International Energy Agency
Programme of Energy Technology Systems Analysis
Annex VIII/IX

*Exploring Energy Technology Perspectives/
Energy Models Users’ Group*

Final Report
HIGHLIGHTS

- Advances were made in the ability to analyze global issues using the ETSAP Tools. ETSAP partners play a key role in all of these, most notable among them:
  - International Energy Agency’s development of the *Energy Technology Perspectives* global model to examine the role of advanced technologies in meeting multi-lateral energy, environmental and security goals;
  - U.S. Energy Information Administration adopted and adapted the ETSAP models and methodology to be the foundation for the preparation of its annual *International Energy Outlook*;
  - The European Fusion Development Agreement (EFDA) consortium looking to examine the long-term global potential for nuclear fusion, and
  - ETSAP EMF-22 Integrated Assessment Model (IAM) using TIMES.
- Several major multi-country/state undertakings employing the ETSAP tools were begun, including:
  - Australia’s Agency for International Development sponsored Energy Planning and Systems Analysis Project (EPSAP) involving 8-ASEAN countries and the Asian Center for Energy (ACE) in a coordinated capability building and planning undertaking;
  - European Union NEEDS (New Energy Externalities Development for Sustainability) project developing a 25-member states pan-European energy model using TIMES, which merges energy bottom-up modeling with externalities and life cycle assessment technique;
  - The Northeast States for Coordinated Air Use Management (NESCAUM) is building a 6-state New England-MARKAL model to assess Clean Air Act goals and to support the New England Governors/Eastern Canadian Premiers climate change commitment, and
  - US Agency for International Development is sponsoring an 8-country Southeast Europe Regional Energy Demand Planning initiative to provide a consistent framework for energy planning in the region.
- A concerted multi-national effort has made the TIMES, an advanced modeling framework poised to be the successor to MARKAL, together with a new user-interface VEDA, ready for mainstream use.
- MARKAL continued to be used by member countries to evaluate national and local policies for energy, pollution control and emissions trading.
- The MARKAL/TIMES community has grown to over 50 countries with some 120 government, research and university institutions actively employing the methodology.
- Continual improvement has been made on the ETSAP website.
Table of Contents

HIGHLIGHTS.............................................................................................................................................. 2

Summary of Annex Activities .................................................................................................................. 6

International Studies, Collaborations, and Contributions ................................................................. 7

ETSAP Partner Activities......................................................................................................................... 9

Systems Analysis and Modeling Tools Research and Development Program] .................................. 14

International Studies, Collaborations & Contributions ..................................................................... 16

International Energy Agency’s Energy Technology Perspectives Project: Description of the Model and Its Applications [Energy Technology Office, IEA Secretariat] .............. 16


Global Multi-Regional MARKAL Model (GMM) [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland] ................................................................. 23

Decomposing the Global MARKAL-MACRO Model GMM [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland] ................................................................. 24

Marginal Abatement Curves in the Energy-System GMM Model [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland] ................................................................. 25

Impacts of RD&D on Carbon Mitigation Costs [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland] ................................................................. 27

Toward a Nash Equilibrium MARKAL? [Loulou, Kanudia and Labriet] ............................................. 31

Assessment of abatement costs and permit allocations using World-MARKAL [Vaillancourt, Loulou, Kanudia] .................................................................................................................. 33

The European Union energy research initiative ACROPOLIS Assessing Climate Response Options: POLicy Simulations – Insights from using national and international models [Several ETSAP institutions, and others] ................................................................. 37


Asia-Pacific Economic Cooperation (APEC) [ETSAP Partners from Australia, Japan and the US, plus China] .................................................................................................................. 46

European Union NEEDS (New Energy Externalities Development for Sustainability) project developing a 25 member states pan-European energy model using TIMES [Various EU ETSAP Partners and other EU institutions] .................................................................................. 48

Summary of ETSAP Partner Activities ................................................................................................. 52

Belgium ......................................................................................................................................................... 52
Summary of Annex Activities

Summary

In Annex VIII, the Energy Technology Systems Analysis Programme (ETSAP) continued to advance the state-of-the-art of models and methods for analyzing energy systems. ETSAP’s more that 20 years of dedication to this commitment is bearing fruit for the ETSAP partners as well as an ever growing number of transition and developing countries. The increasingly wide-spread adoption of the ETSAP Tools (MARKAL and TIMES and their associated data handling and analysis systems) by governmental and planning institutions across the globe is establishing the methodology as the framework of choice in its field. With countries around the world increasingly concerned about energy security and beginning to think about a post-Kyoto regime, and what this may entail with respect to evolution of their energy systems in what is sure to be a changing world, the ETSAP Tools are poised to make a major contribution to the on-going international cooperation aimed at improving national energy security, reducing greenhouse gas emissions and fostering sustained environmental responsible economic growth.

The overall goal of the Annex was to serve national governments and work in international forums by fostering the development of constructive policy options to reduce emissions of greenhouse gases and to promote the development and use of improved energy technologies. In particular, the aims of the Annex were to encourage:

- the widespread use of the ETSAP tools, methodologies, data services and knowledge by the governments of the ETSAP contracting parties;
- the constructive use of ETSAP tools by other countries as well as international organizations in multilateral collaboration, discussions and negotiations;
- the establishment of linkages with economic and environmental models and approaches that complement the work of ETSAP;
- the maintenance and ongoing use of the ETSAP worldwide network of systems analysts, and
- the demonstration and deployment of new methods, with increased flexibility to depict complex energy systems.

There were three principal programs of work in Annex VIII:

- International studies and collaborations, to examine the benefits of international cooperation and trade to meet future requirements to enhance energy security, promote new technologies and reduce greenhouse gas emissions;
- National activities and studies, appropriate to and funded by the individual Participants, aimed at supporting the objectives of this annex, and
- Ongoing research and development activities, primarily to further the development of the TIMES model and its supporting software, the next generation of the MARKAL family of models.

On bilateral and multilateral bases, individual ETSAP participants continued their collaborations, networking, and programs of outreach.

ETSAP Annex IX was also established to foster Outreach to the world-wide community of experts employing the ETSAP Tools (see text of the Annex in Appendix C). The main activity in
this regard was an international workshop held in Taipei, Taiwan in April of 2005 (as reported in Appendix I).

More that 50 countries have now been exposed to the ETSAP Tools, with more than 120 institutions currently using the framework world-wide (see Appendix H for a complete list of these countries and institutions). The major activities conducted during Annex VIII are each summarized below.

**International Studies, Collaborations, and Contributions**

**International Energy Agency’s Energy Technology Perspective Project: Description of the Model and Its Applications**
[Energy Technology Office, IEA Secretariat]

The Energy Technology Policy Division (ETPD) of the Energy Technology Office of the IEA Secretariat has developed a detailed global MARKAL model. This model is now extensively being used by ETPD for energy technology assessments.

**System for the Analysis of Global Energy markets (SAGE)**
[United States Department of Energy, Energy Information Administration]

ETSAP experts are cooperating with the U.S. Department of Energy’s Energy Information Administration to develop the System for Analysis of Global Energy markets (SAGE). The primary purpose of the new modeling framework is to produce annually the “International Energy Outlook” forecasts.

**Global Multi-Regional MARKAL Model (GMM)**
[Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

The primary focus of this work was the development and application of the Global Multi-Regional MARKAL Model (GMM) for the examination of alternative energy development paths and the evaluation of flexible climate policy instruments.

**Marginal Abatement Curves in the Energy-System GMM Model**
[Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

There are several possibilities for considering the effects of non-CO\textsubscript{2} GHG abatement in a “bottom-up” modeling framework. One of them is the explicit inclusion of abatement technologies. The second approach is the use of aggregate marginal abatement curves (MACs), built on the basis of assessment of abatement technologies. This work incorporates marginal abatement curves for two main non-CO\textsubscript{2} greenhouse gases, namely methane (CH\textsubscript{4}) and nitrous oxide (N\textsubscript{2}O), considering both energy-related and non-energy-related sources, into the Global, Multi-regional MARKAL model (GMM).

**Impacts of RD&D on Carbon Mitigation Costs**
[Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

The MERGE model was used as part of the Swiss NCCR-Climate Program on “Climate Variability and Risk.” This effort evaluates the economic advantages of endogenous and induced learning via public and private RD&D spending in support of carbon-free generation technology.
**Toward a Nash Equilibrium MARKAL?**
[Loulou, Kanudia and Labriet]

A new approach to using employing game-theory to a regionalized global bottom-up model (MARKAL) was developed and applied.

**Assessment of abatement costs and permits allocations using World-MARKAL**
[Loulou, Kanudia and Vaillancourt]

This effort examined the equitable and realistic allocation of initial emission permits to all countries in the context of a world cooperative climate stabilization strategy. The methodology uses multi-criteria decision analysis (MCDA) to take into account several equity criteria, operationalize and quantify them, and construct a general approach to organize negotiations of permit allowances.

**ACROPOLIS – Assessing Climate Response Options: POLICY Simulations – Insights from using national and international models**
[Several ETSAP institutions, and others]

The ACROPOLIS European research project is an attempt to overcome the difficulties linked to the harmonisation of the results from different energy models. ACROPOLIS is aimed at applying and comparing several existing energy models to address the potential impact of a number of policy options to reduce greenhouse gas (GHG) emissions.

**The European Fusion Development Agreement (EFDA) Consortium to Examine the Long-term Global Potential for Nuclear Fusion: The World TIMES Project**
[European Fusion Development Agreement]

The main objectives of the EFDA World TIMES project are:
- the construction of a Regionalized World energy/emission model based on the TIMES framework;
- the adaptation of the VEDA interface needed to manage the large databases and to operate the model;
- the testing of the model on some demonstration scenarios, and
- the delivery of the model and the transfer of the required know-how to EFDA.

**“Climate Policy Scenarios for Stabilization and in Transition“**
[ETSAP Participation in EMF-22]

The EMF-22 corresponds very tightly to the objectives of the current and next ETSAP annexes, and constitutes an ideal context for the active development and application of the World TIMES model. ETSAP will actively participate in EMF-22 using a World TIMES model underdevelopment, which includes a new Climate Module.

**Asia-Pacific Economic Cooperation (APEC)**
[ETSAP Partners from Australia, Japan and the US, plus China]

Among the various models available to the Asia-Pacific Economic Cooperation (APEC) economies, the MARKAL model is used or is under development in no less than 15 of the 21

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1 http://www.iwr.uni-stuttgart.de/acropolis
member economies. This puts MARKAL in a unique position of being able to serve as a common analytic platform for examining issues of interest to the APEC Economies. An assessment was done to examine the maximum potential for renewables in four of these countries (Australia, China, Japan and the US).

**European Union NEEDS (New Energy Externalities Development for Sustainability)** [Various EU ETSAP Partners and other EU institutions]

This project involves the use of energy systems modeling (including scenario building) and the creation of internalization strategies for the 25 member pan-European Community. This research aims at generating partial equilibrium technology rich economic models of each MS/NAC and of the EU as a whole using TIMES. The work will identify, discuss and analyze the terms and conditions (including barriers and enablers) for an effective formulation and implementation of long term strategies based on the internalization of external costs, as well as broadening of the basis for decision support beyond the assessment of external costs by examining the robustness of results under various stakeholder perspectives.

**ETSAP Partner Activities**

**Belgium**

Impact of opening the Belgian electricity market: an analysis with MARKAL [CES KULeuven]

An assessment using the Belgian MARKAL model extended with three neighboring countries (France, Germany and The Netherlands) to permit trade in electricity showed that liberalization of the electricity market can result in improvements of environmental conditions and thus reduce the cost of climate policy in Belgium.

**Canada**

Various activities conducted by the Canadian MARKAL/TIMES model team are mentioned in the International Studies, Collaborations, and Contributions section of this report.

**Finland**

Development of the Finnish National TIMES Model and Case Studies Utilizing the Model [Technical Research Center of Finland (VTT)]

After the adoption of the Kyoto Protocol in 1997 there was a large demand for a technology program, which could help Finnish companies in the forthcoming strategic decisions in changing operational environment. Therefore, a national technology program, “Technology and Climate Change (CLIMTECH),” was established in Finland. To assess the opportunities and implications of Greenhouse Gas reduction policies a TIMES model for Finland was developed and used.

Ongoing development of TIMES.
Germany

Research using TIMES [Institute of Energy Economics and the Rational Use of Energy (IER) at the University of Stuttgart]

- The assessment of existing and new technologies in the power supply sector.
- The development of methods and tools to study complex systems on different levels of detail with respect to time and geographical resolution.
- Technological and macroeconomic analysis of energy systems to examine climate change protection strategies and the consequences of liberalization of energy markets.
- Ongoing development of TIMES.

Greece

An Analysis of the Greek Energy System in View of the Kyoto Commitments [Centre for Renewable Energy Sources]

The current Greek Energy System was analyzed to evaluate alternative policies and determine additional measures required in order to achieve the Kyoto targets. Four scenarios were developed, depicting the evolution of the Greek Energy System under alternative policies, taking into consideration medium and high oil prices. Incremental investments and differential costs are then calculated between non-Kyoto and Kyoto scenarios and they are compared to permits costs.

Italy

Evaluation of Green Certificates Policies using the MARKAL-Macro-Italy model. [ENEA, APAT]

After the ratification of acid deposition and greenhouse gas conventions of Geneva and Rio, domestic energy policies have added the aim of protecting the environment and mitigating climate changes, in line with several European directives. The development of renewable energy sources (RES) is a key strategic measure. The overall impact of the present Italian RES-E obligation were evaluated by means of a model of the Italian energy–environment system built with the MARKAL/TIMES methodology. The contribution of each RES-E presently expected from policy makers to the economic equilibrium mix resulting from computable economic equilibrium scenarios.

The TIMES Energy System Model for the Piemonte Region (TIMES-Piemonte). [LAME - Politecnico di Torino]

This project focused on the modelling of the Piemonte Region energy system using TIMES, in order to evaluate sustainable energy strategies, options for the regional contribution to the fulfilment of Kyoto targets and local energy programs (biomass, district heating networks, cogeneration plants). The TIMES-Piemonte Project main features are the very detailed level of description attained, both in the supply and distribution side as well in the demand one (mainly in the residential sector). Base and environmental scenarios have been analysed.
The TIMES Model for the National and Regional Electrical System (TIMES-Ele Italia) [LAME - Politecnico di Torino]

The Project deals with development of a National and Regional Electrical System model and its implementation in TIMES. The structure is based on 20 regions with electrical trade between the neighbors and import/export with foreign countries, 5 grids, 8 timeslices and 11 milestone years over a 2000-2030 time horizon. The project is a cooperation among LAME - Politecnico di Torino (responsible for the Model Structure and implementation), AIEE (Italian Association of Energy Economists) and CESI (Italian Electrical System Research Centre, project leader). Calibration and Base scenario with aggregated and disaggregated demand have been made.

Japan

At the Japan Atomic Energy Research Institute (JAERI), the Research Group for Energy System Analysis headed by Mr. Sato made a study on Japan's long-term energy demand and supply toward the year 2050 by applying the Japanese MARKAL model. This study was promoted under the Committee of Nuclear Reactor Development and Utilization of the Japan Atomic Industry Forum, and particular attention was paid on the potential role of nuclear energy in the context of depletion of fossil energy resources and climate change problem. The Research Group made in addition a study on long-term scenarios of developing advanced nuclear power reactors and fuel cycle systems in Japan.

The Netherlands

ECN Policy Studies performed a wide range of activities related to the use of or the further dissemination of the ETSAP tools (the MARKAL model and methodology). These activities covered (model) methodology enhancement (the SAPIENT project), scenario analysis (the ACROPOLIS project), direct policy relevant analysis (the CO\textsubscript{2} QUOTA project) as well as the opportunity to provide training sessions for new users and the given presentations at international fora and workshops (EMF-IEW).

South Korea

An analysis of greenhouse gas reduction potential in power generation, paper industry and household sector was conducted. The purpose of the project is to assess technological reduction potential in these sectors. In addition to this main activity, the training of modelers and outreach initiatives using ETSAP Tools were also undertaken.

Sweden

MARKAL activities at the Department of Energy Technology [Chalmers University of Technology]

Activities at the Department of Energy Technology focussed mainly in two areas:

- a continuation of a study on the value of extended transmission capacities between the Nordic countries and northern Continental Europe, and
- work on a better representation of the transport sector in the MARKAL_Nordic model.
Activities at Profu related to the use of the MARKAL model

All activities during 2004 have been associated to the use of the MARKAL-NORDIC model, which describes the stationary energy system of the four Nordic countries Sweden, Norway, Denmark and Finland. Activities carried out during 2004 may be summarized into:

- Analysis of the effectiveness of Swedish climate policy,
- Analysis of a common Swedish-Norwegian market for tradable green certificates (so-called electricity certificates),
- Analysis of a new set of energy and carbon-dioxide taxes, and
- “Linking” the regional MARKAL-NORDIC model to the global IEA-ETP MARKAL model.

Switzerland

Various activities of the Energy Economics Group (EEG) at Paul Scherrer Institute (PSI) are mentioned in the International Studies, Collaborations, and Contributions section of this report.

In addition, in collaboration with the University of Geneva, PSI-EEG has undertaken the development of a “bottom-up” energy-systems MARKAL model for Switzerland. The Swiss MARKAL model allows a detailed representation of energy technologies and the assessment of the impact of policy measures on the long-term trajectory of the Swiss energy system (Schulz et al., 2004) and is being used in evaluating long-term sustainability strategies in Switzerland, such as the concept of the 2-kW/capita society.

Turkey

MARKAL was used to analyze different strategies for mitigation of greenhouse gas emissions of the energy sector in Turkey. The methodology has been explained and a reference scenario and three alternative scenarios have been compared in the eventual sections.

United Kingdom

Options for a Low Carbon Future: Review of Modeling Activities and an Update

The background analysis for the 2003 UK Energy White Paper (DTI, 2003a) produced a large number of studies of the technological options for and costs of reducing UK CO₂ emissions by 60% by 2050. More than 70 sets of scenarios and technology assumptions were explored based on the following low carbon technologies and practices.

United States

A Portfolio Approach in Local Energy Planning and Building Upgrades: Case of New York City

The adverse economic impacts of the Great Blackout in America’s Northeast in the summer of 2003, coupled with the increasing demand for electric power due to the urban heat island (UHI) effect demonstrates the need for better energy planning and mitigation strategies in major metropolitan areas such as New York City. This study proposes to use a portfolio of models interactively to evaluate mitigation strategies covering demand side management,
upgrades in buildings (e.g. green roofs), and distributed electricity generation (building combined heat and power). A detailed New York City MARKAL model will be developed to simulate current and projected energy and electricity demands, electricity transmission and distribution requirements and peak load patterns.

Hydrogen Economy: Opportunities and Challenges

This study examined the transition from a petroleum-based energy system to a hydrogen economy. A hydrogen economy is the long-term goal of many nations because it provides security, environmental, and economic benefits. The transition involves many uncertainties. They include development of fuel cell technologies, hydrogen production and distribution infrastructure, and the response of petroleum markets. This study used the U.S. MARKAL model to simulate the impacts of hydrogen technologies on the U.S. energy system and identify potential impediments to a successful transition to a hydrogen economy.

Evaluating the Pollutant Emissions and Air Quality Implications of Future Technology Scenarios

The U.S. Environmental Protection Agency’s Office of Research and Development (ORD) is carrying out several activities involving the use of the MARKAL model to evaluate future technology scenarios. One such activity is the development of pollutant emissions growth factors for ORD’s Global Change Air Quality Assessment. The purpose of the Assessment, which is being carried out under the U.S. Federal government’s Climate Change Science Program, is to evaluate the air quality implications associated with global change, considering factors such as economic growth, population growth, climate-induced meteorological change, land use and land cover change, technology change, and government policy. The Assessment is a multi-model exercise, involving the linkage of models to address these factors.

U.S. EPA Coalbed Methane Outreach Program

On behalf of the Environmental Protection Agency’s (EPA) Coalbed Methane Outreach Program (CMOP) the EPA US-national MARKAL (EPA-MARKAL) model has been augmented to include the ability to track methane emissions from the energy system, and limited other sources (landfills and manure handling). This Methane sub-model includes a wide range of methane emission sources and handling options that could be introduced to mitigate methane emissions. The approach employed could be introduced to other MARKAL models by experienced modelers.

A New England MARKAL Model

The Northeast States for Coordinated Air Use Management (Nescaum), with the assistance of the International Resources Group (IRG), has developed a New England-specific version of the MARKAL model based on regional data and in cooperation with energy and air quality divisions of the respective states. This planning tool allows for the analysis of a range of transportation, energy and air quality protection programs with a time horizon of 30 years and a focus on the cost and environmental implications of key program design elements.
 Systems Analysis and Modeling Tools Research and Development Program

ETSAP continued its now 25 years of tradition advancing the current state-of-the-art with respect to least-cost energy system modeling through the completion of the initial production version of the TIMES model and numerous enhancements to MARKAL.

At the same time major strides were made with respect to the data handling systems for both TIMES and MARKAL. With respect to TIMES the initial version of the VERSatile Data Analyst (VEDA) has been completed and is in use for several major TIMES (and MARKAL) undertakings. ANSWER, the stalwart data handling system for MARKAL saw major enhancements as it gain powerful facilities with respect to the multi-region capabilities needed for the IEA-ETP model.

TIMES

Documentation

Extensive and comprehensive documentation for TIMES has been assembled and is available for the ETSAP website at www.etsap.org/documentation.

What TIMES Adds

TIMES is the evolutionary successor to MARKAL. The main features that TIMES adds on top of MARKAL include:

- Fully flexible time periods/years, variable length and data/model year independence;
- Fully flexible time slices, annual/seasonal/weekly/day-night levels all (but annual) user defined;
- More accurate cost representation, annual with construction and incremental investments;
- All “processes” represented uniformly, plus vintaging and aging;
- Representation of intra-process commodity flows;
- More flexible user constraints;
- Time dependent discount/hurdle rates;
- Flexible units: energy, material, economic values;
- Climate module, and
- GAMS code is simpler to understand, maintain and upgrade.

It is currently being used to support major undertakings including EFDA and NEEDS.

MARKAL

Documentation

Long overdue, the 1983 Fishbone et al MARKAL Users’ Guide, sometimes previously not so affectionately referred to as “the bible,” has finally been replaced. The new documentation strives to both provide a substantive background as to the principles embodied by MARKAL, as well as elaborate the full details associated with both the input data, its relationship to the model structure, and the mathematics itself. The complete documentation is available from the ETSAP website at www.etsap.org/documentation.
IEA ETP Enhancements

This modeling activity is built on the MARKAL energy system model developed by the Energy Technology Systems Analysis Programme, a long-standing Implementing Agreement under the auspices of the IEA.

In the course of constructing the International Energy Agency’s (IEA) Energy Technology Perspectives (ETP) global model several enhancements were made to MARKAL that will immediately benefit the ETP project, as well as the global community of MARKAL users.

Data Management and Analysis Systems ("Shells")

VEDA

The VERSatile Data Analyst (VEDA) supports both MARKAL and TIMES. VEDA consists of two independent but closely related software, VEDA-Front-End (VEDA-FE), which oversees the management of the input data and submitting of model runs, and VEDA-Back-End (VEDA-BE) used to analyze the results of the model runs. VEDA was explicitly developed to support the increased complexity associated with developing and applying large multi-region models.

VEDA is now being used for the major multi-region modeling initiative including the global models of the Energy Information Administration (SAGE), European Union (NEEDS), and European Fusion Development Agreement (EFDA), and the New England MARKAL undertakings.

ANSWER

During Annex VIII, the ANSWER continued to be developed to meet the needs of the expanding MARKAL user community. The single most important development was the creation of a special version of ANSWER tailored to meet the needs of the International Energy Agency’s Energy Technology Perspectives (IEA-ETP).

The current ANSWER user base includes about 90 institutions in some 35 countries.
International Studies, Collaborations & Contributions

International Energy Agency’s Energy Technology Perspectives Project: Description of the Model and Its Applications [Energy Technology Office, IEA Secretariat]

The IEA Energy Technology Perspectives (ETP) model is a technology-rich partial equilibrium model of world energy supply and demand. It complements the IEA World Energy Model because of its technological detail, its potential to identify cost-optimal policies, and its extended time horizon. Therefore, the tool is well suited to assess the prospects of technologies to meet long-term energy policy targets in the fields of emissions and supply security. The model is especially suited for analysis of important changes in the energy system, either because of technological change, important cost reductions through technology learning, or a changing policy environment, such as climate change, or uncertainty of energy supply and associated implications for energy security. Typically the tool is used for analysis of R&D decisions, deployment policy strategies for emerging technologies and investment decisions in infrastructure and capital equipment with a long life span. The central question then that the ETP model meant to examine is how technology can help to meet the shared goals of the IEA member countries (an environmentally acceptable and secure energy supply that sustains economic growth).

Within the Agency, the model has been used for analysis of topics such as CO₂ capture and storage, renewables and energy technology learning analysis. The model is currently (spring 2005) being applied for hydrogen and fuel cell policy analysis, and for analysis of oil and gas and alternative fuel supply technologies. The plan is to focus later this year also on demand side analysis (energy efficiency), notably in the residential/commercial sectors and in the manufacturing industry. The operational framework for the ETP model is depicted in Figure 1.

The model is based on a technology library that contains about 1500 energy technologies. These technologies cover the energy system ‘from well to wheel’. The model is driven by the demand for 106 energy services such as cars, lighting, refrigeration and industrial heat. The world is split into 15 regions. Each region has its own technology efficiency and cost characteristics and its own energy resources. Certain energy commodities can be traded between regions. Policies such as taxes and subsidies and deployment targets can be added to the model.

Special attention is given to the model calibration. The model is linked to the IEA energy statistics and other data sources through a set of spreadsheets, called the Energy Model Builder (EMB). The ETP model is calibrated with the Reference Scenario of the IEA World Energy Outlook. The primary data inputs required by MARKAL are passed from the EMB to the ANSWER modeller’s support system which oversees the management of the data and the submission of model runs. The results for the sensitivity runs are analyzed using ANSWER and the VEDA-BE system.

