showcasing the full range of UK energy modelling programs, a conference proceeding was produced.

3.5. Example Project: Analysis of Long-Term carbon reduction scenarios using UK MARKAL-MACRO

A major application of the UK MARKAL energy systems model has been to quantify the cost and energy system implications of long-term 60% reductions in CO_2 emissions. This project was commissioned by the Department of Trade and Industry (DTI) and DEFRA as part of the analytical underpinning for the 2007 UK Energy White Paper Energy. The new MARKAL model has undergone a complete rebuild with a range of enhancements to improve its analytical sophistication. In addition, a thorough model and data validation process were undertaken. A major methodological extension was moving to the hard-link neoclassical macro-economic module (the MARKAL-MACRO model). This extension has the advantages of making energy service demands an endogenous mitigation response, and quantifying macro-economic implications of large scale CO_2 reductions.

The MARKAL and M-M model runs focus on characterizing uncertainties between alternate energy pathways under scenarios of long-term carbon reductions.

For this project, the UK MARKAL and MM runs covered an extensive set of 50 scenarios. These included use of alternate sets of technology and conservation data based on the UK-ERC literature review with technology expert and stakeholder feedback, with a second set adjusted for insights from the DTI Energy Review. Scenarios for base-case and 60% CO_2 reductions by 2050 included:

- Central, high, low cost technology assumptions;
- Alternate CO_2 emissions trajectories: constraint imposed from 2030 or 2010;
- Central, high, low and global fuel prices;
- Restricted innovation (no development beyond 2020 or 2010 levels);
- No nuclear/CCS (central cost), and
- Renewable sensitivity (including the renewables obligation (RO) for electricity generation).

Illustrative results are presented below, focusing on alternate resource fuel price assumptions, taken from the DTI energy review (www.dti.gov.uk/energy/review/page31995.html)

Figure 6 details UK final energy consumption for the base cases and 60% CO_2 reduction cases under central, low and high fuel prices assumptions. Generally higher resource prices give greater impetus for energy reductions in both base and CO_2 constrained scenarios. One exception is in the CO_2 constrained fuel price cases, where relative fuel switching between gas and coal entails either greater efficiency improvement (under low price assumptions) or an increased shift to zero carbon energy carriers and technologies (under high price assumptions).

Under such stringent domestic CO_2 reduction targets, all sectors contribute to emission reduction and increasing marginal CO_2 prices are detailed in Figure 7. High resource price assumptions give lower marginal prices as the costs of low carbon technologies and measures are relatively lower. The M-M model gives lower prices than the MARKAL model (marked ST in Figure 7) as its behavioural response to reduce energy service demands provides additional flexibility in meeting the constraint.

A major advantage of the M-M model is a quantification of macro parameters. Again higher resource assumptions lead to a smaller GDP loss as the base case energy sector has already decarbonised to a greater extent meaning achieving the target is easier. For the full range of scenarios the M-M model gives a GDP loss varying between 0.2% and 1.5% (in 2050). This is equivalent to other estimates (e.g., the Stern Review), but the M-M results may be thought of as a lower bound