The present version of the model is run out to 2050 generating a linear programming matrix of 750,000 rows and 920,000 columns.
Figure 1: Structure of the ETP model

The ETP model was developed in close cooperation with ETSAP. Important changes were introduced in the MARKAL code (by Gary Goldstein, the ETSAP Primary Systems Coordinator of International Resource Group) and in the ANSWER shell (by Ken Noble of Noble-Soft Systems) in order to facilitate multi-region modelling. These include, amongst others the list of enhancements list here (see the Research and Development Section for more details).

- **ANSWER ETP enhancements:**
  - A technology library facility in ANSWER which serves as a repository for the characterization of all future technologies. Technologies in the 15 regions are linked to the repository (the _LIBRARY region), so that each technology needs be defined just once, and is then inherited subject to option regional adjustments;
  - Technology operators, that allow region-specific adjustments to library technologies, such as investment cost multipliers or a later starting year for advanced technologies in developing countries;
  - Bulk copying facilities, to expedite the task of copying technologies from the library region to the 15 regions, and of copying region-specific information that is not in the library from one to many regions, and
  - A batch run facility, where the user can build a large number of different scenarios and run them in one go.

- **MARKAL ETP enhancements:**
  - Vintaging of demand devices which greatly reduces the need to “clone” technology representations due to improvements in efficiency over time;
  - Technology DECAY factors, similar to technology GROWTH factors, which allows easier modelling of the gradual phase-out of existing technologies;
  - Cross-regional user-defined constraints;
  - Global emission constraints;
Technology CO₂ emission coefficient calculations, based on energy and material inputs and outputs of processes;
A slack cost option for energy carriers that prevents energy production from exceeding energy consumption, and
A new formulation of endogenous technology learning, so-called “heuristic” learning, that results in much faster solution times.

These improvements are available to all users of the ETSAP Tools, and allow all participants to more easily build multi-region models.

Among the assessments conducted with the IEA ETP model to date are these listed below.

- Prospects for CO₂ capture and storage (additional sensitivity analyses), April 2005.
- ETP Energy Technology Perspectives-general model characterization and analysis of hydrogen and biofuel perspectives, March 2005.
- CO₂ Capture and Storage: four scenarios, January 2005.
- IEA Publication on CO₂ Capture and Storage, December 2004.
- CO₂ capture in the cement industry, November 2004.
- The future role of CO₂ capture in the electricity sector, September 2004.
- Renewables and technology learning, August 2004.

With regard to the Carbon Capture and Storage applications some preliminary results and conclusions are presented here as illustrative of the use of the ETP model. The full report, and the other mentioned above can be found at [www.resourcemodels.org](http://www.resourcemodels.org).

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Figure 2: CO₂ Capture Potential

Figure 3: Coal use without Capture (depending upon US$/ton Carbon Tax)
Figure 4: Coal use with Capture (depending upon US$/ton Carbon Tax)

Figure 5: CCS Transportation Fuels
Some preliminary conclusions with respect to Carbon Capture and storage include:

- If CO2 emission mitigation is taken seriously, CCS will play an important role;
- With CCS coal has a future in a CO2 constrained world;
- This has important supply security benefits;
- Incentives of 10-50 $/t CO2 needed;
- Mainly an electricity sector option, but also possibilities in transportation fuel production;
- IGCC with synfuel cogeneration looks attractive, if investment cost <2000 USD/kW, and
- A role may exist for combine biomass co-combustion and CCS.

See the References in Appendix J for further reading.

**System for Analysis Global Energy Markets (SAGE) [United States Department of Energy, Energy Information Administration]**

The US Energy Information Administration produces an annual volume, the *International Energy Outlook*. As was the case last year, the projections for the 2005 *International Energy Outlook* will be based on the Energy Information Administration’s new international energy modeling tool, System for the Analysis of Global Energy markets (SAGE).

SAGE is an integrated set of regional models that provide a technology-rich basis for estimating regional energy consumption. For each region, reference case estimates 42 end-use energy service demands (e.g., cars, trucks, residential lighting, etc.) are developed on the basis of economic and demographic projections. Period-by-period market simulations aim to provide each region’s energy services at minimum cost by simultaneously making end-use equipment and primary energy supply decisions.

The Energy Information Administration has enhanced SAGE for this year’s analysis. Most notable are substantial improvements to the electricity sector model and to the technology market share algorithm. In the electricity sector model demand time slices previously used to represent seasonal and time-of-day demands are now used to represent slices of the aggregate load duration curve. This provides better usage modeling for peaking (e.g., gas turbines) intermediate (e.g., combined cycle), and baseload (e.g., coal, nuclear) generation facilities.

The second significant SAGE improvement for 2005 is a substantially enhanced market share algorithm for managing “all-or-nothing” price-based technology selection in the minimum cost market solution. The market share improvements allow definition of technology market groups and close enough price margins for each defined group. The model can then endogenously select shares of “close-enough” technologies by comparing their marginal prices to those of the selected technologies and applying the close enough criteria.

Several figures below show historical and forecast information from the 2004 *International Energy Outlook*. 

21
Figure 2. World Marketed Energy Consumption, 1970-2025


Figure 3. World Marketed Energy Consumption by Region, 1970-2025


Figure 35. World Natural Gas Consumption, 1970-2025


Figure 62. Fuel Shares of World Electricity Generation, 2001-2025


**Global Multi-Regional MARKAL Model (GMM)** [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

With direct support from ETSAP, the Energy Economics Group (EEG) at Paul Scherrer Institute (PSI) in Switzerland has concentrated efforts on the development and application of the global multi-regional MARKAL (GMM) model for the examination of alternative energy-technology development paths and the evaluation of flexible climate policy instruments emphasizing the role of technological learning. Recently, the model has been used in the context of several research projects sponsored by the European Commission (ACROPOLIS, CASCADE-MINTS, SAPIENTIA) and the Swiss National Center of Competence on Research on Climate Change (NCCR-Climate- Phase I) for the assessment of the impact of flexible climate mitigation policies. In the context of this work, climate policy instruments that could exploit “where”, “when”, “what” and technology-related flexibilities have been examined. In addition, the combined effects of several policy instruments in the areas of mitigation of climate change, internalization of air pollution externalities and renewable portfolio standards have been examined and potential synergies and trade-offs between them have been identified (Barreto and Kypreos, 2004; Rafaj et al., 2005, Rafaj and Kypreos, 2004).

PSI-EEG has also undertaken the implementation of marginal abatement curves (MACs) for two main non-CO$_2$ greenhouse gases, namely CH$_4$ and N$_2$O, in the energy-system GMM model (Barreto et al., 2004). Our results illustrate the importance of including non-CO$_2$ greenhouse gases (GHG) when examining cost-effective strategies for mitigation of global climate change. The incorporation of non-CO$_2$ GHGs may have noticeable effects on the costs and composition of mitigation strategies.
In addition, PSI-EEG has conducted work on an iterative approach for the decomposition of the global MARKAL-MACRO Model (Kypreos, 2004). This approach could a more computationally efficient solution of the model, since the bottom-up part of the model could be solved using efficient linear programming solvers and the much smaller non-linear programming part representing the macro-economic production function would be solved separately with a commercial NLP algorithm.

**Decomposing the Global MARKAL-MACRO Model GMM** [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

Large NLP MM models e.g., models with more than 50000 rows, converge slowly when solved with CONOPT as NLP problems while for cases with more than 100000 rows it is almost impossible to identify a solution. This study explains how the GMM optimization problem can be separated to a large linear MARKAL-ED (MED) model and a simple MACRO Stand-Alone (MSA) model easily solvable with traditional NLP solvers using iteration³.

The basic procedure is simple and described here.

- The baseline case that assumes known exogenous demands is solved with MARKAL-ED to get the equilibrium demands and the energy cost.
- Then, with fixed energy cost⁴ and demands the MSA model is solved to identify the associated macroeconomic variables and GDP.
- The procedure is repeated for the CO2 constrained case.
- The demands are adjusted during iterations based on the duel demand function of MM associated with the production function of the model and up to the point where GDP stabilizes within a pre-specified margin.
- If the exact solution as in MM is desired we can store the MED and MSA and solve for the full MM as NLP problem restarting from the stored levels.

The procedures above have been investigated using a Swiss case as an example. Before starting the effort to apply the algorithm to large scale GMM models we recommend the following approach:

- To develop a scenario generator (SG) based on the calibration of the model for the starting year, the socioeconomic development, the price and income elasticities, and the demand decoupling factors. These factors should extend past trends and appreciate the specific assumptions of the scenario storyline (e.g., factors like energy intensity, technological change, energy conservation and the expected environmental policies). Past trends on energy intensity could be elaborated using the IEA databases and the methodology applied by IEA (IEA, 2004)
- To adjust baseline demands for price changes (e.g., due to resource depletion or due to environmental policies) we can apply the present version of GMM-ED.
- Finally, the economic growth impacts of policies can be estimated with the proposed algorithm of MSA iterating with the version of GMM-ED that incorporates demands adjusted to economic growth.


⁴ (or alternatively, with a quadratic cost function and variable demands)
While the procedure is operational and has been tested, there are issues remaining that will require further investigation before such an approach can be put into general practice. The full implementation details are included in the PSI report.

**Marginal Abatement Curves in the Energy-System GMM Model** [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

The consideration of non-CO\(_2\) greenhouse gases (GHG) is an important aspect when examining cost-effective strategies for mitigation of global climate change (e.g. Manne and Richels, 2000, 2003; Reilly et al., 1999, 2003). Although CO\(_2\) is the most significant contributor to climate change, other GHGs play also an important role, in particular due to the fact that they are associated with a much more potent greenhouse effect in the atmosphere than CO\(_2\). Including non-CO\(_2\) GHGs may have noticeable effects on the costs and composition of mitigation strategies. Thus, they represent an important component when it comes to enhance the degree of flexibility of climate-change mitigation strategies.

There are several possibilities for considering the effects of non-CO\(_2\) GHG abatement in a “bottom-up” modeling framework. One of them is the explicit inclusion of abatement technologies, an approach that has been followed by Rao and Riahi (2004) and Delhotal et al., (2004), among others. The second approach is the use of aggregate marginal abatement curves (MACs), built on the basis of assessment of abatement technologies.

Following the work of Manne and Richels (2000, 2003) for the MERGE model and Turton and Barreto (2004) for the ERIS model, we incorporate marginal abatement curves for two main non-CO\(_2\) greenhouse gases, namely methane (CH\(_4\)) and nitrous oxide (N\(_2\)O), considering both energy-related and non-energy-related sources, into the Global, Multi-regional MARKAL model (GMM). GMM is a global, five-region, “bottom-up” energy-system model developed and applied at the Paul Scherrer Institute (PSI) in Switzerland (Barreto, 2001; Barreto and Kypreos, 2004; Rafaj et al., 2004a,b). The model is part of the MARKAL family of models, a group of “bottom-up”, perfect-foresight, energy-system optimization models that allows a detailed representation of energy supply and end-use technologies (Fishbone and Abilock, 1981, 1983; Loulou et al., 2004).

This approach uses the regional marginal abatement curves for non-CO\(_2\) GHGs estimated by U.S EPA (2003). By incorporating MACs for these non-CO\(_2\) GHGs, the context for the examination of energy-technology strategies in the GMM model is substantially improved. Although we have restricted the implementation of methane and nitrous oxide in the GMM model, the approach is general enough as to consider MACs for other GHGs.

**Definition of baseline emissions**

Following US EPA (2003), the categories considered in this analysis are as follows: CH\(_4\) emissions from coal, oil and gas production, solid waste management and manure management, N\(_2\)O emissions from adipic and nitric acid production. Baseline emissions must be defined for these different sources of emissions. Baseline emissions can be endogenous if they are linked to a model variable or exogenous if they are specified from sources external to the model. In this

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formulation, energy-related methane emissions from coal, oil and gas production are endogenous to the model. Emissions from other sources are exogenous to the model.

Other sources of CH$_4$ (enteric fermentation and rice paddies) and N$_2$O (soils) emissions are also considered exogenously. However, since no MACs are specified for them in the US EPA study (2003), they are treated here as non-abatable emissions. It must be noticed that these sources of emissions currently represent a large fraction of the total emissions of these non-CO$_2$ gases worldwide (Reilly et al., 2003), but, uncertainties still abound regarding the potential, costs and feasibility of implementation of those measures.

Definition of marginal abatement curves

The marginal abatement curves (MACs) are given to the model as stepwise curves relating abatement costs and abatement potentials. These abatement potentials are given either as absolute potentials, e.g. in tons of the respective GHG or carbon-equivalent, or in relative terms (e.g. percentage) of a given baseline. In what follows, it is assumed that the abatement potentials are given as a fraction of the baseline and that emissions from non-CO$_2$ GHG are expressed in terms of carbon-equivalent (C-eq) emissions using the 100-years global warming potentials (GWP) reported by IPCC (2001), namely 21 for CH$_4$ and 310 for N$_2$O. Correspondingly, abatement costs are given in US$/ton C-eq.

The abatement potentials have been derived on the basis of considerations of availability, reduction efficiency and technical and economic applicability of the different abatement options (Delhotal et al., 2003). Abatement potentials per price step, region, and GHG are specified for a reference time period, here chosen as 2010. We did not consider no-regrets options in this specification. That is, all MACs were shifted upwards such that abatement costs are always positive. Abatement potentials for other periods are computed using the so-called technical-progress multipliers (tm). These multipliers represent the fact that abatement technologies may improve over time, thus increasing the abatement potential achievable at a given cost. The multipliers allow extrapolating the MACs beyond 2010, the reference year.

![Figure 1](image)

**Figure 1:** Illustration of the effect of technical multipliers to shift marginal abatement curves out into future periods.
It has to be recognized that these multipliers provide only a rudimentary way to represent technical change in non-CO\textsubscript{2} abatement options and that this takes place only exogenously (i.e. it does not depend on the amount of cumulative abatement). Moreover, at this point their choice is somewhat arbitrary and dependent on the modeler’s judgment. Delhotal et al. (2003) have proposed a methodology for shifting MACs into the future on the basis of technology assessment for individual technologies, but figures are not yet available for multiple regions and/or sectors.

The full implementation details are included in the PSI report.

**Impacts of RD&D on Carbon Mitigation Costs** [Energy Economics Group (EEG) at the Paul Scherrer Institute (PSI), Switzerland]

This formulation of the MERGE model defines RD&D as a decision variable, and presents numerical examples which reveal the implications of RD&D directed in favor of carbon mitigation policies to stabilize carbon concentrations (e.g., at 450 ppmv)\textsuperscript{6}.

MERGE is an integrated assessment model (IAM) that provides a framework for assessing climate-change management proposals. Kypreos apply the MERGE5 version described by Manne and Richels which already includes some generic technologies capable of learning-by-doing (LBD), but he introduces algorithms that model both learning-by-searching (LBS) and learning subsidies. The world modeled by MERGE is divided into nine geopolitical regions with an ETA-MACRO model describing each of these regions to captures price-dependent substitutions of energy forms and energy technologies to achieve specified CO\textsubscript{2} reduction targets.

ETA is a simplified ‘bottom-up’ engineering model: MACRO is a ‘top-down’ macro-economic growth model that balances the non-energy part of the economy of a given region using a nested constant-elasticity-of-substitution (CES) production function. The model also captures autonomous (e.g., price-independent) effects and macro-economic feedbacks between the energy sector and the rest of the economy. Adding a climate and damage model makes MERGE an Integrated Assessment Model. MERGE divides the world into nine geopolitical regions: Canada, Australia and New Zealand, China, Eastern Europe, OECD Europe and the former Soviet Union, India, Japan, Mexico and OPEC; USA and the rest of the world.

The model maximizes a welfare function and links the regional ETA-MACRO submodels, and aggregates the regional welfare functions, adjusted for the non-market damages, into a global welfare function using appropriate Negishi weights.

Model analyses was carried sufficiently far to conclude that increased commitments (either private or public) to the development of new technologies to advance along their respective learning curves has a potential for substantial reductions in the cost of climate mitigation at a level necessary to reach safe concentrations of atmospheric carbon.

The MERGE-ETL model with endogenous technological learning (ETL) was used to examine the impact of RD&D with special emphasis given to CO\textsubscript{2} sequestration systems. Three reference technologies were defined: an IGCC plant, a pulverized coal plant, and a combined gas and steam turbine power generation system without sequestration options. Then, a parallel set of the same technologies, with the exception that these include sequestration of CO\textsubscript{2} were introduced. In the

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baseline cases, technological learning favors new, advanced systems such as integrated coal gasification with combined cycle, gas combined cycle, wind turbine and new nuclear plants, as well as non-electric back-stop systems. Apart from this, the model formulation does not significantly change the conclusions of the original MERGE model for the first half century. The results differ significantly for the second half of the century. Without learning use of synthetic fuels dominates while in the case with endogenous learning, the market penetration of carbon-free technologies reduces emissions to 16.3 Gt of carbon per annum. In the 550-ppmv stabilization cases, a significant development and market penetration of low-carbon generation options is required to fulfill the imposed CO$_2$ reduction targets. Technology learning in this case favors new advanced systems, in particular GCC, NNU and WND and mainly IGCC systems with carbon sequestration together with non-electric renewables. The application showed the importance of technological progress for carbon control, since this brings in low-cost reduction options and hence reduces GDP losses and the marginal cost of carbon control.

Several scenarios related to CO$_2$ emission control are presented as illustrations of the results generated by this version of MERGE. Apart from the business-as-usual (BaU) cases, where CO$_2$ emissions are not limited, we have considered the implications of stabilizing atmospheric carbon concentrations to 550-450 ppmv. All scenarios are assessed with and without ETL options. The baseline case is designated as BaU-N, where technological change is exogenous, whereas BaU-S designates the case where the TFLC and learning subsidies apply. The database for the baseline cases reflects the original technology data of MERGE5, while the growth data are downwards adjusted to reflect the assumptions of the Innovation Modeling Comparison Project (IMCP). Constraints are introduced only on the CO$_2$ concentration. although MERGE considers all other greenhouse gases (GHGs), carbon sinks and aerosols.

In the BaU-N case, the world GDP grows more than 9 times (*i.e.*, to US$312 trillion in 2100) between 2000 and 2100; but primary-energy supply and carbon emissions are strongly decoupled from economic growth and increase to 1225 EJ of primary energy per annum (at 45% efficiency for the backstop electricity) and 20.25 GtC/yr carbon emissions in 2100. In the BaU-N case, global CO$_2$ concentrations increase to 708 ppmv, while the average temperature rise between the year 2000 and the year 2100 is 2.38°C Celsius. Most of the economic growth occurs in economies (currently) in transition and in developing countries. Regional differences in income, primary-
energy intensity, and carbon intensity of GDP are decreasing over time. The currently less-developed countries assume a high economic growth such that they will produce most of the global GDP in the year 2100 while OECD countries will contribute by 38% to the total output. It should be noted that the potential socio-economic growth underlying this scenario is exogenous as well as the autonomous efficiency improvement.

Energy efficiency and decarbonization contribute to improved energy, economic, and environmental indices. Policies that support technological learning result in a strong contribution of renewables in meeting non-electric-sector demands. This shift enhances the use of non-electric backstop technologies. For the BaU-S case, therefore, renewable-energy sources and nuclear contribute 35%, coal 47%, oil 8% and gas 10% of the energy mix compared to a 55% contribution for coal in the BaU-N scenario. Learning in the BaU-S case reduces emissions to 17.9 GtC/yr in the year 2100.

Figure 2 illustrates the impact of learning on the generating cost of electricity for the 450-ppmv cases. We assume a moderate exogenous rate of generation cost reduction that of 0.2% per year. The most significant mechanism in cost reduction is the contribution of the LBD while LBS is important during the first, introductory periods of the new technologies.

![Graph](https://example.com/graph.png)

**Fig. 2:** A significant cost reduction over time is shown when LBD applies. RD&D policies are important in the early stage of introducing a new technology.

**Stabilizing carbon concentrations**

Economic considerations govern the transition to a low-carbon economy. Two of these considerations represent key options for the second half of this century: the exhaustion of oil and gas resources, and the significant cost reduction in carbon-free energy technologies. When R&D policies are appropriately applied, we attain a significant reduction of energy generation cost and carbon control costs, as shown in Figures 2 and 4. Obviously, the stronger the carbon constraint
is, the faster the penetration of carbon-free technologies into the market mixes, and the stronger the relative cost reduction.

![Cumulative undiscounted GDP losses relative to BaUS](image)

**Fig. 3:** Cumulative and undiscounted GDP losses for the Carbon stabilization cases, relative to BaU-S. The cumulative and undiscounted GDP losses are significantly reduced in the case of LBD and LBS. For the 450-ppmv cases, the cumulative loss of 1.26% is reduced to 0.55%.

The scenarios where atmospheric CO₂ concentration is held to 450-ppmv assume that efficient strategies will be adopted worldwide and a full-scope transfer of “know-how” will take place. Under these circumstances, the following conclusions can be made: First, the induced cumulative GWP losses of the carbon-stabilization are low (e.g., in relation to the cumulative baseline-GWP): for example, below 1.26% in the case without learning, while with ETL policies the GWP losses are less than 0.55% (Figure 3). Secondly, the marginal costs related to carbon stabilization are also reduced to a fraction of the marginal cost without learning (Figure 4), but remain always significant for the case of the 450 ppmv atmospheric carbon limit.

![Marginal Costs in $/tC](image)

**Fig. 4:** The marginal costs of carbon control are reduced by almost 50% in the period of 2090 in the case of Endogenous Technological Learning in relation with cases without.
The variance on control cost estimates as function of the appropriate carbon stabilization policy emphasizes the need to reduce the scientific uncertainty on climate change if one expects significant policy commitments to take place.

MERGE-ETL views the development of clearer and innovation energy technologies as a long-term strategy to mitigate global climate change. Kypreos points out, however, that such a penetration of new technologies is not necessarily going to happen in the real world relying on market forces. These new technologies are still expensive and not competitive against fossil fuels or other barriers. The new systems identified as promising require initial support for their development, otherwise that may be locked out of energy markets.

**Toward a Nash Equilibrium MARKAL? [Loulou, Kanudia and Labriet]**

An example of game theory is the classic Prisoner’s Dilemma. Suppose you and a friend are arrested for robbery. You are put in separate cells. The police lack sufficient evidence to convict either of you, so they try to get one of you to testify against each other.

The police tell you that if you testify against your friend, you will be released, provided your friend does not testify against you. He, on the other hand, will get 15 years in prison. If neither of you testifies, you will each get only four months in jail. Your friend has been given the same options. What would you do? Puzzles such as these are the work of theorists such as Nobel Prize winner John Nash, who is now well known from the cinema *A Beautiful Mind* based partly on his life.

Labriet, Loulou and Kanudia explore various equilibrium computations, including cooperative and non-cooperative (Nash) equilibriums to assess different approaches of greenhouse gas abatement in a regionalized, global bottom-up model. The objective function is to minimize the sum of abatement cost and damage cost. There are arguments as to the use of damage costs instead of emissions targets. In the case of a cooperative equilibrium, one could rely on using a concentration target, and then convert it to global emission constraints to be used in the MARKAL model.

Indeed, it is not yet clear whether the real international framework related to climate change will be closer to a cooperative or to a non-cooperative situation. Coupling damage and abatement costs into an integrated MARKAL model would then allow endogenous GHG concentration calculation and the computation of both cooperative and non-cooperative cases.

In the case of a non-cooperative equilibrium, the concentration resulting from the players’ actions are unknown, since each player (i.e., region) has only its own total cost as an objective. If global agreement on greenhouse gas reductions could not be agreed upon through negotiations, each country (or region) would then examine its own costs and benefits of abatement. But each country would also be likely to take into account the likely actions of other countries when making their decisions, since the latter depend on the emissions of all players. This leads to the Nash equilibrium.

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31
In this case, each region, r, chooses emissions $e_r$, so as to minimize its total cost:
\[
\text{Abatement cost} + \text{Damage cost},
\]
where it is understood that damage cost depends on global emissions.

**Climate and damages modeling**

The causal chain begins with emissions, which are developed in MARKAL. The next step involves a climate model providing concentrations of greenhouse gases in the atmosphere and global temperature over time. Finally, economic damages are produced.

The climate model is based on Nordhaus’ 1999 DICE/RICE-99 models. The approach uses a simplified "minimodel" to represent the basic dynamics of climate change (radiative forcing and two-reservoir model for temperature change). This representation is highly simplified and is intended only to depict the broad features of climate change (Nordhaus). Still, given the uncertainties, it is not clear whether complicating the model with a more elaborate specification would produce more reliable results.

Damage functions based on RICE-99 are available on a regional and sectoral basis (agriculture, see-level, health, non-market, catastrophic impacts, etc.). Damage expressed as a GDP loss due to temperature increase is considered as quadratic.

Some caveats include the high degree of uncertainty on shape and parameters of the damage functions, the speed of temperature increase is not taken into account in damage calculation, and adaptation to climate change is not clearly separated from damage calculation. There is also a lack of feedback to MARKAL demands.

Two approaches were considered: a full representation and a simplified one. A full representation augments MARKAL with the complete set of climatic equations and damage functions. The drawbacks of that include creation of many additional non-MARKAL constraints, some of which are non-linear, non-convex. The simplification asks the basic questions: “What error is made in assuming that damages depend only on total cumulative emissions, irrespective of the shape of emission trajectory?” And “are damages a function of global cumulative emissions?”

To test this hypothesis, they chose 30 emission trajectories (21 from literature, 9 artificial). Some examples are:

- Stabilization Scenarios from IPCC (“Post-SRES’’): IMAGE 350/450/650/750ppm, MARIA 550ppm, MERGE Stbz;
- Other scenarios: RICE 2001, EMI constant at 90 level;
- Fictitious emission trajectories: e.g., Constant emissions through time, increasing emissions

The emissions trajectories range widely, from increasing to decreasing to increasing and then decreasing, illustrating the full range of possibilities. Yet the combined results of all the scenarios resulted in a linear plot of damage (trillion$ in 2100) vs. cumulative emissions (GtC in 2100). Although the value was different, the same linear form was produced on the 2050 horizon. The conclusion appear to be that: a) damages can be considered as independent of emissions trajectory on the time horizon considered; b) linear damages related to cumulative emissions are a good approximation in view of the uncertainties. The reason the authors give is that late emissions have less time to be absorbed by ocean layers, but have also less time to provoke damages. The analysis was done for global damages as well as for damages in each of the 15 regions of the model. The linearity property was verified for the regional damage functions as well.
Computing abatement strategies with an integrated model

Based on these results, cooperative and non-cooperative games can be much more easily solved via an augmented techno-economic optimization model as they are equivalent to local optimization problems where only the cumulative emissions of the local country is involved.

- In the non-cooperative case with GHG interdependency, each country minimizes its own abatement costs and residual damages by taking into account the world cumulative emissions (Nash equilibrium where cumulative emissions by other countries are representative of decision taken by the other countries); in other words, each country solves a local optimization problem. But given the linearity of damages, this is equivalent to a case where each country decides its non-cooperative strategy by considering only the part of its damages due to its own emissions.

- In the cooperative case with GHG interdependency, countries together minimize the world abatement costs and residual damages of climate change. Given linear damages, this is equivalent to a case where each country takes into account only its own contribution to the damage incurred by all countries.

Consequently, the integrated MARKAL model includes damage function for each of the 15 regions of the world model. Climate modeling and damage calculation are in fact “hidden” in these damage parameters, and any change in the climate and damage assumptions (e.g.: climate sensitivity, discount rate, GDP projections and time horizon for damage calculation, etc.) will be reflected in new damage parameters (sensitivity analysis).

First results show that Nash equilibrium is better for all regions (total system cost, including damage, of each region is reduced compared to business-as-usual), but that USA, China, Australia-NZ, Eastern Europe and Former Soviet Union lose from cooperation. Reallocation of the gain from global cooperation (side-payments) will have to compensate these regions.

Resulting temperature increase in 2050 is 1.54 C (BAU), 1.38 C (cooperation), 1.53 C (Nash). Atmospheric concentration in 2050 is: 490 ppm (BAU), 439 ppm (cooperation), 485 ppm (Nash). Technology choices behind the results rely on coal decline (electricity production), increase of renewable energy and reduction of demands (elastic demands).

Assessment of abatement costs and permit allocations using World-MARKAL [Vaillancourt, Loulu, Kanudia]

In the long term, the Kyoto Protocol itself will be insufficient to stabilize the greenhouse gas (GHG) concentrations in the atmosphere: the participation of developing countries will be essential. International cooperation mechanisms, such as permit trading systems, can help achieve global economic efficiency. However, initial allocation of emission permits raises many issues on equity. The main objective is to propose a decision aid tool which can provide relevant information to the parties on various permit allocation schemes. A dynamic multi-criterion decision analysis (MCDA) model is proposed to share the global quantity of permits among 15 regions, taking into account multiple definitions of equity. The World-MARKAL energy model is used to determine the cost-effective opportunities and to compute the gross reduction cost (before permit exchanges) for each region. Then, it is possible to calculate their net reduction costs (after permit...
exchanges) according to different allocation schemes. Ranges of permit allocations and net costs are presented for each region.

This research examines a permit trading system where all countries participate to achieve a long-term greenhouse gases (GHG) stabilization target. The main objective is to propose allocation schemes that lead to a fair distribution of net abatement costs among world regions. These costs are good indicators of the need to emit of regions and their opportunities to abate, two criteria that are intuitively appealing, but are difficult to translate into straightforward indicators. These allocation schemes therefore complement the ones based on the more often proposed allocation criteria (population, gross domestic product (GDP), etc.). The World-MARKAL model is used to model the stabilization scenario and to calculate the regional abatement costs which are the basis for the proposed allocations. The optimal solution of the model (before permit trading), as well as the net abatement costs of regions (including permit trading), are presented. Some sensitivity analyses are discussed.

### Emission reductions and gross costs

Global cooperation leads to the equalization of the marginal abatement costs across all regions, with the world marginal costs ($/t), as well as the global percentages of reduction (%), are presented in Table 1. The decrease in the marginal cost in 2020 is related to an increase of emissions in the AIM’s stabilization trajectory, and consequently, a very low increase in the global percentage of reduction between 2010 and 2020: from 21% in 2010 to 24% in 2020. The increase in the marginal cost for the following periods is explained by higher percentages of reduction: 38% in 2030, 40% in 2040 and 45% in 2050 and by the continued increase in economic activity in all regions.

<table>
<thead>
<tr>
<th>Period</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal cost ($/t)</td>
<td>0</td>
<td>50</td>
<td>35</td>
<td>158</td>
<td>177</td>
<td>423</td>
</tr>
<tr>
<td>Global reduction (%)*</td>
<td>0</td>
<td>21</td>
<td>24</td>
<td>38</td>
<td>40</td>
<td>45</td>
</tr>
</tbody>
</table>

* The global reduction (%) is the relative difference between the emission of the base scenario (A1B) and that of the constrained scenario (stabilization at 550 ppmv).

### Permit trading and burden sharing: equalizing net abatement costs

Two permit allocation schemes were examined. At each period, the objective is to equalize either the net abatement costs per unit of GDP-ppp (purchase power parity) or and the net abatement cost per unit of GDP-ppp Squared. The first scheme (S-GDP, Table 2) respects the horizontality principle, since it equalizes the net costs across regions as a percent of GDP. The second scheme (S-GDP2, Table 3) reflects the verticality principle, since it aims at allowing more permits to the poorest regions, those for which the GDP is the lowest.

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Table 2: Permit allocations and net costs for the S-GDP scheme

<table>
<thead>
<tr>
<th>Region</th>
<th>% Allocation</th>
<th>Gross cost</th>
<th>Trading</th>
<th>Net cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2050</td>
<td>B$</td>
<td>+/-</td>
</tr>
<tr>
<td>Africa</td>
<td>5.8</td>
<td>7.7</td>
<td>767</td>
<td>-377</td>
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<td>Asia</td>
<td>7.2</td>
<td>8.0</td>
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<td>197</td>
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<td>Australia-NZ</td>
<td>1.5</td>
<td>1.6</td>
<td>70</td>
<td>-17</td>
</tr>
<tr>
<td>Canada</td>
<td>1.9</td>
<td>1.2</td>
<td>111</td>
<td>-40</td>
</tr>
<tr>
<td>China</td>
<td>15.2</td>
<td>18.1</td>
<td>1518</td>
<td>270</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>1.9</td>
<td>1.8</td>
<td>103</td>
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<tr>
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<tr>
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<td>100.0</td>
<td>100.0</td>
<td>8043</td>
<td>0</td>
</tr>
</tbody>
</table>

* With this scheme, the net abatement costs per unit of GDP (%GDP) are equalized across regions at each period. However, because of the discounting of the trading costs on one hand and of the GDPs on the other hand, the net abatement costs per unit of GDP percentages are not identical at the end of the time horizon.

Table 3: Permit allocations and net costs for the S-GDP2 scheme

<table>
<thead>
<tr>
<th>Region</th>
<th>% Allocation</th>
<th>Gross cost</th>
<th>Trading</th>
<th>Net cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2050</td>
<td>B$</td>
<td>+/-</td>
</tr>
<tr>
<td>Africa</td>
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<td>7.8</td>
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<td>Canada</td>
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<td>Eastern Europe</td>
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<tr>
<td>FSU</td>
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<td>India</td>
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<td>272</td>
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<tr>
<td>World</td>
<td>100.0</td>
<td>100.0</td>
<td>8043</td>
<td>0</td>
</tr>
</tbody>
</table>

* The regions, whose GDP is the highest (the United States, the Western Europe, China), face an increase of their net costs compared to the S-GDP scheme.

Two sensitivity cases were then preformed. In the first case, the GDP measure based on the purchase power parity (ppp) is replaced by the market exchange rates (mex). Using GDP-mex benefits more to the developing regions (see US vs. China in Figure 1)v, which receive thus more
permits. Consequently, although the global net cost (8043 B$) is identical in both cases, this cost is higher when it is expressed as a percentage of the GDP-mex (0.51%) than as a percentage of the GDP-ppp (0.42%), since the global GDP-mex is lower than the global GDP-ppp.

Fig. 1: Evolution of the GDP (ppp and mex) for the USA and China

In the second sensitivity analysis the stabilization level is increased from 550 ppmv to 650 ppmv. A higher level of stabilization implies a large decrease in the global abatement cost, from 8043 B$ to 2337 B$ (and from 0.42% to 0.12% of the global GDP). See Fig. 2 for a comparison of the world marginal cost trajectories for the two stabilization scenarios. The regional distribution of gross costs is also different, even if the trends are generally the same. For example, the United States and China are still the two regions that face the higher gross costs, but this time, the United States (523 B$) has a higher cost than China (420 B$). The impact on permit allocations, and consequently on the net costs, is therefore significant.

Fig. 2: World marginal cost curves for two stabilization levels
Conclusion

Permit allocation schemes based on cost distribution allows obtaining solutions with equalized net costs per GDP for all regions. No region faces negative costs with these schemes. The S-GDP2 scheme goes further, as it allocates even more permits to the poorest regions. However, these schemes imply significant reductions in the developing countries on the short-term, and consequently, may not respect the conditions of the developing countries to take part in the existing global mitigation agreements.

This economic approach for permit allocations represents one vision of equity among others. While multi-criterion approaches aim at combining several (often conflicting) visions of equity to allocate permits, the economic approach proposes a single criterion to obtain allocation schemes, leading to an equitable burden sharing expressed in monetary units. The two approaches are therefore complementary: whereas the first one provides relevant information on various equitable permit allocation schemes (but may lead to negative costs for some regions), the second directly indicates which allocations are needed to obtain an equitable distribution of abatement costs (according to principles such as the horizontality or the verticality).

The European Union energy research initiative ACROPOLIS Assessing Climate Response Options: POLicy Simulations – Insights from using national and international models [Several ETSAP institutions, and others]

The ACROPOLIS European research project is an attempt to overcome the difficulties linked to the harmonisation of the results from different energy models. ACROPOLIS is aimed at applying and comparing several existing energy models to address the potential impact of a number of policy options to reduce greenhouse gas (GHG) emissions. Several ETSAP institutions participated.

The project consortium consists of 7 European Union (EU) and 5 non-EU organisations, involving up to 15 different energy models. Among the models are global models (with different detail in territorial disaggregation), others representing regional energy markets and the balance national (single country) energy models. From the ETSAP group the following institutions and models are involved:

Chalmers University of Technology - Dept. of Energy Conversion [Bo Ryden] – MARKAL-Nordic
Ente Nazionale Energia e Ambiente – ENEA [Giancarlo Tosato] – MARKAL-Italy
Netherlands Energy Research Foundation - ECN Policy Studies [Remko Ybema] – MARKAL-MATTER
Paul Scherrer Institute – PSI [Socrates Kypreos] – Global MARKAL-Macro Trade (GMMT)

The time horizon of the models ranges from 2020 to 2100. From the methodological point of view, most of the models include a relatively detailed technology description and are based on a bottom-up approach. However, some of them are more aggregated and include less characterization of technological options (top-down approach).

http://www.ier.uni-stuttgart.de/acropolis
ACROPOLIS also tried to reduce the communication gap between modelers and policy-makers for a particular application: the role of different policies and measures to reduce GHG emissions and fostering deployment of more advanced and climate-friendly technologies.

The considered policy options for the development of GHG abatement scenarios consisted of:

**Case 1.** The adoption of a renewable portfolio policy (via appropriate subsidisation schemes) and the combination with internationally traded green certificates.

**Case 2.** The set up of an international (global) emission trading regime to allow for flexible fulfillment of an agreed, ambitious global GHG abatement target.

**Case 3.** The establishment of energy efficiency standards both in demand and supply sectors, and in agreement with the specificities of the regional coverage.

**Case 4.** The implementation of an energy-taxation policy based on the internalisation of environmental external costs of all energy fuels and technologies.

Some remarks are required for clarification:

First of all, one should underline the different approaches applied in terms of scenario definition. In some cases the approach was to set an environment-protection target and determine the technology and policy mix that could make it happen (and possibly at what cost). In other cases, the focus was to assume a given policy portfolio (subsidies, taxation instruments, technology-fostering measures, etc.) and determine the resulting GHG emissions.

Secondly, the comparability of results (and its harmonisation) depends heavily on the characteristics not only of each model, but also of its regional coverage. The ACROPOLIS report provides information on the assumptions made, analysing in most cases the impact of crucial hypothesis on the results.

It should also be noted that the case studies had a strong focus on electricity generation. The conclusions drawn from the results have to be used with some care because some of the scenarios (namely Case 3 on efficiency standards) could lead to different conclusions when the whole energy system is considered.

Finally, most of the case studies only examine a specific part of the energy system which may lead to an undesired leakage effect by changing the relative costs between the sectors. The design of a successful climate strategy needs, as much as possible, an integrated approach covering all sectors of the economy.

Prior to the analysis baseline projections for all the models participating in the comparison exercise were obtained. To provide enough flexibility to the models, input harmonisation was restricted to GDP growth, population and energy prices (or energy resources for those models with endogenous price formation).

For population and GDP, the assumptions of the scenario B2 in the UN IPCC Special Report on Emissions Scenarios were adopted. At the country/regional level, country modelers were asked to make their own assumptions.

The main findings of the model comparison exercise for each of the four selected scenarios are summarised below, more detail is available in the reports.

**Case 1: Renewable energy targets/Green certificates**

The renewable energy portfolio case was defined as a constraint on a minimum share of primary energy from renewable sources. For EU countries, the target selected matches the recent EU directive to reach 22% of electricity from renewable energy sources by the year 2010. Similar targets were scheduled for other countries/regions according to their natural resource endowment.
and present primary energy mix. The implementation modality was to define a given target and then determine, *ex-post*, the conditions under which this projection may develop (techno-economic parameters, potential resource availability, and substitution feasibility).

All models basically agree in identifying biomass as one of the most promising options for renewable electricity, as well as wind energy – an option significantly present in the market already for the baseline projection. On a global scale the substitution is basically expected to take place by replacing coal-fired power plants as well as, but to a lesser extent, gas-fired power plants. In Europe with gas as the dominant fuel for power generation in the future, renewables would penetrate mainly at the expense of gas power plants.

These conclusions depend somewhat on the specific conditions of a given country, which becomes more evident when examining the results from national models. This also translates in different cost estimates to fulfill the renewable share target (the range is from 0.5 to 12 € cents per kWh, although a reasonable confidence window would be 2.5 to 4 € cents per kWh for the green certificate value).

**Case 2: Long-term emission trading**

This scenario focused on global emission trading to reduce CO$_2$ emissions. Rather than confining the exercise to the Kyoto Protocol time-frame, it was decided to analyse a long-term scenario in which all countries progressively accept differentiated carbon emission abatement targets.

Emission reduction targets were based on a scenario allowing for the stabilisation of CO$_2$ concentration at around 550 ppm. Emission trading is assumed at each point in time amongst all countries actively pursuing climate protection policies. The timing of participation varies among countries, beginning with the Annex B countries, the US joins in 2010 and all countries are participating by 2045. The Annex B countries continue their reduction effort after the first commitment period. For non Annex B countries the targets are based on the GDP per capita and the population projections. The policy option investigated in this case study uses flexibility mechanisms namely emission trading between the parties. It is, however, assumed that Russia and other eastern European countries will sell only 50 percent of their emission permits stemming from “hot air” by 2010 (no banking is allowed in this exercise).

The model simulation showed a very good agreement in the stylised results. All models indicate a significant decline in the use of coal, with reductions from 40 to 60% over the baseline, as well as a significant oil demand reduction. Similarly, nuclear power is above the baseline in almost all simulations, and the share of renewables (mostly concentrated in the power generation sector) also increases in all models by about 10% with respect to the baseline. Carbon emissions permit prices change from model to model and over time but, for the period 2010 – 2020 there is a general consensus on a figure ranging from 15 to 40 €/tC (by 2010) and between 55 and 70 €/tC by 2020. The models that can estimate the impact on GDP report GDP losses for the global as well as for the European economy of between 0.2 to 1.3% in the long run (2030). For the Kyoto time horizon the impact is lower.

**Case 3: Efficiency standards**

The implementation of the efficiency standards case has been relatively complex due to the different technology characterisation within the models. Some models exhibit very detailed technology portfolios, but only in one or two sectors, and rely on aggregate parameters in other sectors. Five models addressed energy efficiency standards specifically in the transportation sector, residential sector, industrial sector and power generation sector. The exercise was implemented by imposing additional energy efficiency parameters in the technologies included in each model. The results not only depend on the model used but also on the specific characteristics of the country considered and the corresponding costs. Sectors/countries with high potential for
energy efficiency improvements offer cheap and large energy saving opportunities (and therefore costless emission abatement). This is typically the case for the residential or transportation sector in USA with respect to their EU counterparts. The role of fuel switching in achieving better efficiency (primarily through migration towards natural gas) is of utmost importance in the implementation of the standards in the power generation sector.

An important conclusion is that efficiency standards (whose costs may be endorsed by the industry or partially by the administration through appropriate subsidies) is one of the lowest cost, highest benefit energy policy and a cost-effective measure to reduce greenhouse gas emissions. All of the model results show that both CO₂ emissions (between 4 and 11% on a global scale for efficiency standards in the power sector) and total energy costs decline due to reduction in final energy and primary energy demand as well as lower equipment costs.

Case 4: Internalisation of external costs
The scenario concerning the internalisation of environmental external costs was constructed by adopting the results of the ExternE project for the relevant energy fuel cycles. For the use in energy models the ExternE results had to be scaled and adjusted to yield reasonable data for the technologies included in the different models. Also an extrapolation and adaptation of the data derived for EU to other world zones was necessary. The scenario foresees an energy taxation policy that progressively internalises the external cost of electricity generation until 2010 and remains at a constant level from then on. The adapted external cost for electricity ranges from 0.1 eurocents/kWh for wind energy, 0.5 eurocents/kWh for nuclear, 0.3 eurocents/kWh for modern gas plants, 2 eurocents/kWh for modern clean coal plants, up to 16 eurocents/kWh for coal power plants without environmental measures.

Broadly speaking, this scenario implies for all models and under all circumstances a significant decrease of coal use. The fact that coal is not only the most carbon intensive fuel but also has the highest emissions of non-carbon pollutants (without applying environmental technology), allows for environmental double dividends in energy policy. The internalisation of external costs translates in global carbon emissions from 3% to 5% below the baseline (corresponding to the Renewable Case 1). It should be noted, however, that in the long-run ambitious carbon reductions as specified, for example, in Case 2 cannot be met by relying only on a policy of internalisation of external cost for the electricity sector.

Policy conclusions
With respect to the specific policy options to mitigate climate change addressed in ACROPOLIS, especially for the electricity sector, the following points should be highlighted.

- Obtaining significant GHG emission reductions can be achieved via a relatively broad portfolio of measures, and no fundamental drawback is expected on the joint adoption of most of them. For instance, a minimal renewable energy target via a green certificate market can contribute to the fulfillment of a broader more ambitious, multi-sectoral target.

- Fuel switching is a process that seems to lead most energy markets towards less carbon-intensive primary fuel mix. However this process could be accelerated if the proper incentives are put in place. On the other hand, the adoption of some other measures such as emission standards for coal-fired power plants may induce a change from “conventional” coal to “advanced” coal, discouraging a more radical fuel switch.

- Natural gas seems to be a winning option in many sectors (industrial, space heating, power generation, etc). The higher gas demand is likely to raise gas prices. The great

10 http://www.externe.info/
uncertainty to address is the evolution of these prices, ultimately linked to uncertainties in the pace of new reserve discoveries and of technological breakthroughs.

- An increasing share of renewables in the primary energy mix is also a requisite to achieve a declining carbon emission profile. The role of renewables may change depending on the domestic resources and the demand profile of a given country. However, wind energy and biomass-based electricity are important vectors already growing in the power generation sector almost on a world-wide basis. The role of Photovoltaics in the power generation sector critically depends on its cost, but it is very likely to increase in the medium-long-term. Biofuels are an option nearly competitive in the transportation sector, whereas the role of renewable-based hydrogen is still uncertain (at least for the next two decades). Low-temperature solar thermal devices are expected to enter many markets in a generalised way to diminish the fossil-fuel energy demand of the residential sector.

- Nuclear power generation is a technology whose role in curbing carbon dioxide emission from the electricity sector is and will be crucial, since it competes directly, within the present technological structure of the sector, mostly with coal-fired power plants. The uncertainties are related not only to the future deployment of advanced nuclear technologies and the possible lifetime extension of existing plants, but also (and mainly) to the acceptance and the perception of this technological option by the general public.

- The potential of energy efficiency standards is particularly high in those sectors with relatively little responsiveness to price signals. In particular, energy efficiency standards seem to be a valuable tool to reduce final energy demand from the residential, transport and services sectors.

- The costs associated with an ambitious, long-term, global target leading to a stabilisation of GHG concentrations would be significantly lower if flexibility mechanisms are put in place. The use of carbon emission trading across countries and sectors will certainly lower the costs. The implementation of trading together with other schemes (green electricity certificates, etc) poses no fundamental distortion or efficiency loss problem.

- Alternative environmental protection policies based on price increases through charges rather than prescribing emission targets are in principle also compatible for pollutants other than CO$_2$ (SOx, NOx, and others) as a way of internalising external costs. It could also produce other benefits in addition to the curbing of carbon emissions.

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The project started in April 2004 and was accomplished under the general direction of ORDECSYS, with the active participation of Amit Kanudia (KanORS), Richard Loulou (HALOA), and Denise van Regemorter (Catholic University at Leuven).

The characteristics of the entire model are described in the report *EFDA World TIMES Model: Final Report* and its annexes, while the transfer of the required know-how is accomplished by means of training sessions, model demonstrations, and user’s guides.

The main body of the report contains enough information to allow the reader a general understanding of the TIMES modeling system, its VEDA interfaces, the EFDA scenarios and databases, and typical results obtained from the model. The report is also accompanied by several
annexes containing detailed additional model and database descriptions, and user’s guides for the VEDA Shell and report writer. This rest of the report includes a general description of the TIMES model, the particularities of the EFDA model, some demonstration results, and a conclusion.

**Regions**

The EFDA world TIMES model is disaggregated into 15 regions (Table 1). Each regional model is a complete, self-contained TIMES model. In addition, the 15 models are hard-linked by several energy and emission permit trading variables. The database also distinguishes between the trading of oil and petroleum products produced by OPEC and non-OPEC regions.

**Table 1. List of regions in World-TIMES**

<table>
<thead>
<tr>
<th>Code</th>
<th>Region</th>
</tr>
</thead>
<tbody>
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<td>AFR</td>
<td>Africa</td>
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<td>AUS</td>
<td>Australia-New Zealand</td>
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<td>CAN</td>
<td>Canada</td>
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<td>Central and South America</td>
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<td>China</td>
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<td>Mexico</td>
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<td>Middle-East</td>
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<tr>
<td>ODA</td>
<td>Other Developing Asia</td>
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<td>SKO</td>
<td>South Korea</td>
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<td>USA</td>
<td>United States</td>
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<tr>
<td>WEU</td>
<td>Western Europe</td>
</tr>
</tbody>
</table>


The details of the database structure (list of demands, types of technologies and fuels, naming conventions, etc.) are presented in an annex to the report. The complete database (including the values of the technological and economic parameters) is best accessed via the VEDA-FE browser, as it contains an exceedingly large amount of quantitative information.

**The construction of the EFDA Demand Scenarios**

A demand scenario is constituted by a set of annual demands for energy services, for each region and each period of the planning horizon. The demand projections do not purport to be forecasts. Instead, following the approach of the IPCC SRES group, we construct a set of reference demands that are a coherent set of projections forming a particular view of the future. The approach taken to construct the reference demand scenario consists of four steps, listed and depicted below:

- **Step 1**: define a set of socio-economic drivers such as GDP, Population, Number of Households, etc., and assign a driver to each particular demand category (assigned drivers may be region and time dependent);
- **Step 2**: obtain projections for each driver for each region, each time period;
- **Step 3**: Choose elasticities of each demand to its assigned driver (may be region and time dependent);
- **Step 4**: Compute each demand.

**Reference scenario**

The reference scenario represents a situation with the following main characteristics: Population growth is moderate during the entire century, with a marked slowdown after 2050. This corresponds to the assumptions of the IPCC B2 storyline. GDP growth (as calculated by the GEM-E3 model) is strong, especially in less developed countries. There is a strong convergence in the developments of developed and less developed countries by the end of the century. This GDP growth structure is compatible with a continued globalization of the world economy, and with strong technical progress. Biomass availability is large, and nuclear capacity is allowed to grow significantly over the horizon.

Moving from the Reference scenario, development of alternate scenarios is depicted in the figure below.
Alternate CO2 TAX scenario

The only additional assumption of the alternate scenario is that a global CO2 tax is applied to all CO2 emissions from the global energy system. The level of the tax rises linearly from $0/ton CO2 in 2010 to $1000/ton in 2100. It should of course be remembered that the application of such a tax may provoke a decrease in energy service demands, endogenously determined with the model. Therefore, it is also implicit that GDP growth is (endogenously) negatively affected by the tax.

Results for the CO2 tax scenario

The main observations are as follows:

Global CO2 emissions are reduced by 35% in 2050 and by 60% in 2100, compared to the Base case. This results in global emissions growing by less than 60% between 2000 and 2100 in the tax scenario, versus more than quadrupling in the base case.

The electricity sector’s emissions are the most affected by the tax, a result that confirms many past studies. In our runs, the emissions from this sector are reduced by 89% in 2100, relative to the base case. Indeed, electricity sector emissions decrease by about 65% from 2000 to 2100, whereas they increased by close to 500% in the same period in the base case.

Emissions from other sectors are less affected than electricity sector emissions, but still quite significant in the case of industry and transports. Industrial emissions are reduced by 36% in 2050 and 37% in 2100, transport emissions by 7% in 2050 but 28% in 2100. Upstream emissions are less affected (~10% in 2050 and ~6% in 2100), and so are commercial emissions (~7% and ~16%,...
respectively in 2050 and 2100). Residential sector emissions are almost the same in both scenarios.

The electricity sector abandons coal and oil almost entirely by 2050, and replaces them by gas and nuclear, plus some renewables. In 2100, this substitution is even more pronounced, and coal is completely eliminated from the slate of fuels in the electricity sector.