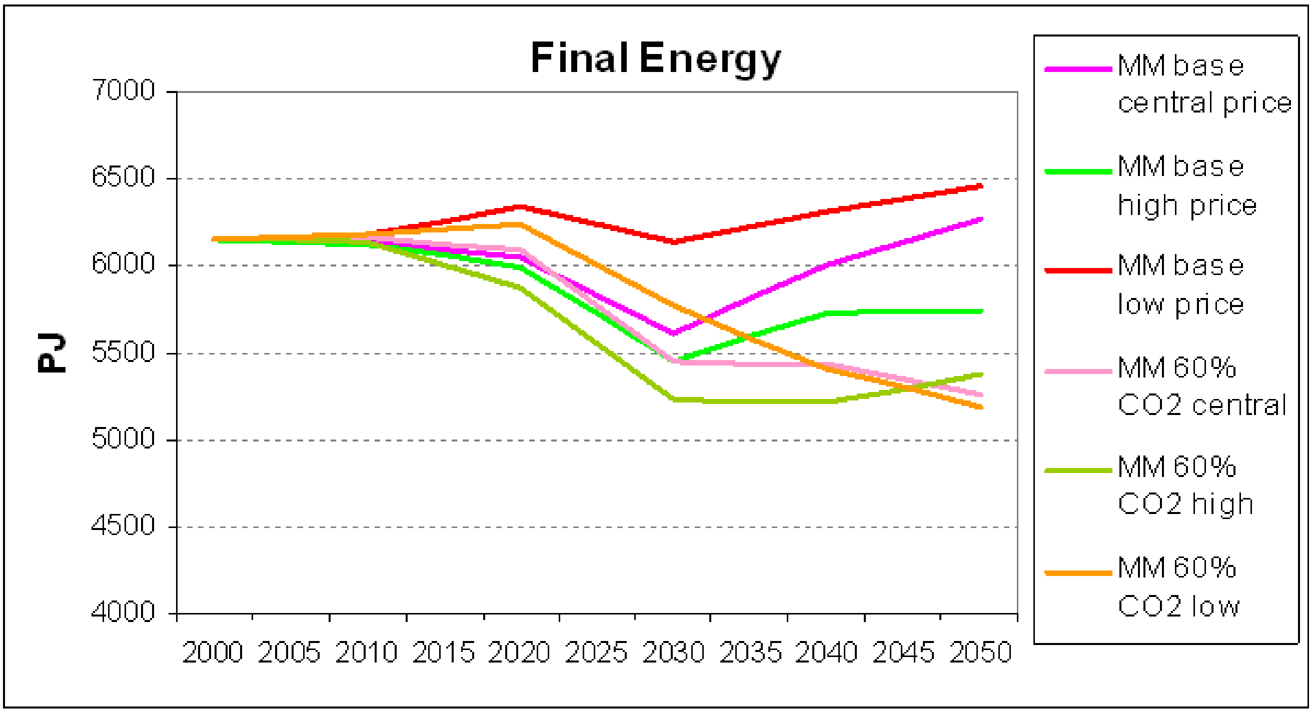

Figure 6: Final energy based on resource price assumptions

because the model does not account for transition costs, nor (as a UK-only model) does it account for trade and competitiveness issues.

A full explanation and analysis of these scenarios is given in the Final Report on DTI-DEFRA Scenarios and Sensitivities using the UK MARKAL and MARKAL-MACRO Energy System Models available at http://www.UK-ERC.ac.uk/content/view/142/112