Summary

The report summarizes three aspects of the EFDA World TIMES project. The first aspect concerns the description of the generic TIMES model developed by ETSAP and used for this project. The second aspect relates to the software tools used for the user-friendly management of the model’s inputs and outputs. These tools are based on the advanced versions of VEDA (front-end and back-end) especially enhanced for this project. They are particularly adapted to the handling of very large, multi-regional databases as exist in the EFDA TIMES model. The VEDA software is described, and the complete user’s guides appear as annexes. The third aspect focuses on the particular implementation of TIMES satisfying the particular EFDA requirements. The EFDA model is described, and a more complete description of the EFDA Reference Energy System constitutes an annex to the report. In order to illustrate the functioning of the model, two sample runs were conducted on two contrasted scenarios, and their results are presented.

This phase of the project should normally be followed by a more intensive utilization of the model to explore a variety of scenarios. The creation of new scenarios would be adapted to the particular issues of interest to EFDA, whether they be of a technological or socio-economic nature. There is simply no limit to the variety of such scenarios. It is however our strong belief that scenarios should be constructed in a coherent and economically consistent manner.

In summary, the value of this phase of the project would be greatly increased by a thorough utilization of the model. There is no doubt in our minds that during this process, many changes will be brought to the model, in the form of a more complete set of technologies, and more generally, the enhancement of the reference energy system.

“Climate Policy Scenarios for Stabilization and in Transition“ [ETSAP Participation in EMF-22]

ETSAP decided to be an active participant in the 22nd Forum of the Energy Modeling Forum, which started in 2004 and will extend over three years. The EMF-22 corresponds very tightly to the objectives of the current and next ETSAP annexes, and constitutes an ideal context for the active development and application of the World TIMES model. Richard Loulou (KANLO, France, and GERAD, Canada) is the ETSAP representative on EMF-22 and has participated in the initial phases of the program of work, leading to the November 2004 meeting of EMF-22, where he presented the World TIMES model and some recent applications on behalf of ETSAP.

The activities done in 2004 included:

a) June to December 2004: Improvements and additions to the World TIMES database (Richard Loulou and Maryse Labriet, with inputs from Amit Kanudia). In particular, the following tasks were accomplished:

- Addition of a hydrogen module (production, consumption by sectors);
- Capture and Storage of CO2;
Harmonisation of electricity generating technologies;
Review and modification of natural gas and coal trading between the 15 regions, and
General review of oil production and oil reserves.

b) Preparation of participation and participation in the EMF-22 kick-off meeting (November 10-12 2004 in Brussels). Presentation of a set of scenario results by Richard Loulou. Contacts taken with EMF-22 officials to secure access to EMF data and results from previous EMF projects (EMF-19 and 21), in particular Marginal Abatement Curves for non CO2 Greenhouse Gases, and CO2 sequestration by Forests.


The program of research of EMF-22 for 2005-2007 includes the following main activities:

1. Develop GHG abatement hedging strategies for climate stabilization in the face of uncertainty
2. Include all main GHG’s in the analysis of stabilization strategies
3. Develop new base cases for economic, energy, technology and environmental indicators
4. Investigate black carbon and other new sources of radiative forcing

ETSAP plans to be particularly active in the first two activities, but will also benefit from the research results obtained by EMF-22 from the other two activities. The full participation of ETSAP will require developing a tool for simulating hedging strategies in TIMES, which could take the form of a Stochastic Programming option for the model.

The advantages for ETSAP of participating in EMF-22 include those listed below.

ETSAP will promote TIMES as a valuable tool for global energy/environment analyses.
The ETSAP community would win a wider general audience and recognition, via EMF conferences, EMF publications, and the diffusion of EMF results to the IPCC.
Participation in EMF-22 is perfectly timed to capitalize on Annex IX projects such as EFDA, Climate Module, etc., and on the expertise and team work experience gained there.
Participating in EMF would provide a strong incentive to test and further improve the TIMES model, which in turn would bring benefits to all model users, and primarily to ETSAP members and outreach modelers.
Using the TIMES model for EMF studies would reinforce the “bottom-up”, technology-oriented view of the world to the global climate change issues and solutions, a view currently taken by a very small minority of EMF models. In this respect, a closer look at the terms of reference of EMF-22 shows that several aspects of the study would greatly benefit from a detailed, technology oriented model such as World-TIMES.

Asia-Pacific Economic Cooperation (APEC) [ETSAP Partners from Australia, Japan and the US, plus China]

The objective of this work was to enhance the energy-modeling capabilities in APEC Member Economies with respect to new and renewable energy technologies and to work with the participating member teams to perform case studies on the effects of different penetration rates of
renewable technologies. The MARKAL modeling teams from Australia, China, Japan, and the United States agreed to participate in the study. The participants included Gary Goldstein, (coordinator, International Resources Group USA); Pat Delaquil (Clean Energy Commercialization, USA); Barry Naughten (Australian Bureau for Agriculture and Resource Economics, Australia); Wenying Chen (Tsinghua University, China); Osamu Sato (Japan Atomic Energy Research Institute, Japan), and John Lee (Brookhaven National Laboratory, USA).

A generic database of renewable technology characterizations, derived from the most recent data available from the US NREL and PERI as well as US DOE, was developed that may be used in APEC as well as non-member countries.

In the next step, the characterization (technical performance and costs) of renewable electric-generating technologies currently used in the participating-Member MARKAL models was examined. The APEC characterizations fell toward the optimistic end but were generally within the range of what was found in the various Member models. The renewable technology characterizations to be used in the assessment were then assembled for each database, refined for local conditions in each of the Member Economies, and structured for being conveniently incorporated into the existing Member MARKAL models.

A series of scenarios looking to establish increasing percentages of electric generation from renewables were run, with and without modest reductions in future carbon dioxide (CO$_2$) emissions. Owing to the cost effectiveness of the selected technologies (especially after 2020), some level of adoption of these technologies was seen even without imposing any renewable portfolio goals.

Over the entire model period, the overall impact on the energy system of modest renewable targets was an initial increase in costs, but the cost impact was surprisingly small. In addition, MARKAL results with the technology characterizations in the database showed the following benefits to each of the Economies:

1. Improvement in long-term energy security, as characterized by lower energy imports;
2. Slight change in economic conditions, as characterized by modest increases in total system cost over the modeling horizon;
3. A lower cost of meeting any CO$_2$ reduction targets; and
4. Reduced environmental pollution—both in CO$_2$ (graph below) and in local air pollutants.
In the above figure the APECR+ indicate the inclusion of the APEC renewable technologies with %-electric from renewables, with the CO2 scenarios adding a modest (% below Reference levels in 2030) limit of CO2. [Note, not all scenarios were run for all countries.] As can be easily seen, the APECR scenario alone have a direct and substantial impact on the level of CO2 (and other) emissions. When looking at the costs, not surprisingly the APECR technologies also enabled the CO2 limits to be met more cost-effectively as well.

This assessment highlights the potential role of renewable resources and energy technologies within selected APEC Economies, and demonstrates the merits of using a common framework to examine APEC energy/economy issues. This endeavor represents only an initial foray in this arena for APEC, with other potential areas for future studies such as alternate fueled vehicles, hydrogen potential, energy security and other pressing issues of interest all the APEC community under consideration.

Table 1. APEC Member Economies and MARKAL Capabilities

<table>
<thead>
<tr>
<th>Economy-level MARKAL models</th>
<th>MARKAL models under development</th>
<th>No MARKAL Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Malaysia</td>
<td>Brunei Darussalam</td>
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<tr>
<td>Canada</td>
<td>New Zealand</td>
<td>Chile</td>
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<tr>
<td>China</td>
<td>Thailand</td>
<td>Papua New Guinea</td>
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<td>Hong Kong, China</td>
<td>Viet Nam</td>
<td>Peru</td>
</tr>
<tr>
<td>Indonesia</td>
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<td>The Russian Federation</td>
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<td>Philippines</td>
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<td></td>
</tr>
<tr>
<td>Chinese Taipei</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

European Union NEEDS (New Energy Externalities Development for Sustainability) project developing a 25 member states pan-European energy model using TIMES [Various EU ETSAP Partners and other EU institutions]

Energy Systems Modeling

Important advances have been made in the ability to analyze global, national and local issues and to support the formulation of policies using comprehensive partial equilibrium models. The IEA-ETSAP bottom-up technology oriented models generators are powerful modeling tools to support long term energy planning, ensuring the consistency of EU strategic issues with national policies, as well as cross country consistency. Moreover their inbuilt flexibility ensures the integration of the models with LCA (a life-cycle analysis) and ExternE (externality evaluation) methodologies.
Using the key base data received from the other research streams for each energy security, environment protection and economic development target, this stream calculates equilibrium quantities and prices and provides them to the other streams iteratively, until compatible values are reached.

The work undertaken here is relevant mainly because it generates and makes available a unique partial equilibrium economic model of the EU energy system built upon the trade equilibrium of 25 MS/NAS models having the following properties:

- Long term time horizon (2050, by 5-year step), to support the definition of long term strategies, taking into account different standards of energy devices and technologies development;
- High technological detail, in energy supply and end-use sectors including endogenous technology learning, locally and globally;
- Basic standard modeling in which exogenous and endogenous variables are kept separated;
- Reaction to new policies with different equilibrium, interacting with ExternE and LCA results;
- Full representation of all energy vectors included in the detailed energy balances;
- Break down of demands for energy services, each one dependent on its own price;
- Based on life cycle energy costs on long term perspective with clairvoyant or myopic decision framework (which makes policy simulation easier);
- Evaluation of policies at technology level (integration of the external cost into the cost of a technology) and at a more energy system level (with the internalization of externalities in the decisions of the economic agents) both on country level and EU wide perspective with the possibility of adding cross country policy bounds (e.g. iron and steel industry refineries);
- Methodological consistency with other important global energy modeling efforts (IEA-Paris, US-EIA);
- Capability of analyzing the impacts of different policies and price mechanisms (such as different tax or subsidy schemes for commodities and technologies), and trade-off between security and environment.

According to different policy options and exogenous scenario assumptions for the time horizon under analysis this research will provide:

- Equilibrium quantities and prices of energy vectors (primary energy and secondary fuels), energy technologies, emissions (GHG and local air pollutants) and other burdens.
- Evaluation of the expected long-term results of LCA (dynamic, regionally and policy dependent fuels mix, technologies mix, demand levels);
- Evaluation of the expected long-term results of ExternE (Dynamic, regionally and policy dependent prices for energy – material commodities and fuel mixes), and different levels of consumer surplus and welfare.

Another important set of results will deal with the analysis of different policy and measure schemes in order to support national policies, providing a common basic framework for the definition of EU strategies:

- Assessment of target-based policies (e.g. setting thresholds for CO2 emission);
assessment of regulatory instruments and price mechanisms for reducing GHGs and local atmospheric pollutants;

trade-off between climate and economy analysis of long-term trends, taking into account the present and future availability of energy technologies, their costs and performance;

internalization level of external costs in order to reach policy goals (Trade-off external / direct costs, separated between climate change and others), and

development of coherent long-term strategies and sound climate protection policies on national and Pan-European level.

Furthermore, this stream makes available a tool that is valuable per se. In fact the country databases / models, mutually in equilibrium through the trade of the most important energy – environment – material commodities provide a tool capable of performing comprehensive energy systems analyses in the MS and NAS in order to support the formulation of energy/environmental/economic policies and decision making both at national and Pan-European level. This tool will be open and updateable without changing the software, and accessible to other researchers.

Energy Technology Roadmap and Stakeholders Perspective

The general objectives of this research are: (1) To identify, discuss and analyze the terms and conditions (including barriers and enablers) for an effective formulation and implementation of long term strategies based on the internalization of external costs; (2) To broaden the basis for decision support beyond the assessment of external costs by examining the robustness of results under various stakeholder perspectives. From the technical point of view the stream should also contribute to the integration of results generated by other analytical tasks within the project.

The specific objectives are to:

address and evaluate sustainability of the candidate technologies and/or technology mixes taking into account their performance under economic, environmental and social criteria;

investigate the sensitivity of results of sustainability assessment to specific patterns in stakeholder preferences;

explore to what extent the stakeholders accept the assessed external costs as the basis for internalization;

examine possible differences in the ranking of options established by employing alternative approaches to the evaluation, and

identify most robust technological options and prioritize developments for the promising but less robust ones.

External cost estimates generated using the “impact pathway approach”, if accepted by the stakeholders, is highly attractive as directly comparative aggregated measures of environmental system performance. It has been proposed by some authors that the total (internal plus external) system-specific costs of energy supply can serve as an integrated relative indicator of sustainability. The use of total costs as an aggregate measure of sustainability performance is not universally accepted. The balance between strictly economic and environmental performance may shift or vary between stakeholders and countries. The social dimension, which plays a central role in the decision process, does not come to the surface when the systems ranking is solely based on total costs. As an example, nuclear wastes and hypothetical severe accidents contribute marginally to the external costs estimated, but nuclear power remains controversial in some countries. Also, depending on the stakeholder perspective, less controversial issues such as resource depletion may not be adequately reflected in total costs. Finally, though some specific estimated impacts (such as mortality and morbidity) are considered reasonably robust, there may be no consensus on their monetization (and in particular, the value of reduced life spans measured...
by Years of Life Lost, or YOLLs). This implies that: (1) Acceptability of results based on external cost assessment by the Stakeholders is an issue; (2) Complementary evaluation approaches, allowing appropriate level of stakeholder involvement need to be employed.

The framework will facilitate the assessment of a Technology Roadmap aimed at providing a portfolio of sustainable electricity supply options under consideration of stakeholder views. A Technology Roadmap based on somewhat different principles has been developed in the USA but it is not transferable to the European situation and not compatible with the goals of energy policy in EU. First, there are distinct differences in consumer behavior, availability of fuels, dependence on imported fuels, environmental agreements and legislation, and in commitment to Greenhouse Gas (GHG) emission reductions. Second, the effect of enlarged EU needs to be considered. Third, the externality issues and the interplay with stakeholder perspectives are to be focused on, which was not the case in the US study.

This research will examine the robustness of outcomes of external cost assessment and other alternative evaluation approaches as well as the robustness of the identified, seemingly attractive electricity supply strategies. For this purpose potentially important factors that influence the decision-making process but are not in focus of the assessment of external costs will be considered. Characterization of technologies based on the knowledge generated within other research will be supplemented according to the needs defined by the evaluation criteria of interest. The impact of stakeholder preferences on the evaluation will be mapped based on the input from stakeholders and on patterns observed in the energy debate. The evaluation may be carried out on the level of individual technologies and possibly also on the level of electricity mixes defined the energy systems modeling discussed above. Multi-criteria decision analysis (MCDA) will be employed to perform the mapping of options, thus allowing use of the technical knowledge in a structured process that is also open to accounting for values. The results of such mapping will be compared with those obtained from the total cost assessment, focusing on reasons for possible discrepancies. Most robust options exhibiting stable performance, with low sensitivity to changes in preference profiles will be identified and best opportunities for improving the performance of promising but less robust technologies will be explored. Apart from providing advice and value-based inputs to the sustainability assessment, the acceptability of the results of external cost assessment and its use in decision-making will be investigated.

It is anticipated that the NEEDS modeling framework will provide a consistent EU-wide framework for examining energy, environment and economic issues, will taking into consider life-cycle costs and externalities, for some time to come.
Summary of ETSAP Partner Activities

**Belgium**

Impact of opening the Belgian electricity market: an analysis with MARKAL [CES KULeuven]

Roel Claes, Denise Van Regemorter conducted an assessment that examines whether the liberalization of the electricity market can result in improvements of environmental conditions and thus reduce the cost of climate policy in Belgium. For this the existing Belgian MARKAL model is extended with three countries (France, Germany and The Netherlands) in such a way that Belgium can trade electricity with these countries. The simulation results show that, in the case of no restrictions on the CO₂ emissions, the impact of liberalizing the electricity market is very small. This can largely be explained by the assumptions in the model, i.e. perfect competition on the energy market and relatively similar production cost structure in all countries. Opening up to trade in electricity with CO₂ emission restrictions results in large imports from France to Belgium. However this result depends on the climate policy and the technological options and their cost in the neighboring countries.

Introduction

In the past electricity production in the EU countries was organized as a regulated monopoly. Over time it became clear that it was possible to allow competition to develop in this industry. Forerunners such as the United Kingdom and most Scandinavian countries made this change some years ago. In the European Union, it was not until 1999 that the electricity market was opened to competition.

The opening of the electricity market was seen as an important tool to improve the efficiency of the electricity production industry. Competition would lead to lower prices and a better use of energy resources. This is of particular importance given the climate change commitments of the EU under the Kyoto protocol which implies for the EU a reduction of the greenhouse gases (GHG) emissions of 8% by 2008-2012 compared to the 1990 level. The power sector is a major source of emissions accounting for around 30% of EU CO₂ emissions. It is not clear at this stage to what extent the constraint on GHG emissions could influence trade in electricity. There are many scenarios which demonstrate that electricity trade could help to meet Kyoto targets. On the other hand it may well be that some Member States face problems in reconciling both trade and environmental objectives related to Kyoto.

In Belgium, the electricity market has been characterized by a regulated monopoly until liberalization and is still very concentrated. Because of Belgium’s strategic location, cross-border trade of electricity and the energy policies of neighboring countries can affect its own energy policy regarding competition in energy markets. Regarding climate change Belgium is required to reduce its greenhouse gas emissions by 7.5 % in the period 2008-2012 compared to 1990. Energy-related greenhouse gas emissions have grown significantly during the 1990s, and are currently about 15% higher than in 1990. Here also the opening of the electricity market can have an impact.

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11 Impact of opening the Belgian electricity market: an analysis with MARKAL
The liberalization of the electricity market may lead to a change in the composition of the technologies employed and in electricity trade. These changes can also lead to changes in GHG emissions. However, it remains an open question whether emissions will increase or decrease for a given country and for all countries involved. The answer to this question is important for fixing the national policy measures to reach environmental targets.

This analysis uses the MARKAL model to examine the implications of the liberalization of the electricity market in the long term for Belgium regarding the cost of energy, the mix of technologies and the environmental cost. For this the existing Belgian MARKAL database was extended with the electricity sector of three countries (France, Germany and The Netherlands) such as to allow trade of electricity with its neighboring countries.

The database
The Belgian database covers the entire energy system (electricity sector, residential and service sector, industry sector and transport sector). For the other countries only the electricity market is modeled. The parameters for new technologies in the three added countries are taken from the Belgian database. This means that all the countries have power plants with the same characteristics, they differ in terms of demand in electricity, existing capacity of the power plants and potential for hydro and wind energy.

The demand for electricity in the countries other than Belgium is divided into two sectors: industry and residential sector.

The price elasticity of the industrial and residential demand is assumed -0.3 as for Belgium. The growth of the demand in the industry is assumed to be 1.2%/year and in the residential sector 1.9%/year in the reference case in the three countries.

The electricity sector in the neighboring countries is modeled at the level of wholesale markets. Each country has its own wholesale market which is connected to the Belgian market by a transmission network. In 2000, there exists a connection between Belgium and France and between Belgium and The Netherlands. There is no connection between Belgium and Germany but investment in a transmission line is possible. The cost of investment in transmission lines was derived from the literature and different steps are considered in function of the distance.

A nuclear phase out is assumed in Belgium, Germany and The Netherlands. France can invest in new nuclear power plants. It should be mentioned that given the investment cost and efficiency assumptions for coal and nuclear power plants, the two power plants are very close in terms of annualized cost when no CO2 constraint is imposed.

Results of the MARKAL simulations
Two scenarios are considered. The first one investigates the impact of opening the electricity market without CO2 emission constraints and the second one examines the implications of the liberalization of the electricity market with CO2 emission restrictions. The effect of trade in electricity (without a CO2 constraint) is investigated by comparing the baseline scenario (a business as usual scenario without trade) with the trade scenario where trade between Belgium and the other countries is possible.

In the CO2 scenario a CO2 emission bound is added corresponding to the Belgian Kyoto target (a CO2 emission reduction of 7.5% in the period 2008/2012 compared to the 1990 level). No emission constraint is imposed on the other countries in a first step. The trade in electricity in this
scenario is fixed to the level of the trade scenario. The implications of the liberalization of the electricity market will be studied by comparing the $CO_2$ scenario with the $CO_2 + trade$ scenario where trade between Belgium and the other countries is possible. In a second step different reduction target are considered for the other countries.

**Impact of opening the electricity market**

The impact of opening the electricity market is investigated by comparing the baseline scenario (without trade) with the trade scenario (where trade in electricity between Belgium and the other countries is possible).

The baseline scenario is a business as usual scenario. There is no trade between Belgium and the other countries and there is no constraint on the $CO_2$ emissions. Table 1 shows that electricity in Belgium is mainly produced by nuclear power plants until the nuclear phase out (2020). Coal production decreases in the period 2005-2010 because the old coal plants are being closed. With the nuclear phase out coal power are again penetrating as a substitution for nuclear power: after 2010 most investments are made in new coal plants because this is the cheapest technology. No investments are made in wind power.

### Table 1: Electricity production in Belgium in the baseline scenario (TJ)

<table>
<thead>
<tr>
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<tr>
<td>coal</td>
<td>41.9</td>
<td>29.0</td>
<td>13.3</td>
<td>79.5</td>
<td>103.9</td>
<td>236.7</td>
<td>333.2</td>
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<td>nuclear</td>
<td>153.2</td>
<td>153.2</td>
<td>153.2</td>
<td>106.3</td>
<td>106.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>STAG</td>
<td>2.6</td>
<td>0.0</td>
<td>65.2</td>
<td>59.3</td>
<td>53.8</td>
<td>53.3</td>
<td>0.0</td>
</tr>
<tr>
<td>gas turbine</td>
<td>29.1</td>
<td>68.5</td>
<td>4.1</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>hydro</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
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<tr>
<td>wind</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>CHP</td>
<td>19.3</td>
<td>38.4</td>
<td>62.7</td>
<td>67.9</td>
<td>65.7</td>
<td>59.4</td>
<td>57.2</td>
</tr>
<tr>
<td>other</td>
<td>34.5</td>
<td>1.0</td>
<td>2.6</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
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<tr>
<td>TOTAL</td>
<td>283.2</td>
<td>292.6</td>
<td>303.6</td>
<td>318.7</td>
<td>334.4</td>
<td>354.0</td>
<td>395.0</td>
</tr>
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<td>Export</td>
<td>1.4</td>
<td>1.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Import</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

In the trade scenario possibility of trade in electricity is introduced. There are no great differences compared to the baseline scenario. Imports in 2010 and 2015 reduce the domestic production with STAG power plants but in the periods thereafter there is no significant trade. However electricity production increases and the shift towards coal away from gas, observed in 2030 in the baseline, is observed already in 2020.

It is cost effective to trade electricity in 2010 and 2015 mostly because it allows more flexibility in the investment in new capacity and around these periods installed capacities are beginning to be scrapped. However there is not sufficient difference between countries in the structure of a cost efficient energy system to induce a full shift to import/export, contrary to what was observed for the Nordic countries. No country has a cheap source of energy available. Moreover we have assumed the same cost for new technologies in all countries and the cost of nuclear and coal power plants are very close. The allocation of the demand by time slice should also be further examined, differences between countries for this allocation could be an opportunity for trade and they are not considered here.
Introducing trade decreases slightly the electricity price in Belgium, around 1% for residential use and 2% for industrial use and this increases the electricity demand. In the residential sector the increase is mainly due to an earlier shift to electric water heating (at night) which in the baseline is only cost efficient in 2030. The price decrease can be explained by the reduction in the investment cost due to a weaker peaking constraint. Allowing for trade contributes to the reserve margin needed to satisfy the peak and limits thus investment in Belgium.

In terms of environment, opening the electricity market is not beneficial: the CO$_2$ emissions in Belgium are increased from 2015 onwards because of the higher use of coal power plants.

In terms of welfare, trade in electricity causes a small increase in welfare: the discounted total surplus increased by 600 million euro compared to the baseline scenario which represents approx. 0.2% of the total system cost.

The overall impact remains rather small and this can be explained by two elements:

1. MARKAL assumes perfect competition and therefore opening the electricity market does not allow any gain from reducing the strategic behavior of the actors on the market, and
2. the assumptions in the database regarding the cost of future technologies (similar in all countries) and no potential of relatively cheap energy source in one of the countries.

**Impact of opening the electricity market with an environmental policy**

The effect of opening the electricity market, when a CO$_2$ policy is in place is investigated by comparing the CO$_2$ scenario (with fix trade) with the CO$_2$ + trade scenario (where trade in electricity is possible).

In the CO$_2$ scenario trade is kept fixed (exogenously) at the level of the trade scenario and a bound of 7.5% compared to the 1990 level is put on the CO$_2$ emissions in 2010 in Belgium (the Belgian Kyoto target). No CO2 constraints are imposed on the other countries.

With the CO2 constraint and no trade, electricity demand is decreasing and there is a shift in the technologies used. The changes in electricity production in Belgium are given in Table 2. STAG plants are replacing the coal power plants. Because of the cost efficiency of the STAG when a CO2 constraint is imposed, investment in this technology already starts in 2005 instead of investment in gas turbines in the trade scenario. Wind power and hydro are becoming more cost efficient but their contribution remains small because of the small potential in Belgium.

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
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<tbody>
<tr>
<td>coal</td>
<td>-0.5</td>
<td>0.0</td>
<td>-75.1</td>
<td>-154.3</td>
<td>-300.4</td>
<td>-336.4</td>
</tr>
<tr>
<td>nuclear</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>STAG</td>
<td>33.2</td>
<td>30.4</td>
<td>50.3</td>
<td>61.8</td>
<td>191.5</td>
<td>240.7</td>
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<tr>
<td>gas turbine</td>
<td>-36.5</td>
<td>-30.0</td>
<td>-35.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>hydro</td>
<td>0.0</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>wind</td>
<td>0.0</td>
<td>1.4</td>
<td>14.0</td>
<td>15.6</td>
<td>15.6</td>
<td>15.6</td>
</tr>
<tr>
<td>CHP</td>
<td>2.4</td>
<td>-4.3</td>
<td>5.2</td>
<td>18.3</td>
<td>30.3</td>
<td>24.2</td>
</tr>
<tr>
<td>other</td>
<td>0.0</td>
<td>-2.6</td>
<td>-1.0</td>
<td>-1.0</td>
<td>-1.0</td>
<td>-1.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-1.5</td>
<td>-4.4</td>
<td>-41.1</td>
<td>-59.0</td>
<td>-63.4</td>
<td>-56.3</td>
</tr>
</tbody>
</table>
When trade is allowed, the impact depends on the CO2 policy imposed in the neighboring countries. No specific climate policy is considered here for the other countries because the complete energy system is not modeled. Instead, to explore the impact of CO2 constraints on the results for Belgium, we consider different reductions for the CO2 emissions in the other: 0%, 5%, 10% and 15% compared to the reference (with trade). These scenarios are more exploratory than policy oriented.

When no CO2 constraint is imposed on the neighboring countries \((CO_2 + trade\ scenario)\), allowing for trade is entirely beneficial for Belgium, there is nearly no change in welfare compared to the trade scenario. Comparing to the CO2 scenario without trade the welfare increases with 2997.3 million €. Instead of investing in STAG, wind energy and CHP, the imports are increasing representing respectively 15% and 40% of total electricity consumed in 2010 and 2020.

Table3: Electricity production in Belgium with climate policy and with trade (difference in TJ compared to CO2 scenario without trade)

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>nuclear</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>STAG</td>
<td>7.5</td>
<td>-30.9</td>
<td>-28.2</td>
<td>-33.2</td>
<td>-148.8</td>
<td>-185.9</td>
</tr>
<tr>
<td>gas turbine</td>
<td>-8.5</td>
<td>4.4</td>
<td>0.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>hydro</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>wind</td>
<td>0.0</td>
<td>-1.4</td>
<td>-12.6</td>
<td>-14.2</td>
<td>-14.8</td>
<td>-2.2</td>
</tr>
<tr>
<td>CHP</td>
<td>0.0</td>
<td>2.5</td>
<td>-7.7</td>
<td>-23.3</td>
<td>-29.5</td>
<td>-20.5</td>
</tr>
<tr>
<td>other</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-1.0</td>
<td>-25.4</td>
<td>-47.9</td>
<td>-70.7</td>
<td>-193.1</td>
<td>-208.6</td>
</tr>
<tr>
<td>Export</td>
<td>0.0</td>
<td>-1.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Import</td>
<td>0.0</td>
<td>28.6</td>
<td>99.0</td>
<td>132.7</td>
<td>260.7</td>
<td>265.7</td>
</tr>
</tbody>
</table>

When tighter bounds are imposed on the other countries the benefit for Belgium is reduced. The consumer/producer surplus is reduced and the marginal abatement cost increases, though this remains limited because the CO2 reduction imposed in the other countries is limited compared to the Kyoto target imposed in Belgium. STAG and CHP are replacing the imports.

Table4: Change in total discounted surplus (million €) and marginal abatement cost of CO2 (€/ton) in Belgium

<table>
<thead>
<tr>
<th></th>
<th>Discounted surplus</th>
<th>CO2 marginal abatement cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>No trade</td>
<td>-2997.3</td>
<td>48.6</td>
</tr>
<tr>
<td>With trade and 0% reduction in neighboring countries</td>
<td>0</td>
<td>38.4</td>
</tr>
<tr>
<td>With trade and 5% reduction in neighboring countries</td>
<td>-365.6</td>
<td>39.3</td>
</tr>
<tr>
<td>With trade and 10% reduction</td>
<td>-470.8</td>
<td>40.9</td>
</tr>
<tr>
<td>With trade and 15% reduction</td>
<td>-591.7</td>
<td>39.6</td>
</tr>
</tbody>
</table>
Imposing a more severe constraint on the CO2 by assuming for the other countries a stabilization of the CO2 emissions compared to 1990 increases the loss for Belgium up to 860 million €, which is still less than when there is no trade. The availability of nuclear power plants in France explains partly this result. When a nuclear phase out is also imposed in France the loss for Belgium is increased with 25% remaining however lower than when there is no trade.

Opening the electricity market when a CO2 policy is implemented allows reducing the cost of this policy. Though trade is always beneficial with the scenario tested, the reduction is however very dependent on the CO2 policy implemented in the other countries.

Conclusion

This assessment explores how to integrate electricity trade in the MARKAL model and examines the impact of the liberalization of the electricity market on the cost of the energy system with and without climate policy for Belgium. To do this the model was adapted to allow for investment in transmission capacity and extended for the electricity sector to France, Germany and the Netherlands.

The impact of liberalizing the electricity market in the case of no CO2 emission constraints is small. This can be explained by the relatively similarity in the structure of the energy system in the different countries, the absence of a cheap source of energy in one country and the perfect competition assumptions of MARKAL. This is in line with the results of the studies for the Netherlands and for the Nordic countries.

Opening the electricity market in the case of emission restrictions on CO2 in Belgium results in more imports of electricity and therefore decreases the cost of the CO2 reduction. However this gain decreases when CO2 constraints are also imposed in the other countries. It depends also partly on the possibility of having nuclear power plants in France.

This study is still at a preliminary stage and the research will continue with the new model MARKAL/TIMES which allows more flexibility. Special attention will be put on the contribution of import and export to the peak equation and to the baseload equation because of the great sensitivity of the model and of the results to these aspects. The possibility of trade in emissions will also be considered.

Canada

Various activities of the KanORS, HALOA and the associates on the Canadian MARKAL/TIMES model team are mentioned in the International Studies, Collaborations, and Contributions section of this report.

Finland

Development of the Finnish National TIMES Model and Case Studies Utilizing the Model [Technical Research Center of Finland (VTT)]

After the adoption of the Kyoto Protocol in 1997 there was a large demand for a technology program, which could help Finnish companies in the forthcoming strategic decisions in changing operational environment. Therefore, a national technology program, “Technology and Climate Change (CLIMTECH),” was established in Finland.
The primary energy supply in Finland is mainly based on oil, coal, gas and nuclear energy, and on biomass fuels. In electricity, nuclear energy has a high share, but even larger is the total contribution of combined heat and power (CHP) in both industries and communities. Hydropower and imports of electricity are also significant.

The forest industry produces by-products usable as fuels, such as bark, sawdust and spent pulping liquors. Finland also has a large industry that manufacturer equipment and components for energy production and use.

The modeling methodology is MARKAL combined with the EFOM approach, further enhanced as the method continues to be developed. The new TIMES framework is the replacement for MARKAL and EFOM. These models can answer numerous policy and planning questions. The model version currently in use at VTT is a single-nation model for Finland (Lehtilä & Pirilä). Exports and imports of energy carriers are accounted for by supply and demand curves, which are specified by exogenous parameters. The new TIMES-version of the model commissioned in 2003 is planned to be expanded into a multi-nation version covering all Nordic countries.

The Finnish Meteorological Institute estimated the impacts of climate change on energy production by 2030. The most important changes for energy production in Finland were found in hydropower availability. Increased winter precipitation and more frequently snowmelt periods were estimated to increase the total annual hydropower production. Warmer summer periods were estimated to enhance the production potential of peat by about 17-24%.

Energy intensities fell rapidly during 1994-2000 due to efficiency improvements and structural changes. Recent baseline projections in Finland indicate that total primary energy consumption will increase to slightly over 1500 PJ in 2010. Due to the measures needed to reach the Kyoto emissions target, growth will be reduced to about 1.2% per annum. Decoupling of primary consumption from economic growth thus appears to be fully achievable in Finland by 2020.

Combined heat and power production increases in all scenarios, but may stabilize at the level of 40%. Wind generation increases to about 1 TWh by 2010 and to 3-12.5 TWh by 2030. The optimistic scenario produces the largest expansions in wind power due to declining production cost of advanced offshore wind turbines. Existing technologies based on steam and gas turbines in CHP continue to play a major role along with new technologies until 2030. Biofuel gasifiers in large steam turbine plants would become attractive by 2020. Gasification technologies appear to have significant potential in the efficient and flexible use of solid biofuels. The production of pyrolysis oil could open up considerable potential to reduce oil consumption in district heating. With rapid development, bio-oil could become competitive by 2010 and could have a major market share by 2020.

Demand for heat in both new and old buildings is projected to decrease due to global warming, but also through demographic changes in population distribution, stricter building codes and subsidies for renovation. Total consumption of heat will decrease. Biofuel-based heating and electric heating will grow, while oil heat declines. Through the implementation of biotechnological methods like fungal pre-treatment of chips (biopulping) and enzyme-aided refining, electricity consumption can be reduced.

Emissions of fluorinated gases (HFCs, PFCs and SF6) are projected to increase rapidly in Finland due to the increasing use of HFCs as substitutes of ozone depleting refrigerants and because of the expanding use of commercial refrigeration and air-conditioning system (Oinonen & Soimakallio, 2002). In the baseline scenario total GHG emissions would increase about 17% from the 1990 level by 2010, and about 30% by 2030. Emissions from energy production and transport have the strongest tendency to increase in Finland due to increasing electricity use and transportation volumes. Potential impacts of emission trading on the Finnish energy system were
analyzed. The market price of emission allowances was assumed to be 10€ /tCO2 in 2010 and 30€ in 2030. In the conventional scenario it appears to be profitable to purchase relatively large amounts of emission allowances, whereas selling them proves to be profitable in the optimistic case.

The significant changes in the energy sector causes due to GHG reductions induce substantial changes in emission of other pollutants. SOx emissions are reduced due to diminished use of coal and peat. NOx emissions are expected to decrease considerably due to the penetration of hybrid engines and fuel cells. Particulates are abated by very efficient particulate emission controls but a shift toward smaller-scale combustion of biomass may increase particle emission unless advanced control technologies are used.

Antti Lehtila of VTT contributes substantially to the ongoing development of TIMES.

Germany

Assessment of Sustainable Energy Strategies for the State of Saxonia

For the federal state of Saxonia IER has coordinated the “Energy Programme Saxonia“ which aimed to develop sustainable energy strategies in the context of the liberalization of the energy markets in Europe and climate change protection policies. Stakeholders from policy, industry and public groups and organizations were participating in this energy dialogue. In order to assess the effects of different measures on the energy system a TIMES model of Saxonia has been developed /Fahl, et. al. 2004a/. Within the climate protection program of the Federal state of Hessen (InKlim2012), IER uses a TIMES model of Hessen to analyze strategies to reduce cost-effective greenhouse gases.

Forum for Energy Models and Energy Economic Analysis (FEES)

The third and fourth model experiment of the Forum for Energy Models and Energy Economic Analysis (www.ier.uni-stuttgart.de/forum), which is intended to be an open communication platform for energy modelers and analysts in Germany and is coordinated by IER, have been studying climate protection in liberalized energy markets (MEX III) and the long-term contribution of the German energy economy to the European climate change protection (MEX IV). The type of participating models comprised bottom-up models of the electricity sector on a national or European level, national bottom-up models of the entire energy system, top-down models (CGE models as well as econometric models) and a cross-impact matrix approach. IER has been participating with two models, the global top-down model NEWAGE and a national TIMES model for Germany /Remme, et al. 2004a/. In 2004, the ongoing fifth model experiment focusing on innovation and energy technology has started.

Enquete Commission “Sustainable energy supply under the conditions of globalization and liberalization”

The German TIMES model has also been applied in a scenario study for the Enquete Commission “Sustainable energy supply under the conditions of globalization and liberalization” of the Federal Parliament. The scenario analyses carried out by IER has been focusing on the impacts of greenhouse gas abatement policies, the future role of combined heat and power in Germany and the achievement of renewable energy targets for a time horizon until 2050 /Fahl, et al. 2002/.
Study of opportunities for district heating

Within a project for the national district heat association AGFW the long-term perspective of district heat in Germany using a national model TIMES has been studied /Blesl, et al. 2004a/. To better describe the regional aspects in the heat market, e. g. heat demand, building types, 11 sub-regions for have been introduced in the German model. In each sub-region the district heat supply and the residential sector have been modeled under consideration of the region-specific conditions.

Model integration to analyze sustainable development strategies

To analyze sustainable development strategies in Germany in a study for the Federal Ministry of Economics /Fahl, et al 2004b/, an integrated assessment model system consisting of the global resource model LOPEX, the CGE model NEWAGE-World, a European TIMES model and the environmental impact assessment model EcoSense has been developed including a linkage between TIMES and EcoSense, in which the external costs per pollutant derived by EcoSense are internalized in the TIMES-ES model. One part of the ongoing European project NEEDS (New Energy Externalities Developments for Sustainability) project, in which a multi-regional TIMES model of the European member states plus Norway and Switzerland will be developed, is to improve and apply the methodology for linking impact assessment and energy system models.

Emissions trading in the EU power sector

For a national utility IER has analyzed the impacts of emission trading on the European electricity sector. In order to study the interactions between electricity generation, electricity trade and emission certificate trading, IER has developed a TIMES model of the electricity and public CHP sector (TIMES-EE) consisting of 30 countries and covering the time horizon until 2030 /Blesl, et al. 2004b/.

ACROPOLIS project

Together with IPTS, Sevilla, IER has coordinated the ACROPOLIS project of the European Union. ACROPOLIS has been addressing policy questions in reducing GHG emissions on the global and national level. Key element of the project were four case studies analyzing the role of energy supply policies related to renewable portfolios and tradable green certificates, the impact of internalization of social and environmental external costs, the effects of a policy of energy efficiency standards on the end use side and the impact of international flexibility mechanisms. Several MARKAL/TIMES models have been participating in this project (www.ier.uni-stuttgart.de/acropolis). In the ongoing European CASCADE-MINTS project, which evaluates the possible development of the world energy systems and its implications for Europe regarding the perspectives of a hydrogen economy and the impacts of energy policies, IER participates with the electricity sector model TIMES-EE and the global CGE model NEWAGE /Uyterlinde, et. al. 2004/. In the EU project SAPIENTIA (Systems Analysis for Progress and Innovation in Energy Technologies for Integrated Assessment), which is a continuation of the SAPIENT project /Das, et. al. 2003/, IER uses a three-regional World TIMES model to study the impacts of R&D and learning on technology development.

The electricity sector in South Africa

In cooperation with the Energy Research Centre (ERC) in Cape Town a student from Stuttgart developed in his master thesis a South African electricity model in TIMES to study mitigation
strategies for greenhouse gas and flue gas emissions using block-wise capacity expansion representation leading to a MIP problem /Schulz 2003/.

Uwe Remme of IER contributes substantially to the ongoing development of TIMES.

**Greece**

**An Analysis of the Greek Energy System in view of the Kyoto Commitments**

[Centre for Renewable Energy Sources]

Greece has developed the Hellenic Action Plan for the abatement of CO2 and other Greenhouse Gas Emissions by February 1995, as a follow-up to the United Nations Framework Convention on Climate Change. In the context of European Union policy on climate change agreed upon by the European Council of Ministers in 1998, Greece’s greenhouse gas emissions by 2008-2012 should not exceed an increase of 25% compared to 1990 levels. The EU target for 2008-2012 is to reduce emissions by 8% compared to 1990 levels. Although per capita emissions in Greece are lower than the EU average, emissions per unit of total primary energy supply (TPES) are the highest in Europe. Greece’s greenhouse emissions are closely related to an energy mix mainly composed of lignite and oil. Lignite in Greece produces about half of the CO2 emissions. The major policy aspect in the Greek Action Plan for greenhouse gases abatement is the decarbonization of the Greek Energy System by introducing low carbon (natural gas) or no carbon (renewable) energy sources. National measures adopted include an intensive energy efficiency plan for the demand sector and an aggressive investment policy concerning direct support of renewable energies and the penetration of natural gas in both the supply and demand sectors.

Specific actions for the supply sector include improvement of the efficiency of existing lignite plants, increase in CHP capacity, and penetration of natural gas and renewable energy in electricity generation. For the demand sector actions include buildings (residential/commercial), industry and transport. In the buildings sub-sector actions concern energy specifications and standards development, use of passive and active solar systems, appliance labeling and fuel diversification by using natural gas. In industry, fuel substitution by natural gas and increase in cogeneration capacity. Finally, in the transport sector improvements in infrastructure and of public transport need to be considered.

A number of specific measures were adopted by the Greek government for the implementation of the Action Plan. Following the Operational Programme for Energy, a new Operational Programme for Competitiveness, which was initiated in 2000, will offer financial incentives for investments in RES, energy efficiency, cogeneration and fuel substitution for the period 2000-2006. The electricity market was liberalized in 2001, ending the monopoly of the Public Power Corporation. Starting in February 2001, any private investor can produce electricity, subject to the issue of a permit by the Regulatory Authority for Energy. A specific mention of electricity produced by Renewable Energy Sources is included in the law, which states that the Hellenic Transmission System Operator should buy RES electricity as a first priority. Natural gas started to penetrate into the Greek Energy System in 1997 and is expected to have important market shares of both the demand and supply sectors. The natural gas market will be liberalized in 2006.

Considering all the above, the CRES modeling team (D. Agorisa, K. Tigasa, G. Giannakidis, F. Siakkisa, S. Vassos, N. Vasilakos, V. Kiliais, M. Damassiotisa) performs an energy policy analysis for the achievement of the Kyoto targets taking into consideration all the recent
developments and potential problems that might arise from the changes in the structure of the Greek energy system. The models used in this study are R-MARKAL and WASP IV\(^{12}\).

**Scenario definition**

The philosophy behind the scenario building was to prepare a reference case, using medium oil prices without any constraints regarding CO\(_2\) abatement. A second scenario was then created for medium oil prices including Kyoto commitments. Finally, in order to assess the worst case situation, the above two scenarios have been analyzed using high oil prices. The scope behind this consideration is to be able to calculate the incremental investments together with the differential costs between non-Kyoto and Kyoto scenarios for medium and high oil prices. Thus, the level of additional supporting measures required, towards the achievement of the Kyoto targets is calculated. Finally, marginal abatement costs for the two oil price scenarios are calculated and compared to the EU trade marginal costs undertaken by the European Commission. These marginal costs concern either EU-wide emissions trade including the ACEA/JAMA/KAMA agreement (20 Euro/tn CO\(_2\)) or EU-wide emissions trade excluding the ACEA/JAMA/KAMA agreement (32 Euro/tn CO\(_2\)).

In all of the scenarios, programmed investment planning was included as a forced input:

- The limit for the penetration of Wind Farms was raised up to the limits of the capacity of the high voltage grid, which together with the present subsidies scheme, more or less determine the economic potential of wind investments.
- The fact that the economic potential for Small Hydro is about 500 MW was taken into consideration.
- It was assumed that natural gas penetration in the demand sector will not exceed the levels forecasted by DEPA.
- An assumption was made for possible electricity imports, taking into consideration the capacity of the Northern interconnections, the electricity prices and the production capacity limits in Balkan countries.

In the emissions abatement scenarios the national targets for CO\(_2\) abatement have been incorporated as a constraint for the period 2008-2012. Considerations here include CO\(_2\) emissions from energy and non-energy industrial processes and the constraint applied is +36\% for the period 2008-2012.

**Non-Kyoto Scenarios**

Non-Kyoto scenarios (medium and high oil prices) reflect the required energy system structure in order to meet the forecasted demand under present policies.

The installed capacity of the electricity generation system should increase by about 74\% by the year 2010 to meet the electrical energy and peak load demands. Natural gas is expected to have a dynamic penetration in electricity generation as well as in CHP in the industrial and tertiary sectors. The market share of natural gas in electricity generation is expected to rise at a level of 14 \% by 2010. Lignite plants will continue to be the basis of the mainland system for the next ten years. The market shares of lignite and coal generated electricity, are expected to be 59\% in total, by 2010. Under present policies, Renewable Energy, (including large hydro) will contribute 13\% of the electricity production in both oil prices scenarios. Natural gas is expected to penetrate in the demand sector at 6\%. Electricity end-use consumption will be 24\% for both scenarios whilst oil products market shares will be 59\% and 58\% respectively.

Finally CO₂ emissions are expected to increase by about 46% relative to the 1990 levels for both scenarios and this is the expected level in the absence of intensive emissions abatement measures. Energy dependency will be 74% which is explained by the increasing penetration of natural gas.

Emissions abatement scenarios using Kyoto constraints

The scope of these scenarios is to calculate the additional required investments in order to fulfill the Kyoto obligations with medium and high oil prices.

In the emissions abatement scenarios the increase of the electricity generation installed capacity will have to be at a level of 79-82% depending on the oil prices. The scenarios development results in an increase in electricity generation from natural gas and a reduction in the operation of conventional lignite plants. In the high oil prices scenario the market share of natural gas for electricity generation is somehow reduced, in favor of new technology plants burning lignite and coal. This is explained by the fact that the price of natural gas is directly related to the price of oil. The market share of natural gas in electricity generation is expected at 19% for medium oil prices and at 16.5% for high oil prices. Cogeneration in industry and the tertiary sector is expected to be 8.4% of the total electricity production, in the medium oil prices and 9.8% in the high oil prices scenario.

To achieve the Kyoto targets electricity generation from conventional lignite plants must be maintained at 49.6% of the overall generation for medium oil prices and at 53.3% for high oil prices. Although the installed capacity of large hydro will not increase, the installed capacity of wind converters and small hydros increased considerably in the CO₂ abatement scenarios. The relevant levels of electricity generation from RES are 19% for medium oil prices and 18.7% for high oil prices. These figures are also in conformity with the obligations to the EU regarding the contribution of RES to electricity generation (20.1%). Natural gas penetration in the demand sector is expected at 5.78% in the medium oil prices and at 5.76% in the high oil prices scenario. Electricity consumption in the demand sector is expected at 24% for both cases. The end-use consumption of oil products is expected at 59.4% and 58.4% of the total final energy consumption respectively. The CO₂ emissions are maintained at +36% compared to the levels of 1990, which is in compliance with the national obligation for the Kyoto protocol. However, the energy dependency in this case will be about 75%. This is just one percentage unit higher than the case of non Kyoto scenario.

Conclusions

In the current measures scenarios an increase of +46% (1990) is forecasted for CO₂ emissions. To avoid this situation the adoption of several additional measures is required particularly for the period 2006-2012.

To ensure a wide penetration of natural gas in the supply sector an attractive gas purchase price policy for electricity production and cogeneration will be required. On this direction, attractive tariffs for the transmission of natural gas based on an improved depreciation of the pipelines and LNG investments have already elaborated. The Greek government is currently looking for alternative gas supply options, in addition to Russia and Algeria, such as Central Asia and the Middle East. The first indications show a strong prospect for reducing the current gas supply prices at the Greek borders.

Old lignite plants should reduce their utilization factor by about 38% in 2010 compared to the levels of 1999 or they will have to incur allowances costs. Several plants could be rehabilitated to increase their efficiency and decrease the levels of emissions.

Wind energy investments should reach an installed capacity of 2130MW by the year 2010 while small hydro should reach a level of 500 MW. Both targets are considered as possible.
Cogeneration investments using natural gas should also reach a level of 800-900MW by 2010. Table 1 depicts the required installed capacities required in the supply sector under Kyoto limitations.

The results of the differential cost calculations shows that potential Kyoto policies compared to non-Kyoto policies include a reduction of investments in conventional electricity in favor of RES, CHP and energy efficiency investments. Requirements for Kyoto compliance include increased electricity generation from natural gas and RES and reduced electricity generation from solid fuels and oil products. In addition to a National investment programme goals for energy efficiency, supporting measures should also include energy efficiency and fuel substitution by natural gas in the residential sector. The marginal abatement cost for CO₂ as a function of the percent increase in emissions indicates a value of +36% the marginal abatement cost is at the levels of 20 Euro/ton. This value is not very high in comparison with other European countries or when compared to the values calculated for EU-wide trading, including (20 Euro/ton) or excluding (32 Euro/ton) the ACEA/JAMA/KAMA agreement of the automobile manufacturers.

In Greece, energy related emissions are mainly due to old lignite plants that will either have to reduce their operation or buy permits. It should be noted that the marginal abatement cost for the Greek energy system is a strong function of the annual use of lignite. For the present calculations a value of 58 million tones per year is used. However, replacement of the old lignite plants with new ones using cleaner technologies is considered in the medium term planning of the Greek electric energy sector.

The main conclusion is that the emission abatement targets of the Greek energy sector are achievable in terms of the investments required. Taking into consideration that Governmental investment tools are expected to contribute a total budget of about 1.5 to 2 billion Euros for investments in RES, CHP, energy efficiency and fuel substitution by natural gas in the demand sector, one could conclude that it will be sufficient to launch a supporting programme with similar budget, for the period 2006-2012.

Although the marginal abatement cost of the Greek energy sector appears low in comparison to the relevant values for EU wide trading undertaken by the European Commission, it is believed that the potential for internal trade in Greece is rather restricted, due to the fact that the more carbon intensive sector is the electricity industry while heavy industry is rather small.

**Italy**

Evaluation of Green Certificates Policies using the MARKAL-Macro-Italy model

[Mario Contaldi, Francesco Gracceva, Giancarlo Tosato]

Following the general trend towards more competitive energy and electricity markets, several countries have shifted to *quantity-based approaches*, which include the competitive bidding processes and the Green Certificates systems. In the Green Certificates system a fixed quota of

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**Excerpt from the final report of ENEA for the ACROPOLIS (Assessing Climate Response Options: POLICY Simulations) project (Contaldi et al., 2003).**

**APAT**

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electricity sold by suppliers on the market must be generated from RES. Electricity suppliers can generate the mandatory share of RES-E directly or purchase it from another supplier or purchase green certificates on the market. RES-E generators benefit both by selling RES-E to the network at the market price and by selling Green Certificates (GC) on the GC market. Under GC schemes the market reaches predefined technically feasible targets at maximum economic allocation efficiency. In Europe it has been implemented by the Netherlands, UK, Italy, Sweden and Belgium, while Denmark has recently postponed its implementation. In Italy, from 2002 all electricity producers and importers have been obliged to certify that at least 2% of their net sales come from new RES-E.

This study evaluates alternative scenarios assuming a progressive increase of the RES-E obligation\(^{17}\). Scenarios are then compared with the targets fixed for each RES by the Italian White Paper on renewable energy sources. Eventually the effectiveness of the RES-E policies implemented through green certificate are compared with the obligation to improve the efficiency of end use devices fed by electricity and natural gas, to be implemented through white certificates, and with the possibility of setting heavier carbon tax schemes.