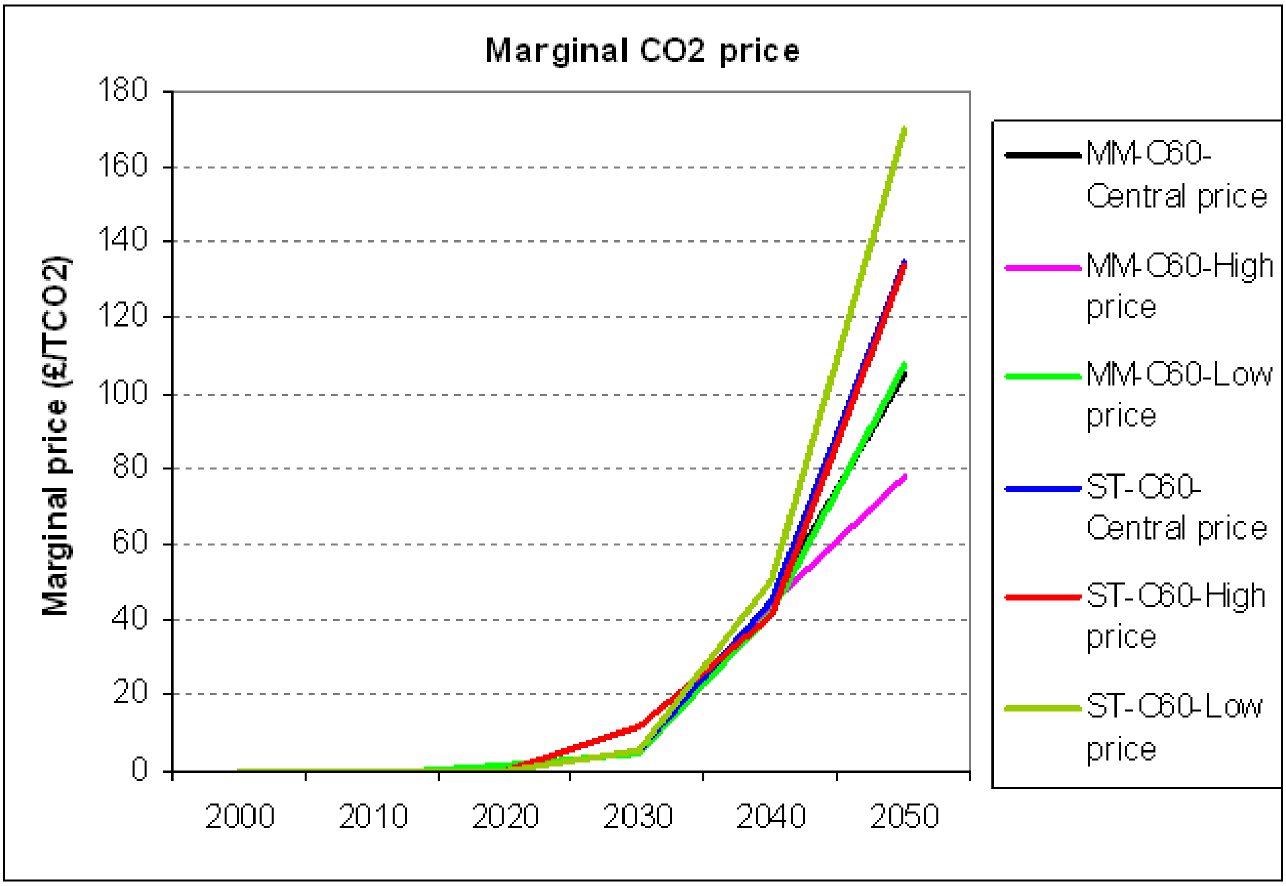

Figure 7: CO_2 prices based on model type and resource price assumptions

4. MARKAL-MACRO-Kazakhstan

A. Cherednichenko (KazNIEK), C. Guivarch (PhD student), G. Sergazina (Climate Change Coordination C), G.C. Tosato (ASATREM)

General framework of the project

In 2004 the EU has funded the TACIS project "Technical assistance to Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan with respect to their global climate change commitments" (map in figure 8). It aimed at assisting the Central Asian countries to fulfil their obligations in respect to the United Nation Framework Convention of Climate Change (UNFCCC) and the Kyoto Protocol (KP). The European Commission has entrusted SOFRECO with the technical assistance mission. For this 30-month 4.5 M€ project SOFRECO joined with IIASA (Austria), University of Tuscia (Italy), Agrotec (Italy) and Natsource (UK).

Specific project objectives were:

- To assist beneficiary countries in the development of a CDM/JI institutional infrastructure and capacity required to implement the UNFCCC and KP requirements at the national level;
- To assist the development of the legal framework;
- To enhance capacity for macro-economic modelling needed to estimate future emission trends, to evaluate mitigation potential and related costs, and to develop climate change abatement scenarios;
- To enhance awareness among key policymakers, the business community and the general public about climate change, the KP and the CDM/JI mechanisms for GHG

mitigation opportunities.

Projects activities were:

Task 1: to assist in development of CDM infrastructure

Task 2: to assist in development of technical capacity for the CDM

Task 3: measures towards creating JI systems in Kazakhstan

Task 4: legal and institutional capacity building

Task 5: to strengthen inventory capacity

Task 6: to enhance economic modelling capacity

Task 7: training

Task 8: public outreach

Objectives of the energy modelling task

The Task 6 of the project aimed at enhancing economic modelling capacity in Kazakhstan. It includes training and public outreach. More specifically it includes the following subtasks:

- To install MARKAL software in Kazakhstan;
- To analyse the Kazakh energy system, in particular, disaggregate the end-use sectors;
- To represent it in MARKAL models, including new technologies in the supply & end-use sectors;
- To compile a baseline and alternative GHG emissions scenarios; and
- To evaluate CO2 abatement costs curves.

Content of the final report

The 175-pages final report, downloadable from http://www.sofreco.com/projets/c886/Reports.htm, consists of an executive summary, three main chapters and a technical annex / statistical tables.

Chapter 2 analyses the energy system of Kazakhstan mainly from a domestic perspective. It focuses on energy domestic supply and demands – more than on fossil reserves and production for export – CO2 emissions and mitigation options. The energy flows through the system in late years is reconstructed with the help of the reclassified energy balances (the methodology and the detailed balances are presented in the technical annex). Quantitative information about supply infrastructures and domestic end-use devices is sketchier than in other countries. Also the economics of the system as a whole is incomplete. GHG data are good, although sometimes not fully consistent with the energy flows (an overview of Kazakh Greenhouse Gas inventories is reported in the technical annex).

Chapter 3 describes how the Kazakh energy system is represented in the three energy models generated by the MARKAL tool: technological least cost (MK), partial equilibrium (PE) and general equilibrium (MARKAL-MACRO, M-M). The three models share the same base demand projections, primary and final resources availability and cost, Reference Energy System and technology characterization database. But the first minimizes the total discounted energy system cost, the second maximizes the total discounted producers and consumers surplus and the third maximizes the utility. The three models have been used to analyse three different sets of policies. The first set includes investments in technologies and command and control policies at the technological level and it is analysed through the results of the technological least cost model. The second set of policies adds to the first set the possibility to transmit the energy price signals to the consumers of energy services, at a degree variable by sector; it is analysed through the results of the partial equilibrium version of the model. The third set of policies adds to the first set the possibility to reduce the general income of all consumers and change the general price index in the country; it is simulated by the MARKAL-MACRO Kazakhstan model. The methodology is briefly described in the technical appendix.

Chapter 4 describes the scenarios run with the three models (table 1 lists the mitigation scenarios, without variants).