**Methodology**

The extension of the MARKAL methodology used in this study combines the energy model built with MARKAL with the long-term macroeconomic growth model MACRO, to provide a dynamic, neoclassical, applied general equilibrium model. The integrated model simultaneously solves energy and economic components using non-linear optimisation, is able to analyse separately price-induced energy conservation and autonomous energy efficiency improvements.

The MARKAL Italy partial equilibrium model represents the domestic energy system and its main emissions of CO\(_2\), NO\(_X\), SO\(_2\) and VOC from 1990 to 2030 by 5 year periods. It represents over 70 independent demands for energy services in four main sectors – agriculture, industry, transport, commercial and households – split by sub-sector, type of service and material. The model calculates equilibrium quantities and prices of more than 300 flows of energy goods and materials. Demand and supply curves of each commodity are specified stepwise by sets of technologies, for a total of over one thousand.

For this study the model has been updated. The present version includes about 50 actual and new power plants types, actual fuel levies and presently available renewable supply, end use efficiency and mitigation technologies, prescribes mandatory EC sulphur levels of fossil fuels, domestic and European sulphur and nitrogen emission limits to 2010, green and white certificates instruments.

In terms of energy security and environment, the MARKAL – MACRO Italy model produces a BAU scenario which can be judged feasible although rather optimistic.

**Scenarios**

In the Base Case scenario (BAU), the Electric Supply Industry has to feed into the network a share of electricity from “new” renewable sources corresponding to the values of the current legislation (2% until 2004, increased by 0.35% per annum (%pa) during the following three years

according to a recent modification). In the enhanced Green Certificate scenario (GC+) the increase of the obligation continues up to 2020, to reach a share of 4.5% in 2010 and a 7% share in 2020. The simulation of this policy in the model is technically difficult because the RES-E obligation is proportional to the total production plus import, it is time dependent and it is applicable only to new investments in each year. The amount of electricity to be produced from renewable sources (2% or more) is then calculated from the reference case, keeping into account previous new investments.

The RES-E obligation is represented in the model by means of a constraint on total electricity produced from RES. The model is free to choose the combination of different renewables that fulfils the constraint and maximizes the utility function. With respect to the consumption of renewable energy sources, when the operators have the obligation to cover 2% (3% from 2006) of total electric production with new renewables (BAU scenario), RES is projected to grow by slightly more than 4 Mtoe in this decade (about 2% of TPES), which is less than the growth observed in the previous decade. After 2010, in absolute terms energy from RES continues to grow until 2020, but at a much slower pace, while thereafter total consumption of RES remains more or less at the same level (about 19 Mtoe). In relative terms, the share of RES on TPES grows only until 2010, as after 2010 the contribution of RES is stable well below 10% of TPES, not far from the current values.

The reason for this modest impact of the current legislation on RES is twofold. Firstly, in the long-term the effective obligation for electricity production decreases (even if it is fixed at 3% of fossil production), because of the increasing production from sources free from obligations (like co-generation and non conventional fossil fuels). Secondly, in the long-term the renewable power plants installed in the first decade (mainly wind power) are no longer in production (due to their limited lifetime).

**Contribution of renewable sources to the Italian Total Primary Energy Supply**

(TPES, Mtoe)

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>TPES</th>
<th>Total</th>
<th>RES-E (%)</th>
<th>Hydro</th>
<th>Biomass / Biogas</th>
<th>Geothermal</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistics</td>
<td>1990</td>
<td>163.4</td>
<td>8.4</td>
<td>5.2</td>
<td>7.0</td>
<td>0.6</td>
<td>0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Statistics</td>
<td>2000</td>
<td>184.8</td>
<td>12.9</td>
<td>7.0</td>
<td>9.8</td>
<td>1.7</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>White Paper 1999</td>
<td>2010</td>
<td>185</td>
<td>20.3</td>
<td>10.9</td>
<td>10.4</td>
<td>3.9</td>
<td>2.9</td>
<td>1.7</td>
</tr>
<tr>
<td>MM-It BAU</td>
<td>2010</td>
<td>209.2</td>
<td>17.4</td>
<td>8.3</td>
<td>10.5</td>
<td>1.9</td>
<td>2.4</td>
<td>1.4</td>
</tr>
<tr>
<td>MM-It GC+</td>
<td>2010</td>
<td>209.9</td>
<td>18.9</td>
<td>9.0</td>
<td>12.1</td>
<td>2.0</td>
<td>2.4</td>
<td>1.4</td>
</tr>
<tr>
<td>MM-It BAU</td>
<td>2020</td>
<td>226.5</td>
<td>19.0</td>
<td>8.4</td>
<td>10.8</td>
<td>1.9</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>MM-It GC+</td>
<td>2020</td>
<td>226.9</td>
<td>23.0</td>
<td>10.12.3</td>
<td>3.7</td>
<td>3.0</td>
<td>1.6</td>
<td>2.3</td>
</tr>
<tr>
<td>MM-It BAU</td>
<td>2030</td>
<td>235.2</td>
<td>19.3</td>
<td>8.2</td>
<td>10.8</td>
<td>0.9</td>
<td>3.6</td>
<td>1.7</td>
</tr>
<tr>
<td>MM-It GC+</td>
<td>2030</td>
<td>237.4</td>
<td>26.2</td>
<td>11.1</td>
<td>12.3</td>
<td>4.6</td>
<td>4.8</td>
<td>1.7</td>
</tr>
</tbody>
</table>

(+ ) Includes also solar thermal.

In the GC+ scenario energy from RES is obviously higher than in the BAU scenario. Differently from the BAU case, it continues to grow substantially also in the long run, both in absolute and relative terms (exceeding 10% as share of TPES). Besides, a remarkable result is that in this case energy from RES approaches the values projected for 2010 by the Italian White Paper, and in the longer term it goes well beyond, even if only in absolute terms. To reach these higher values of energy from RES, in the GC+ scenario, apart from a significant increase of electricity from small hydro (with respect to the BAU case), a key role is played by biomass: it fills most of the gap between BAU and GC+ scenarios, almost reaching in 2010 the resource limit set by the Italian
White Paper. This means that after 2010 the constraint becomes progressively more stringent, with the risk of bearing high costs for gathering additional biomass. On the contrary, geothermal and wind energy increase marginally and approach their resource limit as in the BAU scenario.

**CO₂ emissions**

A main result of the simulations is that the effect on CO₂ emissions (with respect to the current trend) of the projected progressive increase (well beyond the current limit of 2006) of the obligation for Green Certificates is marginal in the near term and quite modest also in the medium and long term. As a matter of fact, the CO₂ reduction due to the increased use of renewables is between 2 and 10 Mt of CO₂. This means that even in the long run the difference between the two scenarios remains under 2%; so emissions continue to grow along the entire time horizon at some 0,5% per year. Compared to the RES-E scenarios, the impact on CO₂ emissions of the other policies (EES and HCT scenarios) is higher: in the High Carbon Tax scenario the stabilisation of CO₂ emissions is nearly achieved, and also energy efficiency measures have stronger positive effects, especially in the near term.

**CO₂ emissions in different scenarios**

![Graph showing CO₂ emissions in different scenarios]

**Conclusions**

The EU targets for developing RES in 2010, 22.1% of the electricity supply and 12% of the TPES, are quite demanding. According to this study, the 22.3% target of RES-E for Italy appears very difficult to achieve: with the present Italian obligation to supply 2% (slightly increased by 2006) of electricity from new renewable sources, at most 18.1% of electricity will be supplied by RES-E (20% if the obligation continues to increase after 2006). Green certificates policies become more effective in the medium term. However, improving the energy security with this policy implies a reduction of the GDP (even if quite small) in the medium term. Green certificates policies look sustainable only in the longer term, if a global and successful learning process is triggered by a strong R&D effort that creates many more viable and competitive technological options.
As to the present options, the comparison of the results of the scenario with the increasing obligation with the Italian White Paper on renewable energy sources shows the critical role of biomass: additional measures seem necessary to develop production according to the domestic potential. Geothermal (whose exploitation is naturally limited) and wind power plants seem more viable to meet the targets. As to the mechanism to implement the RES-E obligation policy, the shift from a price-based supporting mechanism to a Green Certificates “market” mechanism would favour the most competitive technology, such as wind, without effects on less developed but potentially promising technologies, such as photovoltaic. Less mature technologies would be helped only when the most mature ones reach their maximum potential. The main risk of a Green Certificates system is “the fairness of competition between RES technologies at different stages of development” [Meyer, 2003], because “it tends to prevent investment in promising – but insufficiently developed – technologies” [Menanteau et al., 2002], and this poses the question whether it is possible to address the problems of investments in less developed technologies, for instance by creating several GC markets depending on technology.

Implemented and proposed domestic policies towards larger supply of electricity from renewable sources look supplementary to policies towards higher efficiency standards in the civil sector, which are effective in the short term. According to the model, in the EES scenario energy consumption in 2010 is 1.8% lower than in the reference case; the reduction reaches even higher values afterwards. Contrary to Green Certificates policies, White Certificates obligations increase energy security and GDP at the same time, because in principle they force end users to more rational choices. However, it seems necessary to make a large deployment effort at the EU level, together with appropriate information and communication campaigns, to let end users decide using the long term social discount rate and to harvest even part of the no/low regret options.

In the present framework, domestic policies bring a real mitigation to climate change only with additional strong carbon taxes and non negligible GDP losses. If the Kyoto target has to be achieved, a large use of international flexible mechanisms seems cheaper.

TIMES regional and sectoral models [LAME - Politecnico di Torino]

The LAME\textsuperscript{18} Modelling Team is developing TIMES applications with detailed characterisation of Reference Energy Systems, mainly focused on local (Piemonte Region) and sectoral (Italian electrical energy supply, transmission and demand) systems. In addition to these applications, the LAME Team has been charged to make the TIMES-UK model in the framework of the NEEDS Integrated Project, aimed to develop a 25 Member States pan-European Energy Model. The working plan includes the collection and analysis of data in order to integrate the Eurostat Energy DB for UK, the compilation of the UK TEMPLATES and the execution of calibration runs, before the integration of the TIMES-UK into the pan-European Model.

The TIMES Energy System Model for the Piemonte Region (TIMES-Piemonte)

The Piemonte Regional Administration decided in 2002 the development of a modelling tool for the Regional Energy System in order to evaluate sustainable energy strategies, options for the

\textsuperscript{18} LAME – Laboratorio di Analisi e Modelli Energetici (E. Lavagno, M. Gargiulo, R. De Miglio, R. Gerboni, L. Schranz, P. Squillari) is a Research Team working at Energy Department – Politecnico di Torino.
regional contribution to the fulfilment of Kyoto targets and local energy programs (biomass, district heating networks, cogeneration plants).

The steps of the TIMES-Piemonte Project are presented in the following table.

| ✓ | Definition, in agreement with the Regional Reference Team of the detail levels of the system description: supply side and demand technologies, time slices (8) and global analysis horizon (30 years). |
| ✓ | Data collection of the technologies to be taken into consideration (power generation plants, building stock and residential energy devices, industry and agriculture activities, mobility technologies), through the involvement of Data Base Management Services belonging to the Regional Administration and National and local Utilities Information Systems. |
| ✓ | Information processing to assess sectoral RES, technology devices and demand characteristics databases, with reference to the local aggregated economical sectors: residential, industry, transport, services and agriculture. |
| ✓ | Definition of the TEMPLATES structure. |
| ✓ | Demands analysis (2000-2004) and demand projection along the time horizon. |
| ✓ | Data sheets assessment for BASE scenario and TEMPLATES import by VEDA-FE. |
| ✓ | Calibration of the model through the 2000-2004 BASE scenario results. |
| ✓ | BASE scenario runs and results reporting with VEDA-BE. |
| ✓ | Definition of technologies evolution with the Regional Reference Team. |
| ✓ | Generation of new scenarios (two environmental scenarios, an energy policy scenario, a biomass potential use scenario). |
| ✓ | Discussion of the results with the Regional Reference Team. (First Report) |
| * | Resolving alternative scenarios (White Certificates, Emission Permits Trade). |
| * | Proposal for the disaggregation of the demand at province level and generation of new provincial Reference Energy Systems. |

✓ Closed activities        *   Work in progress

A particular feature of TIMES-Piemonte, related to the objectives of the work required by the Regional Administration, is the very detailed level of description of the energy system, either in the supply and transport/distribution side, where all large and medium size plants are identified and characterised and four electrical energy grids are taken into consideration, as well as in the demand side, which has been disaggregated in a high number of technologies and energy services (mainly in the residential sector). Moreover, the particular geographic position of Piemonte requires to take into account suitable electricity import and trade exchanges with neighbouring regions.

The first figure shows the growth of district heating (characterized by a relevant role of cogeneration plants) in the Piemonte Residential sector subject to BASE Scenario and Kyoto Scenario constraints. The second figure shows the consumption of electricity in the same sector: in order to accomplish the constraints of the Kyoto Scenario an higher import from France is required. The energy trajectories show the combined effect of the increase in energy efficiency of appliances as well as in the demand of energy services.
The TIMES Model for the National and Regional Electrical System (TIMES-Elc Italia)

The activity is performed in the framework of a National Program dealing with the development of a National and Regional Electrical System Model and its implementation in TIMES. The structure is based on 20 regions with electrical trade between the neighbors and import from foreign countries. The project is a cooperation among LAME, AIEE (Italian Association of Energy Economists) and CESI (Italian Electrical System Research Centre, project leader). The activities and status of the TIMES-Elc Italy construction are noted in the table below.
| ✔ | Definition with the Project Partners of the detail level of RES-elc: 20 regions, 5 voltage grid levels, 8 timeslices, 11 milestone years (time horizon 2004 – 2030). |
| ✔ | Definition of the detail level for electricity supply technologies (all the medium and large size plants are identified) and their characterisation. |
| ✔ | Processing information to create correspondent RES and technology database. |
| ✔ | Searching data about distribution technologies grids. |
| ✔ | Definition of the TEMPLATES structure (generation and demand). |
| ✔ | Assessment of the RES-Supply Side and calibration runs with the aggregated demand. |
| ✔ | Data sheets assessment for BASE scenario and TEMPLATES import by VEDA-FE. |
| ✔ | Solutions for the cogeneration technologies. |
| ✔ | BASE scenario runs and results reporting with VEDA-BE. |
| ✔ | Runs with fully disaggregated demand. |
| ✔ | Construction of the I/O Table of the inter-regional trade. |
| ✔ | Upgrade of future possible technologies. |
| ✔ | Runs with all Italian regions |
| * | Definition of alternative scenarios |

✓ Closed activities       *       Work in progress

The following figure represents (in a simplified way) the typical RES structure inside a region, with electricity import/export and trade with adjacent regions; the other energy vectors which supply the power plants are described as in-flows coming from a virtual region representing the aggregated Italian Energy scheme.
The analysis of the evolution of the inter-regional electricity exchange under different scenarios and plant siting policies has been required for evaluate planning alternatives for the development of National and Regional transport/distribution grids.

The figures represent, as examples of the trade mechanism with neighboring regions, the situations for Emilia and Puglia in the BASE Scenario.
At the Japan Atomic Energy Research Institute (JAERI), the Research Group for Energy System Analysis headed by Mr. Sato made a study on Japan's long-term energy demand and supply toward the year 2050 by applying the Japanese MARKAL model. This study was promoted under the Committee of Nuclear Reactor Development and Utilization of the Japan Atomic Industry Forum, and particular attention was paid on the potential role of nuclear energy in the context of depletion of fossil energy resources and climate change problem. The Research Group made in addition a study on long-term scenarios of developing advanced nuclear power reactors and fuel cycle systems in Japan. The analytical results showed that innovative water-cooled reactors with reduced neutron moderation (RMWR) have enough potential to build net plutonium breeding systems and thereby to contribute to assure sustainable use of nuclear energy from the viewpoint of uranium resource availability.

Study on Japan's Long-Term Energy Scenarios using MARKAL

The Research Group for Energy System Assessment in Japan Atomic Energy Research Institute (JAERI) made a study, during the period of ETSAP Annex VIII, on the evolution of energy demand and supply toward the year 2050 by using the national MARKAL model of Japan. A set of assumptions was made for this purpose on future economic growths, improvement in energy intensity, and availability and costs of energy sources, and technological progress. Figure 1 shows the assumptions on changes of population and GDP (gross domestic products) with time. It was also assumed that CO$_2$ emission levels at 2010 are to be controlled to the 1990 levels, and those at 2050 are to be reduced to 60% of the 1990 levels. Then, three analytical cases were defined with a different scale of nuclear energy utilization as listed in Table 1.

![Figure 1: Assumptions on future changes of population and GDP](image-url)
Table 1: Definition of analytical cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Nuclear Power Generation</th>
<th>Nuclear Heat for H₂ Production⁽¹⁾</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Reference)</td>
<td>70 GWe at 2030 and thereafter</td>
<td>10 GWt at 2050</td>
</tr>
<tr>
<td>B (Phase-out)</td>
<td>No Investment after 2010</td>
<td>None</td>
</tr>
<tr>
<td>C (Expansion)⁽²⁾</td>
<td>90 GWe at 2050</td>
<td>20 GWt at 2050</td>
</tr>
</tbody>
</table>

(1) Nuclear hydrogen production is assumed to start at 2020.
(2) Expansion of renewable energy use and implementation of CO₂ sequestration are assumed in order to meet emission targets.

For each of the above cases, least cost energy systems were determined by using MARKAL while controlling future levels of CO₂ emissions. The results are shown in Figure 2 to Figure 4.

Primary energy supply is compared in Figure 2. Dependence on oil decreases substantially with time in all the cases. But, alternatives to oil differ between cases. In the case B, natural gas becomes a major energy source contributing more than half of primary energy at 2050, and total percentages of fossil energy do not change with time. On the other hand, in the both case A and C, contribution of nuclear energy increases largely, and the share of fossil energy decreases to around 60% at 2050.

Energy use in the power sector is much more different between cases. Figure 3 indicates that, in the case B natural gas contributes almost two thirds of total power generation at 2050. While, nuclear contributes 48% of power generation in the case A, and 60% in the case C at the same year. These results suggest that nuclear energy has enough potential to meet future energy demand in compatible with the request for environment protection, however, natural gas, and in addition CO₂ sequestration if available, will be only solution in non nuclear cases to achieve strict CO₂ emission reduction goals.

Figure 2: Primary energy supply at the year 2000, 2025 and 2050.
Figure 3: Electric power generation at the year 2000, 2025 and 2050. It was assumed in this study that imported prices of oil will double during 2000 and 2050, and those of natural gas will become 1.5 times higher during the same time period. With these assumptions and additional costs of CO₂ sequestration necessary to achieve strict emission targets, the energy system costs in the case B become much higher than other cases as shown in Figure 4. The cost differences at 2050 are approximately 4 trillion yen; 18% increase in average energy costs, or 36% increase in terms of electricity generation costs. It should be noted however that these results depend strongly on the assumptions of analysis, particularly on future prices of imported natural gas.
In conclusion, it was indicated from this study that the expansion of nuclear energy utilization in Japan will possibly contribute to reduce dependence on imported fossil energy, and thereby, to increase stability of energy supply and to control carbon dioxide emissions at significantly low levels with acceptable costs.

This analytical study was made under the Nuclear Vision Working Group of the Committee on Reactor Development and Utilization, a standing committee of the JAIF (Japan Atomic Industrial Forum, Inc.). Based on the above results, the Working Group then developed the long-term vision of nuclear energy utilization and also the roadmaps of technology development and institutional arrangement. The final report of the whole study was approved by the Committee in November 2004 and was posted on the web page (in Japanese) of the JAIF.

The Netherlands

ECN ACTIVITIES DURING ETSAP ANNEX VIII 2002-2004 [Koen Smekens et al]

The Acropolis Project

The ACROPOLIS initiative, supported by the European Commission and the International Energy Agency, compared the impact of energy technologies and policies to control greenhouse gas (GHG) emissions by using up to 15 energy models. Four case studies are formulated considering policies and measures on renewable portfolio schemes and internationally tradable green certificates, emissions trading and global GHG abatement target, energy efficiency standards and “internalization of external costs”. Main focus of the project is on the electricity
sector. From a large set of quantified results, ACROPOLIS provides an international scientific consensus which could be useful in assessing and designing energy and environment policies.

Conclusions from the MARKAL model work at ECN

The different cases of the ACROPOLIS study have been used as starting point to look at the evolution of the share of renewable technologies in the electricity production. In the reference case (the case including the LRTAP, but also valid for the case without LRTAP which has been used for the external cost comparison) renewables reach a share of about 20-25% in the total production and this remains more or less stable over time. In absolute values there is an increase in production from renewables because the overall production level increases (from about 2200 TWh in 1990 to about 3900 TWh in 2050). As hydro cannot expand further in Western Europe, it is primarily wind and biomass that contribute to the renewable share.

From the model case results, depending on the agreed assumptions in this study, it can be noticed that if a considerable change in favor of renewables has to take place, a certain form of hard targets is necessary. The most obvious one is of course a specific target for renewable, or green, electricity production, which indeed forces the system to comply. Other possible actions, but with a more indirect effect, but fully understandable, are targets on CO$_2$ emission levels or concentrations or the introduction of full external costs, meaning including the pollutants and CO$_2$. External costs, which only take into account the effects of pollutants, have less effect.

All cases show a similar trend in primary energy intensity, although the composition of the primary energy mix changes considerably between the cases, the intensity to GDP remains within a very narrow range, declining from 8.7 to 3.7 MJ/€95 by 2050.

Welfare loss as measure of the penalty for the energy system when applying the case conditions indicates that the renewable target has the largest impact in early decade, while the others see the loss increase by the end of the time horizon. Some of them, like the stabilisation cases, have their largest impact beyond 2050.

![Graph showing primary energy intensity and welfare loss](image)

The CO$_2$ emissions of the energy system follow the primary energy mix: an increasing fuel use with in particular a switch from coal to gas in 2000-2020 and after that a return to coal, leading to increasing emission levels. For long term reduction, a stabilisation target is necessary, all other cases have the level above the 2000 level. The power sector shows the same trend, emissions...
increase with about 50% in the reference case. Only the renewable case and the full external cost case can reduce the power sector emissions below the 2000 level.

The CO₂ intensity of the primary energy use is dependent of the reduction of high C fuels (coal), but the trend is close to the reference case value, except for the stabilization cases where the fuel use becomes fundamental different.

Economic Effects of Grandfathering CO₂ Emission Allowances [Sijm J. et al]

This study has analyzed the potential capital transfers between economic sectors resulting from the grandfathering of CO₂ emission allowances in Western Europe over the period 1990-2030. Four different policy variants of grandfathering have been distinguished. First of all, variant A, which covers CO₂ emissions of the exposed sectors only, has been distinguished from variant B, which includes all CO₂ emissions of all economic sectors of Western Europe. Secondly, each variant has been further subdivided by distinguishing two different methods of grandfathering emission allowances, i.e. a flat rate (F) system, based on past emissions, versus a proportional (P) system, based on projected, future emissions. This latter distinction implies that differences in sectoral emission growth rates are accounted for in a P-system but not in an F-system.

In order to analyze the size, direction and underlying determinants of potential capital transfers due to grandfathering CO₂ emissions allowances, the present study has used a partial equilibrium model called MARKAL-MATTER3.0. This bottom-up optimization model is able to (i) estimate trends in sectoral emissions for both baseline and mitigation scenarios, (ii) generate marginal abatement curves at the sector level of Western Europe, based on a large, comprehensive set of production annex abatement options covering both materials and energy flows, (iii) account for price-induced changes in final demand, (iv) estimate the most efficient allocation of sectoral emissions under different policy constraints and, hence, to analyze potential emissions trading and capital transfers, given a certain initial allocation of CO₂ allowances, and (v) assess the abatement costs of different policy options of grandfathering CO₂ allowances.

Based on the above-mentioned approach, the present study has led to the following main conclusions and policy implications.

a. Capital transfers among economic sectors due to grandfathering are sensitive to the policy variants considered as it can affect both the size and the direction of these transfers. As a percentage of industrial output, however, these capital transfers are generally rather modest,
although they are more substantial in a variant covering all emissions - notably in a flat rate system of variant B - than in a variant covering the emissions of the exposed sectors only (i.e. variant A). Moreover, in all policy variants, they can be quite significant at the disaggregated level of individual sectors.

b. Whereas for both the flat rate and the proportional system of grandfathering the capital transfers are generally higher in variant B than variant A, the total abatement costs, excluding transaction costs, are usually substantially lower in the former than in the latter variant. This implies that from a cost perspective, either a flat rate or a proportional system of variant B should be preferred as both systems result in the same, least-cost situation. However, if for one reason or another variant A is chosen, total abatement costs will be lower in a proportional system than a flat rate system.

c. Although each sector will prefer variant B above variant A - as the former results in the most efficient situation for each sector - those sectors with a growth rate of their baseline emissions below average, i.e. mostly exposed sectors, will prefer a flat rate system of grandfathering CO$_2$ allowances, whereas those sectors with a growth performance above average, i.e. mostly sheltered sectors, will prefer a proportional system.

**Enhancements of Endogenous Technology Learning in the Western European MARKAL Model - Contributions to the EU SAPIENT project [de Feber et al]**

For the first time a large number of learning technologies were successfully implemented in a large-scale integral energy model. With 10 learning key components and about 60 technologies affected by learning we have been able to keep solutions times within realistic limits.

Uncertainty is an important element in the use of energy models for energy forecasting. With the use of a Monte Carlo analysis the most sensitive parameters leading to object values can be determined as well as their impact weight. The results of an uncertainty analysis in progress ratios of wind turbines and comparing this to the impact of R&D on the progress ratio indicates that the uncertainty in the progress ratio is more important than the estimated effect of R&D-expenditures on the progress ratio. This finding supports the idea that it is more important to obtain good data for the one-factor learning curve parameters, than to introduce a more complex two-factor learning curve (either indirect or direct).

For several reasons, ECN has chosen to explore an alternative approach to the 2-factor learning curve, to model the impact of R&D on technology learning. This alternative approach is to assume a relationship between the R&D-intensity of a technology (the percentage of R&D-expenditure divided by the sum of the R&D-expenditure and the total sales over a given period) and its progress ratio. Based on three observations (fuel cells, wind turbines and solar PV) a linear relation between the two parameters was assumed. This exercise suggested a learning-by-doing progress ratio (learning without any R&D) of about 95%.

Applying ‘R&D-shocks’ to technologies selected using the R&D-intensity approach led to several insights. In the first place, it appeared that the scenario conditions (especially with regard to expected carbon prices) had much more impact on the model outcomes than enhancing the progress ratio of specific technologies as a result of additional R&D-expenditures. These results indicate that R&D-policy can never stand on its own. R&D can certainly help to reduce specific technology costs, but to get technologies into the market, deployment policies and external cost pricing are necessary as well. The fact that new technologies have to compete with more conventional technologies that are also able to learn (‘moving targets’) makes it much more difficult for them to enter the market.
Evaluating the R&D-intensity approach to model technology learning, one can say that the positive news is that it is a feasible approach for large integral energy models. However, several of the assumptions behind this model need to be checked. The data on which this model is based are very scarce: only three technologies (wind turbines, fuel cells and solar PV) that are rather new to the energy sector. A characteristic of these technologies is that a very important part of R&D-spending is public R&D. However, it can be expected that if these technologies enter the market more substantially, there will be a shift from public to private R&D, meaning that the assumption that public R&D-spending is representative for total R&D-spending doesn't hold anymore. Also it is difficult to get enough data to assess the R&D-intensity over a certain period. For several technologies one would have to go to analyze large industrial sectors outside the energy system (e.g. the aviation industry for gas turbines, or the ICT-industry for cost reduction of electronics).

Much of the theoretical and data problems mentioned above are shared with other approaches to model R&D-spending on technology learning, such as the 2 factor learning curve. This means that one should be careful at this moment in drawing robust policy conclusions from the exercises done in the Sapient project. Exploring different approaches (2FLC and R&D-intensity) the Sapient energy modelers learned a lot. To continue further riding of our own experience curve combinations of these approaches or new approaches will have to be explored in the future.

MARKAL training sessions

During the course of Annex VIII, ECN provided, on demand, a couple of training session in order to enhance the further and widespread use of the MARKAL model. Chronologically the following trainings took place:

2002:  SCK-KULeuven (Belgium): week long training session for PhD on nuclear energy scenario analysis;
2003:  ERI (South Africa): final week long training session on energy system modeling and scenario analysis;
        Lund University (Sweden) and CIEMAT (Spain): week long session on energy modeling and scenario analysis;
2004:  TERI (India): 10 day long training session on energy modeling and scenario analysis.

Participation in EMF-IEW

ECN Policy Studies is a regular contributor to the EMF-IEW meetings, in 2002, 2003 and 2004 there were presentations on the results of MARKAL model work. The subject of the presentations was related to methodological (learning curves) or analytical (scenarios and CO$_2$ capture and storage). The meetings and associated ECN contributions include:

M.A.P.C. de Feber, A.J. Seebregts, K.E.L. Smekens, and Multi sectoral learning in the WEU Model under the EMF-19 scenarios, K.E.L Smekens

EMF 2003, IIASA:  Technological Changes in Long Term Transition Scenarios, K.E.L. Smekens

**South Korea**

From the year 2001, Korea started establishment of databases on energy technology as 4 years projects. The DB consists of type and market share of energy technology, specific technological and cost data of individual technology adapted in Korea. And we are also searching for cost-effective options.

An analysis of greenhouse gas reduction potential in power generation, paper industry and household sector using MARKAL was undertaking at end of 2004. The purposes of the project are to assess technological reduction potential in these sectors. In addition, training of modelers and outreach initiatives using the ETSAP tools were also begun.

Through the database development and analysis project, the MARKAL model has an important role for exploring energy technology policy options in Korea.

Heesung Shin, Jongchul Hong, and Younggu Park studied carbon emissions reductions and carbon capture and sequestration in the iron and steel industry of Korea. Korea’s iron and steel industry was ranked 6th in the world on the basis of production of crude steel. Production in 2000 was 43 million tons. The main facilities of the iron and steel industry are the iron production facilities that have a total of 11 blast furnaces with capacity of 26,010 thousands tons/year. The steel-making facilities are 12 basic oxygen furnaces with capacity of 26,180 thousand tons/year, and electric arc furnaces with capacity of 23,475 thousand tons/year. The energy consumption of iron and steel in 2000 was about 696.3 PJ. The CO\(_2\) emission from iron and coal works was estimated to be 14.3 million tons carbon, about 12% of the national total.

This study used the MARKAL-MATTER model, with special regard to the characteristics of the iron and steel industry that is able to do the Material Flow Analysis. MARKAL-MATTER is able to evaluate various technologies including the flows of products and materials through their life cycles. One hundred technologies were evaluated. The data are mostly from other countries owing to the shortage of statistical data in Korea. The study period was 1995 to 2035. Five cases were analyzed: a base case, a technology case (all technologies are applied), and three carbon tax cases 30USD/ton CO\(_2\), 60USD/ton CO\(_2\), and 90USD/ton CO\(_2\). Consumption (PJ/y) goes from 682 in 2000 to 718 in 2035 in base case. In the tech case emissions go to 684 PJ/y in 2035. The 30USD/ton was identical to tech case. The 60USD/ton CO\(_2\) and the 90USD/ton CO\(_2\) tax case is due to the selection of CO\(_2\) removal technology. The reduction potential without CO\(_2\) reduction technologies will be at most 7% to 8% between 2020-2035, while with CO\(_2\) removal a 38% reduction can be achieved.

**Sweden**

MARKAL activities at the Department of Energy Technology, Chalmers University of Technology

MARKAL activities at the Department of Energy Technology at Chalmers were in 2004 focussed mainly in two areas: a continuation of a study on the value of extended transmission capacities between the Nordic countries and northern Continental Europe, and work on a better representation of the transport sector in the MARKAL_Nordic model.

Chalmers were also active in the ETSAP activities during the year, including participation at workshops, seminars and both of the ETSAP meetings.
Since the deregulation of the Nordic power markets, the peak power dilemma has been high on the agendas of different energy sector stakeholders. However, since both the demand and supply patterns for power differ to a large extent between the Nordic countries there is much to be gained by collaboration between the countries and such collaboration may be able to solve at least some of the peak power problems since the demand peaks look different in different countries and, in addition, differs between the Nordic countries as a whole and the northern Continental Europe countries, mainly Germany and Poland. In fact, there has already been such a collaboration going on for about a century between certain Nordic countries. In an earlier commenced project which was finished in 2004, MARKAL-Nordic was used in an attempt not so much for direct analysis of the peak problem but merely to improve the representation of power trade, in particular between the Nordic countries and the northern Continental Europe, in order to analyse the value of extended transmission capacity. It was found that especially assuming that the Swedish nuclear capacity is going to phased out that there are some possibly important gains from an extended transmission capacity. The results will be published.

It is generally accepted that CO$_2$-reducing actions in the transport sector are less cost effective than in the stationary energy sector. However, since many actions in the transport sector are complex and e.g. involves the poligeneration of power, heat and alternative fuels, there is a need for an expansion of the MARKAL-Nordic, which traditionally has been covering the stationary sector in great detail but the transport sector in less detail, to represent the latter in an improved way and to analyse the possible interplay between the stationary and transport sectors. This work is still on-going.

In addition, Chalmers also participated in the Swedish part of the work on linking the MARKAL-Nordic model to the global IEA-ETP MARKAL model together with the Profu consultancy company in Molndal, Sweden. Please see the Profu description for further details.

**Activities at Profu related to the use of the MARKAL model**

All activities during 2004 have been associated to the use of the MARKAL-NORDIC model, which describes the stationary energy system of the four Nordic countries Sweden, Norway, Denmark and Finland. Activities carried out during 2004 may be summarized into:

*Analysis of the effectiveness of Swedish climate policy*

The MARKAL analyses were done within the “Control Station 2004” project and initiated by the Swedish Energy Agency. The purpose was to evaluate how well current Swedish policy measures perform in terms of meeting climate change targets. Different scenarios for e.g. future energy use and the time-frame for the phasing out of nuclear power in Sweden were investigated.

Updating of existing taxes and energy-demand projections compared to previous versions of the MARKAL-NORDIC model were two major modelling tasks during this project. The distinction between a tradable sector and a non-tradable sector with respect to CO$_2$-emission permits was also introduced in the modelling.

*Analysis of a common Swedish-Norwegian market for tradable green certificates (so-called electricity certificates)*

The work was initiated by the Swedish Energy Agency. The aim was to estimate the benefits from having a common market instead of two separate markets for electricity certificates in
Sweden and Norway. Competition between different renewable technologies, electricity-certificate prices and electricity-certificate trade between the two countries were, among others, highlighted.

Refined modelling of the Swedish electricity-certificate system and the creation of a corresponding system for Norway were two essential model improvements during this project.

Analysis of a new set of energy and carbon-dioxide taxes

This project was also initiated by the Swedish Energy Agency. The aim was to evaluate effects on energy use, energy prices, electricity and district heating supply etc as a result of introducing new taxes on energy and carbon dioxide in Sweden.

“Linking” the regional MARKAL-NORDIC model to the global IEA-ETP MARKAL model.

In this project the Nordic MARKAL model and the global model of IEA-ETP (the ETP project: the Energy Technology Perspectives project) were used jointly. Common input data related to e.g., fossil fuel prices and technology learning were used. One prime objective was to compare the results of a global model to corresponding results from a regional model with a better data resolution on a regional scale. Consequences of different emission-permit prices, the introduction of targets for renewable electricity, the phasing-out of nuclear power, the role of carbon-dioxide sequestration and disposal etc could, thereby, be evaluated on a global and a regional (Europe and the Nordic countries) scale.

An improved and updated modelling of carbon sequestration and disposal options (based on a recent report by IEA) in MARKAL-NORDIC was carried out within this project.

Switzerland

Various activities of the Energy Economics Group (EEG) at Paul Scherrer Institute (PSI) are mentioned in the International Studies, Collaborations, and Contributions section of this report.

In addition, in collaboration with the University of Geneva, PSI-EGG has undertaken the development of a “bottom-up” energy-systems MARKAL model for Switzerland. The Swiss MARKAL model allows a detailed representation of energy technologies and the assessment of the impact of policy measures on the long-term trajectory of the Swiss energy system (Schulz et al., 2004) and is being used in evaluating long-term sustainability strategies in Switzerland, such as the concept of the 2-kW/capita society.

Attention was also given to the diffusion of fuel-cell vehicles in the passenger car sector of China (Rits et al., 2004). These analyses have indicated that there is potential for promising advanced technologies such as fuel cells and high-quality energy carriers such as hydrogen to play an important role in the transportation sector, and specifically in the passenger car sub-sector, in the long term but a number of hurdles still have to be surmounted.
Turkey

Analysis of the Effects of Greenhouse Gas Emission Reduction on Turkish Energy and Economy Systems

MARKAL Economy-Energy-Environment Model and ANSWER software has been used to analyze different strategies for mitigation of greenhouse gas emissions of the energy sector in Turkey. The methodology has been explained and a reference scenario and three alternative scenarios have been compared in the eventual sections.

Comparison of Results
Total system costs of different scenarios are compared to the cost of the BASE case. Here the change will be examined rather than the exact costs as it would be not realistic to claim to have calculated the exact costs of an energy system. There are too many variables which can affect this number. Yet under ceteris paribus it would be more realistic to compare the change in percentage from the reference scenario.

Figure 1 - Total System Costs in Comparison

Figure 2 - CO2 Emissions in Comparison
Table 1 - Emission Mitigation Rates of Different Scenarios in Comparison

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BASE</td>
<td>204,1</td>
<td>373,4</td>
<td>527,9</td>
<td>739,9</td>
<td>1318,2</td>
</tr>
<tr>
<td>CARBON</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-2,96</td>
<td>-4</td>
</tr>
<tr>
<td>EU</td>
<td>0</td>
<td>-14,47</td>
<td>-20,09</td>
<td>-74,16</td>
<td>-85,34</td>
</tr>
<tr>
<td>KYOTO</td>
<td>0</td>
<td>-14,47</td>
<td>-29,3</td>
<td>-80,71</td>
<td>-89,2</td>
</tr>
</tbody>
</table>

KYOTO and EU scenarios show very radical CO2 emission mitigation while CARBON scenario shows a modest decrease in comparison. This is also due to the scenario settings where the EU and KYOTO scenarios have an upper emission bound (limit). (Table V.1.)

Figure 3 - Total Electricity Production and Importation in 2020

Figure 3 shows that the least foreign electricity dependency is in the CARBON scenario. To be able to achieve the emission targets set for the EU and KYOTO scenarios more than 50% of the electricity needs to be imported. This is due to the fact that the maximum possible investment in renewable technologies is limited in this rather short period of time.

As a side scenario to analyze the possible effects of investments to increase the transmission efficiency, the model is run for all the alternative scenarios under the assumption that the transmission efficiency is increased from 81% to 93%. The loss of electricity by distribution and transmission is up to 19% while this number is 6-7% in EU in average. Furthermore, the scenarios with higher transmission efficiency EU1 and KYOTO1 show very important savings in electricity importation, while the impact on CARBON scenario is rather on the natural gas importation as the natural gas power plants are working in lower capacity to satisfy the same demand as the loss at the transmission of electricity is less.

Table 2 shows that investment in transmission efficiency increase actually reduces the total system cost for all scenarios. This means the economical value of the savings is higher than the
investment in transmission efficiency. Less money would be spent to satisfy the same amount of energy demand while keeping the emissions at the same level as in the base cases.

Table 2 - Economical Effect of Transmission Efficiency Increase: The Change in the Total System Costs

<table>
<thead>
<tr>
<th>Case</th>
<th>Value</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>KYOTO</td>
<td>15017318</td>
<td>-</td>
</tr>
<tr>
<td>KYOTO1</td>
<td>14975597</td>
<td>-0.278</td>
</tr>
<tr>
<td>EU</td>
<td>13799772</td>
<td>-</td>
</tr>
<tr>
<td>EU1</td>
<td>13764061</td>
<td>-0.259</td>
</tr>
<tr>
<td>CARBON</td>
<td>675960</td>
<td>-</td>
</tr>
<tr>
<td>CARBON1</td>
<td>661904</td>
<td>-2.079</td>
</tr>
</tbody>
</table>

Conclusions

Although currently Turkey is not one of the main contributors to the global climate change problem, it has to take measures as soon as possible to curb its greenhouse gas emissions as its economy develops fast and its energy demand grows accordingly. If Turkey does not prepare an integrated approach to its energy production and consumption and its effects on the environment and economy, and starts investing accordingly, future tries will be much more costly and less effective.

The results of the scenarios established and analyzed for this paper show briefly:

- As a first step the most beneficial and effective way to curb CO2 emissions would be to invest in transmission efficiency increase.
- Another beneficial way would be to invest in technical efficiency of the power plants.

Further researching and investigation needs to be done on the demand side. There is a huge area where cost effective measures can be taken to increase energy efficiency of demand technologies and indirectly curb emissions. Yet this area was not the topic of this paper.

On the energy generation side renewable energy sources, especially wind turbines and small hydroelectric power plants show big potential. With zero emissions and moderate cost it is clear immediate action is needed to invest in these technologies if Turkey wants to fulfill its obligations to EU and the United Nations Framework Convention on Climate Change.

The new Renewable Energy Law approved by the Turkish Parliament and its effects on the energy market is also a very important area where MARKAL could be utilized. The possible effects of the regulation can be foreseen with the help of this modeling systems and the Law could be modified accordingly in a proactive way.

**United Kingdom**

**Options for a Low Carbon Future**

Modelling work in the UK during Annex VIII focused on the use of MARKAL to provide analytical support to the development of the UK Energy White Paper (DTI, 2003a) and a number of follow-up activities. One of these follow-up activities was to produce a short overview of the
MARKAL work and to compare the results with those from other studies (Leach, 2004). The following provides a summary of this paper.

The background analysis (DTI, 2003b) for the 2003 UK Energy White Paper produced a large number of studies of the technological options for and costs of reducing UK CO₂ emissions by 60% by 2050. More than 70 sets of scenarios and technology assumptions were explored based on the following low carbon technologies and practices:

- The growth of energy efficiency in homes, industry, commerce and transport;
- An increased use of natural gas for electricity generation;
- The use of coal and natural gas for electricity generation, with the carbon dioxide being captured and stored in geological formations;
- Nuclear power for electricity generation;
- The full range of possibilities for renewable energy—onshore and offshore wind, wave and tidal energy, solar PVs, and biomass for heat, power and liquid fuels for transport;
- Decentralized heat and power based on new micro technologies;
- The production of hydrogen from gas, and coal (with the carbon being captured and stored) and biomass,
- The production of hydrogen by electrolysis from renewable energy and nuclear power, for use as a fuel for homes (e.g. for decentralized CHP), industry and transport.

Some studies assumed all these options were open or emerging and that the choices would be based on cost efficiency, subject to constraints on resource availability (e.g. land availability for biomass and the number of onshore and coastal sites available for wind) and technical factors (e.g. attainable build rate for power plant). Other studies repeated the exercises, but imposed constraints on, for example, the rate of uptake of energy efficiency, investment in new nuclear stations, and investment in carbon capture and storage. All the possibilities were also subjected to sensitivity analysis with respect to economic growth, innovation and costs, and world oil and gas prices.

There were three general findings discussed below.

First, deep cuts in carbon emissions are technically and economically feasible over the long term. The engineering challenges facing industry will be immense: to develop the technologies further and reduce costs; to transform the energy supply infrastructure as it is renewed over the next 50 years; to develop our R&D capacity in new areas, and to develop the policies for the demonstration and commercialization of new options; and not least to invest in the education and training of engineers and skilled labor. However, the options are available and capable of being developed further, including a range of energy efficient technologies and practices, renewable energy technologies, nuclear power, carbon capture and storage, hydrogen production, and perhaps a move to new more decentralized energy supply and demand management systems than we have today.

Second, the costs of a measured transition (this is an important qualification) to a low carbon economy over the next 50 years may or may not be high in absolute terms, depending on how far innovation succeeds in reducing the costs of the alternatives. But relative to total GDP and its growth, costs are unlikely to be high, typically around 0.5-2%—or less than one year’s
growth—of GDP, which can be expected to expand two- to three-fold over the next half century. Studies elsewhere have indicated that the cost range may be wider than this, from being less than 0.0%—which would imply an increase of economic output—to over 4.5%. Most, however, fall in the range 0.5 to 3.5% (with a mean estimate of 2.5%), and similarly conclude that overall effects on GDP would be small in relation to economic growth over the next half century.

Third, innovation, and the policies that support it, will be crucial for developing options further and reducing costs. Presently the costs of the alternatives—renewable energy, nuclear power, carbon capture and storage, fuel cells, hydrogen production for example—are significantly higher than those using conventional fossil fuel options. There are exceptions, with improvements in energy demand management and efficiency providing several examples. However, in all areas there is appreciable scope for reducing costs through innovation. The history of energy supply, conversion and use is replete with examples of costs being reduced with innovation, in some cases by orders of magnitude. There is no evidence that this process has come to an end, quite the opposite.

Studies in other countries and internationally have arrived at similar conclusions regarding the options available or emerging, their costs and the importance of innovation (e.g. Grubler et al., 2002; Alic et al., 2003; Goulder, 2004).

There is a need for greater understanding and dialogue on the possibilities for addressing climate change based on innovation. As a contribution to this process, this paper first summarizes relevant background studies produced for the Energy White Paper (EWP), compares them with recent international studies and selected studies in other countries, and finally draws some implications of the results for climate change policy.

Overview of the UK Energy White Paper ‘Low carbon options’ modeling process
As an input to the Inter-departmental Analysts Group and later to the EWP development process, Future Energy Solutions and ICEPT were contracted to investigate scenarios for CO2 emissions reductions.¹⁹

Use of the MARKAL model
The system that delivers energy services—light, heat, motive power, etc.—to the consumer comprises a diverse array of extraction, conversion, transmission, distribution and end-use technologies, and a complex electricity, gas and fuel distribution network. This study set out to investigate how this system and its component technologies might evolve over the next 50 years to achieve substantial reductions in carbon dioxide emissions, and what the costs would be. In order to capture the full range of technological options available - and their development over a long time horizon - a ‘bottom up’ or engineering-based modeling approach was selected.

Scenarios modeled
The study examined three scenarios for the possible future development of the UK economy and the associated demands for energy related services:

- Baseline,
- World Markets (WM) and
- Global Sustainability (GS).

¹⁹ DTI (2003b) ‘Options for a Low Carbon Future, Economics Paper No. 4’. The paper was based primarily on reports by Future Energy Solutions (FES) and the Imperial College Centre for Energy Policy and Technology (ICEPT)
They were selected to match with other analysis underway within Government, and WM and GS
scenarios are based on those developed by the Energy Futures Task Force of DTI’s Technology
Foresight Programme (DTI 2001). They provide estimates of trends in national economic growth,
structural changes (e.g. reductions in energy intensive industry, change in the utilization of
transport modes, increased share of service sector activities in total GDP) and changes in
population. In the absence of the modeled efficiency and low carbon measures discussed below,
they point to annual reductions in energy intensity of 1.4%, 1.9% and 1.6% for Baseline, WM and
GS scenarios respectively, compared to the UK’s average reduction of 2.1% per year over the
past 30 years.

Applied to each scenario, three levels of abatement by 2050 were considered relative to emissions
in 2000: a 60% reduction – approximating to the level considered by the Royal Commission on
Environmental Pollution (RCEP, 2000) – plus 45% and 70% reductions.

The estimates of future energy consumption and carbon dioxide emissions for each scenario were
developed through a systems approach using the IEA’s MARKAL model. MARKAL is a bottom-
up and technology-based model that identifies the least-cost combinations of technological
processes and improvement options that satisfy specified levels of demand for goods and services
under given constraints, with the objective of minimizing the overall system costs for all time
periods simultaneously. Broadly there are two sets of constraints: those set by technological
feasibility and resource availability; and those set as policy objectives or conditions. The most
common policy objective investigated is the achievement of specified greenhouse gas emission
reductions.

MARKAL is ‘driven’ by projections of the demands for energy services and material goods
throughout the modeled period. These projections were developed externally for each scenario,
and subsequently supplied to MARKAL. In the present application, the period from 2000 to 2050
was divided into ten years blocks. The energy system was modeled for the years 2000, 2010,
2020 and so on to 2050.

The energy system represented in MARKAL omits some parts of the total, responsible for
approximately 15% of total carbon emissions. The most significant omissions are refinery
operations, solid fuel production, own consumption by the oil and gas industries, agriculture,
construction and water transport.

The emissions constraint applicable for any one model run was applied in 2050, and an interim
constraint was applied in 2030 (of approximately half of the full 2050 reduction percentage), to
reflect existing emission reduction policy activities for the short/medium term.

The model was used to provide solutions for the UK energy system to 2050 under the three
scenarios and with the three levels of emissions reduction, taking account of the costs,
performance and emissions of alternative supply and demand technologies specified as available
in each period.

Given the range of uncertainties about future development paths and technological choices 50
years hence, great importance is attached to studies of the sensitivity of results to changes in
assumptions.

Review of key findings
For all three scenarios, when no emission constraint is applied carbon emissions are still seen to
fall from 2000 to 2050. The rate of decline equates to a fall in emissions intensity (emissions per
unit of GDP) of between 2.7% and 3.1% per year – compared to the 30 year historical average of 2.9%. The decline is due to uptake of energy efficiency measures on the demand side, and efficiency improvements in the supply side. Such improvements were a model outcome even in a non-carbon-constrained world, due to apparent cost benefits. Uncertainty surrounding the likely uptake of efficiency measures was addressed through subsequent sensitivity analysis, with constraints placed on energy efficiency improvement.

When carbon emission constraints were applied, substantial changes in the patterns of demand and supply occurred, with the mix of action including a variety of measure types (e.g. further improvements in end-use energy efficiency, switches to lower carbon fuels and change towards more efficient conversion devices) and involving all sectors.

The main findings can be grouped under three headings: the diversity of options for carbon abatement; the effects on costs, prices and economic growth; and implications for innovation policy. (Only the more salient results are discussed below; the reader is referred to DTI (2003b) for more information.)

Diversity in technological options
There is a rich diversity of technology options for reducing CO2 emissions from both energy supply and the main energy consuming sectors of transport, industry, domestic and services. Further, the individual options can be combined in a variety of different ways to achieve the desired emission reductions, leading to a range of possible energy system structures.

Key points include are summarized below.

- Variety of options, many at comparable cost

The long range nature of the modeling and the inherent uncertainties in that process suggest that using the study to pick winners is not appropriate. But the results suggest there are five broad families of options that are important for the realization of a low carbon future: energy efficiency, renewable energy, carbon capture and storage, nuclear power and hydrogen. They may not all need to be deployed simultaneously for achievement of emission constraints at acceptable cost, but it is clear that no one family can offer the reductions required.

It is also clear that there are a variety of competing options within both electricity and transport fuels which have the potential to achieve comparable abatement costs. For example, there are numerous electricity generation technologies capable of performing in the range 2.5 to 3.5p/kWh, including several of the renewable options, gas turbine combined cycle with carbon capture and storage and nuclear power. Thus the modeled costs of meeting emission constraints are relatively robust to changes in assumptions about availability or performance for any one option, as there are a variety of other options to fall back on. This is explored further for nuclear and carbon C&S below.

The figures below illustrate the range of technological or fuelling combinations which were found to meet a 60% reduction under a selection of the various sensitivity runs, for ESI and transport sectors. Note that demand varies depending on scenario (Baseline - BL or Global Sustainability - GS) and assumptions about, and uptake of, energy efficiency, and hence the aggregate height of the bars varies between scenarios. Results are presented for the ESI for runs with the core assumptions for each of the BL and GS scenarios, and for sensitivity runs assuming: higher nuclear capital costs; limits to the supply of natural gas to the UK; limits to the uptake of energy
efficiency measures; a declining capacity credit for increasing wind power penetration; with the exclusion of nuclear power or carbon capture and storage, or exclusion of both.

Figure 2: Electricity generation in 2050 under a 60 % carbon constraint

Results are presented for the transport sector for runs with the core assumptions for the BL scenario, and for sensitivity runs assuming: limits to the uptake of energy efficiency measures; higher cost, dedicated hydrogen distribution infrastructure; two alternative non-fossil fuel tax regimes; the exclusion of both nuclear power and carbon capture and storage.