Conclusions

The analysis highlights under what conditions Kazakhstan benefits from the participation to the KP as Annex I (i.e. with binding commitments). Figure 9 compares possible revenues from selling CO2 emission rights to countries willing to invest in Kazakh power plants and energy processes

Figure 8: General map of Central Asian Countries

with the cost for Kazakhstan of reducing its own domestic emissions. The cost-goal for internal mitigation options depends on the international market for emission permits.

The tools setup during this process are now available to all interested groups and experts for evaluating additional policies, running alternative scenarios and improving the MARKAL-MACRO Kazakhstan models.

Table 1: List of mitigation scenarios analysed with the MARKAL-Kazakhstan models

Code	Description
A-MK-BAU	Base Case, MARKAL
MK3MCBAU	Base Case, MARKAL-MACRO
Least cost	accepting mitigation technologies up to:
C-MK-2	2 US$2000/tCO2
D-MK-5	5 US$2000/tCO2
E-MK-10	10 US$2000/tCO2
F-MK-20	20 US$2000/tCO2
G-MK-50	50 US$2000/tCO2
Partial eq.	accepting mitigation options up to:
L-EQ-2	2 US$2000/tCO2
M-EQ-5	5 US$2000/tCO2
N-EQ-10	10 US$2000/tCO2
O-EQ-20	20 US$2000/tCO2
P-EQ-50	50 US$2000/tCO2
General eq.	accepting mitigation options up to:
M-M2	2 US$2000/tCO2
M-M5	5 US$2000/tCO2
M-M10	10 US$2000/tCO2
M-M20	20 US$2000/tCO2
M-M50	50 US$2000/tCO2

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The objective of the ETSAP Newsletter is to keep ETSAP participants and the wider energy planning and modelling community informed of advancements in the methodology and tools, as well as the status of significant projects completed, underway, or in the planning stage employing the ETSAP Tools.

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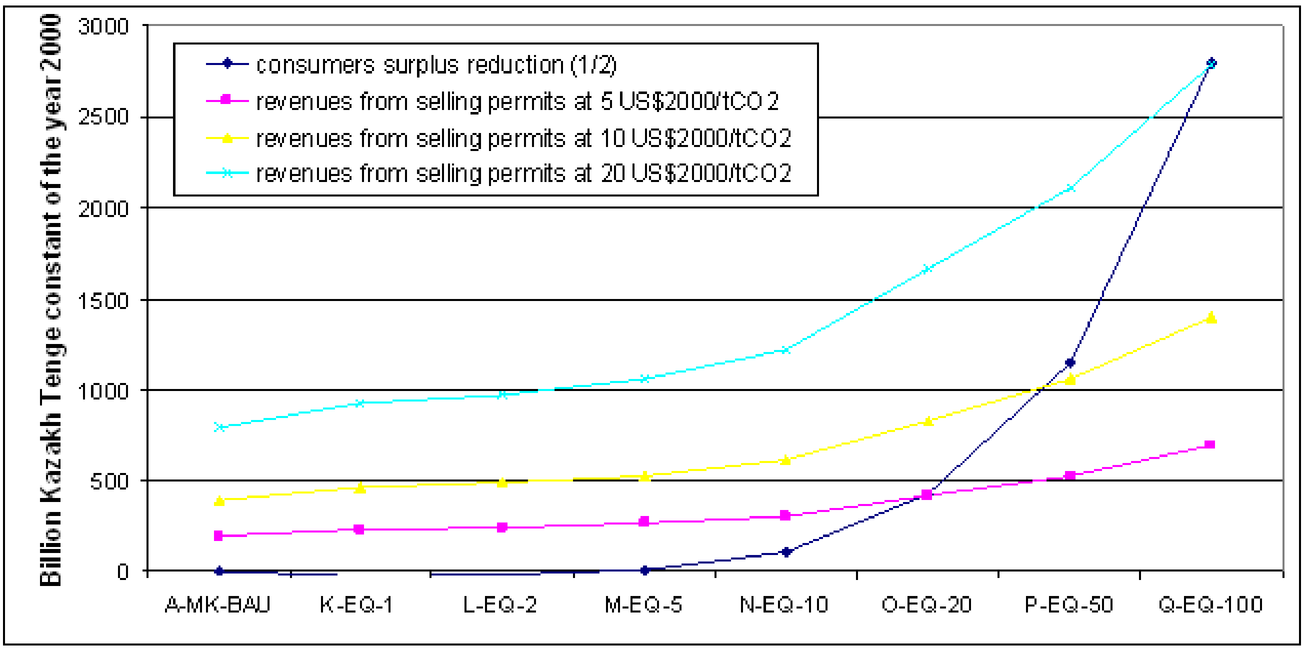

Figure 9: Trade-off between growing domestic mitigation levels and revenues of emission trading