Figure 3: Fuel use in the transport sector in 2050 under a 60 % carbon constraint
Energy efficiency

The implementation of energy efficiency technologies and measures is central to achieving the abatement targets irrespective of which supply side technologies are used.

Energy efficiency is taken up quite strongly even before emission constraints are imposed - with efficiency in energy use improving by around 36% over the period - and more strongly still when they are. Final energy intensity improves annually by around 2.3% without constraints, and by 2.6% for 60% abatement. The thirty year average improvement in energy intensity of the UK economy is 2.1%, reflecting a substantial decoupling of economic growth and energy demand. The modeled scenarios reflect a continuation of the historic experience with some heightened focus on efficiency opportunities.

Besides their direct contribution to abatement, the reductions in energy demand through efficiency measures considerably reduce the costs of other options to meet the abatement targets. When the rate of improvement in energy intensity was limited to the average rate for the last decade (1.6%) the total discounted cost of abatement over the 50 year period in the BL scenario increased four fold (i.e. £41bn to £164bn).

Natural gas takes a growing share of primary energy

Natural gas is attractive economically and has relatively low carbon emissions. In scenarios where overall natural gas supply is not subject to constraints, it takes a growing share of primary energy supplies. The higher gas price scenarios tested made little difference to results, as gas turbine combined cycle power generation is significantly cheaper than other options, and thus assumed gas price changes did not alter significantly its ranking in generation costs. Natural gas clearly has a strong competitive position for power generation. When its use was limited to year 2000 supply levels, construction of new nuclear capacity, further biomass and wind plant took place after 2020, with natural gas reserved for direct use for heating by end-users, and production of hydrogen for road transport. Since this analysis was undertaken, oil and gas prices have risen strongly. Whether such high prices are likely to remain in the long run, and the implications of this for current long term price scenarios, require further study.

Hydrogen production routes and sensitivity to infrastructure costs

With emission constraints applied, hydrogen technologies are deployed in all three scenarios. In the core scenarios, hydrogen is produced from natural gas with CO₂ capture and disposal, and serves primarily the transport sector (with fuel cell vehicles eventually replacing gasoline cars and diesel HGVs). Some hydrogen also penetrates the space heating market, as a ‘hythane’ mixture with natural gas. If natural gas supplies are limited, some hydrogen is produced by biomass gasification. Production through electrolysis of water was never deployed under the cost assumptions made.

There is considerable scope for limiting the costs of the transition to a hydrogen system through making natural gas infrastructure compatible with hydrogen distribution and use as the infrastructure is being renewed over the next 50 years, and initial assumptions about infrastructure costs were based on this premise. To explore the range of possible infrastructure costs, these relatively optimistic assumptions were replaced with costs illustrative of the establishment of a completely new hydrogen distribution infrastructure, with the effect that hydrogen use was much reduced. In its place, other alternative fuels without such new infrastructure needs (such as methanol produced from natural gas) were used. Assuming centralized production of hydrogen and distribution by road tanker, a third less hydrogen was
used, with deployment delayed. Higher emissions in transport were then balanced by further energy efficiency in the residential sector. If a new pipeline infrastructure was required (with even higher costs) most hydrogen use was eliminated. The analysis of infrastructure options and costs was relatively crude and, given this high sensitivity, further work is warranted.

- **Nuclear/CC&S non-availability**

It is possible that certain of the above families of technologies (e.g. nuclear power, carbon capture and storage) or subsets of them may be excluded from future decisions through considerations of safety, public acceptance or other policy or through unexpectedly slow technological development. Sensitivity runs were undertaken to explore the effects of removing nuclear power or carbon capture and storage from the options available to the model, and then the effect of removing both simultaneously.

**CC&S removal:** all the abatement targets are still attainable, but the discounted system cost is increased by 90% for the 60% emission reduction constraint. Both electricity generation and hydrogen production were affected: GTCC generation was replaced with additional nuclear capacity; biomass was diverted from electricity generation to hydrogen production, causing a further increase in nuclear generation. In addition extra energy efficiency savings were made in the industry and residential sectors.

**Nuclear removal:** nuclear capacity is built in most core scenario runs when emissions are constrained to -60%, from around 2030 onwards. If nuclear is not available, it is still feasible to achieve abatement targets through greater deployment of alternative low to zero carbon technologies. For a 60% emissions reduction constraint, nuclear capacity was replaced with GTCC plant with carbon dioxide capture and storage, increases in hydro, wind and biomass generation, and further energy saving in the industry sector. The effect on discounted system cost was negligible.

**CC&S and Nuclear removal:** the 60% abatement target can also be attained without either technology, through large increases in deployment of energy efficiency measures and greater deployment of a wider variety of renewable electricity generation from 2030 onwards. However, this resulted in a much larger increase in total discounted abatement costs, of around 250% - some high cost renewables (e.g. Photovoltaics) were needed to meet electricity demand. This scenario is regarded as technologically feasible, but it is also demanding - in terms of the technical progress needed across a broad range of measures, and the energy system effects and infrastructure needs that would result. This reinforces the case for strong innovation policy.

**Abatement costs**

Abatement costs are highly uncertain, but the effects on the UK’s economic growth prospects are likely to be small. Total discounted abatement costs over the period to 2050 have been calculated at both a 3.5% and a 6% discount rate: the range across the core scenarios and sensitivity runs is £17bn to £170bn, with most of the runs having costs between £30bn and £60bn. Annual costs by 2050 range from £7bn to £42bn per year, with most runs below £20bn per year. The scenario variants giving the highest costs were those involving very limited uptake of energy efficiency measures, a combination of limited energy efficiency and no carbon capture and storage or a lack of innovation (cost and performance improvement) in supply-side technologies.

- **GDP effects**

GDP in 2050 is expected to be at around £2500bn. Hence the annual abatements costs in 2050 range from a low of around 0.3% to a level approaching 2% of GDP in 2050, with most cases less
than 0.5% of GDP. This equates to a reduction of between 0.01 and 0.02 percentage points in the average GDP growth rate over the period between 2000 and 2050 (i.e. from an assumed 2.25% a year under the baseline scenario to perhaps 2.23% to 2.24% a year). While the changes implied by the scenarios might not be disruptive to overall economic growth (and might well produce new economic opportunities), the transformations in the energy industry and in the ways we use energy would be profound, with structural changes and a variety of impacts across sectors.

**Effects on end-user prices and costs**

In the medium term (e.g. 2020), there is little impact on overall sector energy costs, as the model deploys mainly cost-effective energy efficiency measures to that point. In the longer term, abatement measures increase the energy costs of all sectors of the economy. By 2050 total energy costs are about 20% higher than they would otherwise have been for the domestic, service and industry sectors and are over 50% higher for transport. However, MARKAL and other bottom-up models are not able to look at the effect of abatement on energy prices directly (as opposed to costs of action) or at likely behavioral price responses by consumers – probably acting to reduce consumption in the face of rising prices, and thereby at least partially mitigating rising bills.

**Marginal cost range**

The marginal costs of abatement in 2050 vary across scenarios, with most of the runs having marginal costs of less than £900/tC and with more than 50% of less than £500/tC. Marginal costs in 2030 are much lower, typically between £25 and £150/tC. Average abatement costs vary much less between scenarios. For almost all scenarios, a similar set of measures are taken up as the most cost effective, with stable and relatively low costs. The very high marginal costs for some scenarios typically reflect the inclusion of one or more expensive options brought in, for example, through sensitivity analysis assumptions. Whilst the costs of these specific measures may be high, they are responsible for a relatively small share of the overall abatement, and thus average costs fluctuate less.

**Innovation and technical progress**

Innovation and technical progress are central to the attainment of a low carbon economy while continuing to provide energy related services at costs that are not far removed from current levels.

A common feature of the cost data and estimates reviewed for this study is that innovation and technical progress are expected to reduce the costs of the emerging technologies. There will continue to be disputes over the precise costs and on which technologies may emerge. But the ranges in possible costs of many key options overlap strongly and it is very likely that the range of possibilities that do emerge will be even greater than those considered in this study.

The importance of innovation is illustrated by the two sets of sensitively runs which considered greater innovation and frozen performance respectively. The higher innovation rates led to further reductions in emissions under the unconstrained GS scenario of around 15 MtC in 2050, such that 2050 emissions are already 45% lower than in 2000. The cost of the additional abatement needed when the 60% abatement constraint is applied is thus much reduced. When technology performance was frozen at 2010 levels (not realistic but meant to gauge the importance of innovation), total system costs increased more than fourfold. Under the assumptions tested for

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20 In the model runs used for this analysis MARKAL was prevented from deploying additional energy efficiency when the emissions constraints were applied. Consequently these estimates represent an upper limit to the sector costs for the Baseline scenario.
this study, greater innovation may also lead to an increased diversity in power generation and transport technologies, or at least wider deployment of the emerging options, such as hydrogen and fuel cells, and a decrease in nuclear power as new renewable technologies become cost competitive.

The underlying importance of technical progress and innovation for (a) creating options that would not otherwise be available, and (b) for reducing costs, is clear.

- **Advantages to early action**

A variety of scenarios were used to investigate the influence of the timing of abatement action. Whilst long term targets are typically couched as annual emission reductions (e.g. -60% in 2050), from a climate science perspective it is the aggregate emissions from now until a future date that matters. Meeting 2050 targets through rapid change towards the end of the period results in much lower aggregate reductions than does early or progressive action.

The discounted costs are higher for scenarios when abatement starts early and are least when abatement is delayed the most. However, the cumulative abatement to 2050 when starting abatement in 2000 is nearly twice that for the scenario in which abatement starts in 2030. Judged on a cost per tonne basis, the additional costs associated with acting sooner are more than offset by the extra cumulative abatement. If action to reduce emissions is delayed, but the same cumulative reduction is achieved as under a linear reduction from 2000 to 2050, then costs increase progressively: the cost of a linear reduction scenario is £58bn. Achieving the same cumulative reduction to 2050 but starting in 2010 costs £72bn and starting in 2020 costs £123bn. If action was delayed until 2030, then such enormous reductions were required in 2050 that they were impossible with the technology options available. This is true irrespective of discount rate.

These results suggest that it is important from the climate perspective to have a series of interim abatement targets and not just a long term goal, i.e. that phasing is important. The results also suggest that from a climate science perspective early action is warranted and will help reduce overall costs. From the broader innovation research field, there is also good evidence that early action stimulates technical progress and innovation, which reduces the cost of individual measures and stimulates the range of options available. These issues are addressed in Section 3.

- **Action is needed in all sectors**

Results across the study showed that emission reductions are required in all end-use sectors, and by all types of available measure to achieve targets in the long term at lowest cost. Some specific points arising from the study are identified here.

- There is generally an equal role for energy efficiency and fuel switching measures.
- As emission constraints tighten (by scenario, or over time within a scenario) energy efficiency tends to be taken up first, followed by abatement in electricity generation and then in transport.
- Under most scenarios the share of renewables in electricity generation increases to between 25% and 40% by 2050. If new nuclear build and carbon capture and storage are excluded, the renewables share increases further.
- There are strong interactions between some sectors, as fuels change: for example, introduction of biomass-derived transport fuels brings competition between stationary power generation and transport for the biomass resource.
Energy conversion efficiency (i.e. the ratio of Final Energy demand to Primary Energy supply) actually declined because of an increase in demand for processed fuels such as electricity and hydrogen, and the deployment of carbon capture, which involves an efficiency loss.

United States

Brookhaven National Laboratory [U.S. Department of Energy]

A Portfolio Approach in Local Energy Planning and Building Upgrades: The Case of New York City [John Lee, Brookhaven National Laboratory, Upton, NY, USA, Edward Linky, U.S. Environmental Protection Agency, Region 2, New York, NY, USA, Owen Carroll, State University of New York, Stony Brook, NY, USA]

The adverse economic impacts of the Great Blackout in America’s Northeast in the summer of 2003, coupled with the increasing demand for electric power due to the urban heat island (UHI) effect demonstrates the need for better energy planning and mitigation strategies in major metropolitan areas such as New York City. This study proposes to use a portfolio of models interactively to evaluate mitigation strategies covering demand side management, upgrades in buildings (e.g. green roofs), and distributed electricity generation (building combined heat and power). A detailed New York City MARKAL model will be developed to simulate current and projected energy and electricity demands, electricity transmission and distribution requirements and peak load patterns.

The EnergyPlus model (U.S. Department of Energy) will be used to quantify, in selected load pockets and hot spots, the impact on energy use and electricity load in buildings based on changes in specific building characteristics and equipment. The aggregation of these impacts and their associated costs can be modeled as conservation supply curves in MARKAL for analyzing the overall impact of these mitigation strategies, including emission reductions. The Pennsylvania State University / National Center for Atmospheric Research numerical model (MM5) will be used to measure the change in UHI effect resulting from application of mitigation strategies in these load pockets and hot spots. The reduction of this effect in these locations, in turn, reduces the projected cooling demand in MARKAL, which with its energy and environmental pathways provides the common corridor for the networking of model portfolios in urban planning.

Hydrogen Economy: Opportunities and Challenges [Phillip Tseng, John Lee, and Paul Friley]

This study examined the transition from a petroleum-based energy system to a hydrogen economy. A hydrogen economy is the long-term goal of many nations because it provides security, environmental, and economic benefits. The transition involves many uncertainties. They include development of fuel cell technologies, hydrogen production and distribution infrastructure, and the response of petroleum markets. This study used the U.S. MARKAL model to simulate the impacts of hydrogen technologies on the U.S. energy system and identify potential impediments to a successful transition to a hydrogen economy. Insights from the quantitative analysis can provide valuable inputs to decision-makers in planning R&D, and in designing economic incentives.

The analysts assumed that, as a result of successful research, development and deployment, hydrogen production system design and fuel cell vehicles would be cost competitive with petroleum-based technologies. They focus on hydrogen production from coal, natural gas,
biomass and electrolysis. They do not address the chicken and egg problem in introducing hydrogen technologies into the U.S. Energy system.

The MARKAL model’s output includes the least-cost configuration of the energy system, “shadow prices” for energy carriers and environmental emissions, and reduced costs for technologies that are constrained by bounds.

The specific segment of the hydrogen economy modeled consisted of a set of feedstock supply curves of natural gas, coal, and biomass. These feedstocks are sent to three process technologies: gas reforming, coal-, and biomass-gasification. Their output is joined with hydrogen production from electrolysis further downstream. Carbon sequestration is modeled as an option for gas reforming and coal gasification at additional cost. The hydrogen produced is modeled to go through an intermediate delivery infrastructure and storage for meeting the demand of highway vehicles. The economic and technical attributes of the hydrogen fuel cell vehicles improve over time. The quantitative analyses were based on the differences in the model’s output between a reference case and a “Hydrogen Economy” scenario.

The transition requires constructing many new hydrogen plants and fueling stations. The new infrastructure must serve the emerging demand for hydrogen, and meanwhile, utilize the existing infrastructure, such as gas pipelines and railroads to minimize the delivered price. In the U.S., hydrogen plants plausibly will be situated close to the load center and to rail or pipeline terminals to minimize the expenses of transportation.

The “Hydrogen Economy” scenario was based on achieving a production cost of $0.50 to $1.00 per gallon of gasoline equivalent at gate (GGE). At $0.75 per GGE the respective feedstock costs for natural gas, coal and biomass are $3.5, $2.0 and $1.0. per GJ. For transporting via pipeline and storing hydrogen (in gas form), approximately $0.65 to $0.85 per GGE based on an average delivery distance of 50 to 100 miles between production facilities and demand centers. In the next five years the US government will provide R&D funding of about $1.7 billion for hydrogen and fuel cell technology.

The transition from a petroleum-based energy system to a hydrogen economy will reduce demand for petroleum, lower oil prices, and reduce crude oil throughputs into petroleum refineries. Energy security will improve as sources become more diverse.

On the demand side, the model’s results show that hydrogen fuel cell vehicles compete well against conventional and hybrid vehicles.

Given the assumptions on hydrogen conversion technologies and resource costs, coal appears to be the most competitive way to produce hydrogen without considerations about carbon emissions. Recent studies showed that capturing CO₂ adds about 25 to 30% to the cost of producing hydrogen. Hydrogen technologies can reduce carbon emissions if hydrogen is produced from renewable technologies or nuclear energy.

There are several challenges. These include lowering hydrogen price at the pump to $1.60 to $2.00/GGE. This will require improvements throughout the entire hydrogen economy. Improvements in fuel cells will require revolutionary breakthroughs. An economic incentive is needed to encourage the building of hydrogen infrastructures. Determining the best method of transport of hydrogen is a challenge.
Evaluating the pollutant emissions and air quality implications of future technology scenarios [Cynthia Gage, Joseph Decarolis, Cynthia Gage, Tim Johnson, Dan Loughlin, Carol Shay, Sonia Yeh – U.S. EPA]

The U.S. Environmental Protection Agency’s Office of Research and Development (ORD) is carrying out several activities involving the use of the MARKAL model to evaluate future technology scenarios. One such activity is the development of pollutant emissions growth factors for ORD’s Global Change Air Quality Assessment. The purpose of the Assessment, which is being carried out under the U.S. Federal government’s Climate Change Science Program, is to evaluate the air quality implications associated with global change, considering factors such as economic growth, population growth, climate-induced meteorological change, land use and land cover change, technology change, and government policy. The Assessment is a multi-model exercise, involving the linkage of models to address these factors. Figure 1 depicts the linkage between the various types of models.

ORD is using MARKAL to model alternative technological scenarios that input into the emissions modeling process, with a focus on the electricity generation and transportation sectors. The resulting emissions growth factors will be used within the EPA’s emissions processing and air quality models to estimate future-year emissions and to assess ambient ozone and particulate matter concentrations across the U.S. in 2050. To support this exercise, ORD will be regionalizing its MARKAL database (at the sub-U.S. level) and extending the database to 2055.

ORD is also tasked with developing tools to assist regional, state, and local decision-makers adapt to global change. To this end, ORD has partnered with the Northeast States for Coordinated Air Use Management (NESCAUM) to develop a 6-state MARKAL model for the New England
region of the U.S. This model, called NE-MARKAL, will be used to evaluate the implications of various state energy- and environmental-related actions on the energy system and pollutant emissions. ORD and NESCAUM are exploring linkage of the NE-MARKAL model to other models, with the goal of supporting integrated multi-model assessments. For example, ORD has demonstrated the linkage of MARKAL to a response surface model (RSM) that can be used as a screening tool to evaluate air quality impacts. RSM outputs can also be linked to benefits and economic models to evaluate health and economic impacts. ORD has also demonstrated the linkage of MARKAL to a mobile emissions model, allowing for the development of mobile emissions inventories that represent spatial and temporal variability.

Another area of work within ORD is the development of tools for carrying out sensitivity and uncertainty analysis. Modeling future technological scenarios with MARKAL is an inherently uncertain process, as there are uncertainties in characterizations of current and future fuel supplies, energy demands, and technology attributes. It is important to characterize input uncertainties and evaluate their effects on the uncertainty in model outputs. It is also important that uncertainties in model inputs and outputs be communicated effectively to decision-makers.

To address these issues, ORD has implemented a framework for conducting sensitivity and uncertainty analyses with MARKAL. Figure 2 depicts an illustrative example of a parametric sensitivity analysis using MARKAL within the framework. The graph shows the percent changes in a model output (e.g., the penetration of a particular technology) corresponding to parametric changes in four model inputs (e.g., the costs and efficiencies of competing technologies). This figure is useful in showing both the relative magnitudes of responses and the threshold levels by which each input must be modified to induce a response.

![Figure 2. Sensitivity diagram showing the response of Output 1 to parametric changes in four inputs.](image)

The Monte Carlo results can be analyzed with statistical and graphical tools to identify key relationships and to determine probability distributions for model outputs. Figure 3 provides an example output of such an analysis. The scatterplot matrix shown is a tool for visualizing the data so that an analyst can identify complex relationships among model inputs and outputs. In this instance, scatter plots are provided showing the relationship of each input to each output. The points can be shaded or colored to represent the values of other attributes of each solution. The values on the figure are statistical correlation coefficients.
Figure 3. Example of a scatter plot matrix showing the relationship among model inputs and outputs.

The distributions for one or more outputs can also be characterized statistically and graphically. Figure 4 provides examples of a histogram, a cumulative distribution plot, and a box-and-whisker diagram applied to MARKAL Monte Carlo outputs.

Figure 4. Examples of histogram, cumulative distribution function, and box-and-whisker diagrams applied to MARKAL Monte Carlo outputs.

The results of sensitivity and uncertainty analysis are used in improving our knowledge about complex issues, such as fuel switching and cross-sector dependencies. Results are also useful in determining how to allocate efforts most effectively for refining input data and reducing output...
ORD is applying these sensitivity and uncertainty analysis tools and methodologies to evaluate the system-wide impacts (e.g., cost, fuel use, and emissions) of new technologies.

In addition to these activities, ORD has supported the implementation of a technique called Modeling to Generate Alternatives, or MGA, into MARKAL. MGA is an exploratory modeling technique that can be used to develop alternative technological scenarios that meet the specified constraints via very different approaches. The alternatives may reveal interesting, innovative approaches for meeting demands. Further, examination of a large set of these alternatives provides information regarding the flexibility available in cost-effectively solving the problem. For example, if all of the alternatives make use of a specific technology, this may suggest that that technology is necessary for cost-effectively meeting demands.

Figure 5 provides illustrative MARKAL-MGA results. For each of the eight alternatives, the graphs show the capacities of various technologies (represented by shading) that are selected to meet a particular demand over the modeling time period (left to right). The results suggest that there is considerable flexibility in how the demand is to be met.

Figure 5. Technology penetrations in the least cost solution and seven MGA alternatives to meet a particular demand.

**Coalbed Methane Outreach Program [U.S. Environmental Protection Agency]**

The Environmental Protection Agency’s (EPA) Coalbed Methane Outreach Program (CMOP) has requested that the EPA US-national MARKAL (EPA-MARKAL) model be augmented to include the ability to track methane emissions from the energy system, and limited other sources (landfills and manure handling)\(^{21}\). This Methane sub-model includes a wide range of methane emission sources and handling options that could be introduced to mitigate methane emissions. The Methane sub-model has been carefully added as an alternate scenario to the current EPA national model and integrated with the BASE scenario and other model scenarios. This enables easy running of the model with or without the Methane subsystem.

The methane sub-model in the EPA-MARKAL model has been developed and calibrated to perform the following functions:

- Provide projections of future methane emissions from the energy system out to 2030;

\(^{21}\) Information on EPA-CMOP methane projections, including full documentation on the MARKAL workbook and analysis, is available at [http://www.epa.gov/methane/projections.html](http://www.epa.gov/methane/projections.html).
Assess potential mitigation levels of methane emissions by energy system component;
Evaluate the benefit and costs of policies, programs, and actions to reduce methane and/or Greenhouse Gas (GHG) emissions;
Help to prioritize emission reduction opportunities in terms of cost-effectiveness and ancillary benefits, and
Produce emission abatement cost curves.

The Methane sub-model was integrated into the EPA-MARKAL, stewarded by the EPA Office of Research and Development (ORD). It is characterized according to five methane generating sectors:
1) Municipal waste and landfills;
2) Natural gas production, transmission/storage, and distribution;
3) Coal production;
4) Oil production, and
5) Manure management.

In each sector, a subsystem was developed that simulates activities that produce methane, derives emission estimates from these activities, provides alternatives for handling the produced methane, and implements methane mitigation technologies as appropriate, based on least-cost and in response to policy constraints applied by the user. The approach employed for modeling each subsystem within the Methane sub-model is represented by an Excel workbook consisting of 37-worksheets, which proceeds from the source data to the associated methane supply and technology handling options in a form ready for loading into MARKAL. This enables the data and approach to be readily available for other interested parties. A Reference Energy System (RES) network flow diagrams presents each subsystem visually, identifying the various commodities (energy carriers and emissions) and technologies (methane sources and mitigation options) encompassing each subsystem. Figure 1 shows the methane handling sub-RES for Appalachian Underground High Sulfur Coal.

![Figure 1: RES Flow Diagram for Coal Mine Methane Emissions and Mitigation Options](image-url)
Table 1. below summarizes the numbers of emission and mitigation technologies that comprise the methane sub-model. These are described in more detail below, and details of the input parameters (investment cost, operating cost, emission reduction efficiency, lifetime, etc.) are provided for each technology in the associated data workbook.

<table>
<thead>
<tr>
<th>Methane Sector</th>
<th>Emission technologies</th>
<th>Mitigation technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSW / Landfills</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>Coal</td>
<td>40</td>
<td>19</td>
</tr>
<tr>
<td>Oil</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Manure</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56</strong></td>
<td><strong>76</strong></td>
</tr>
</tbody>
</table>

After calibration to AEO2003 the expanded framework was then used to examine methane and Greenhouse Gas (GHG) mitigation options. The result for three of the methane reduction runs are illustrated in Figure 2. With a 10% reduction, most of the additional methane reductions come from the coal sector, through the capture of gob gas from new mines, the utilization of coal mine methane (CMM) as supplemental fuel and the flaring of ventilation air. With a 20% reduction, more coal mine methane is flared and additional landfill gas is both flared and used for supplemental fuel. In the 50% reduction case, several mitigation technologies in the natural gas sector are utilized along with additional reductions of CMM and LFG, pretty much eliminating the latter as a source of methane by the end of the modeling horizon. In the 50% methane reduction case, significant reductions from the oil production sector are also seen.

**Figure 2: Methane Reduction Scenario - 10%, 20% and 50% Reductions**
When looking at GHG reductions continuous methane mitigation cost curves were generated, as shown in Figure 3. There are several observations worth noting regarding the curves. First, unlike the methane-only reduction runs, the amount of methane reduction achieved does NOT necessarily follow that of the GHG mitigation levels. As the GHG constraint gets more severe there is a major shift to imported natural gas at the expense of coal, particularly underground, which limits the methane reduction opportunities and results in less mitigation of methane. But for intermediate levels of GHG reduction mitigation of methane plays an important role with the cumulative level of methane reduction corresponding to a direct methane-only reduction of about 20%.

Figure 3: Cumulative Methane Mitigation Cost Curve - GHG Reduction Runs

With a Methane sub-model added to the EPA US-national MARKAL model it can be used to investigate policies and strategies to encourage the use of cost-effective energy supply options embedded within the methane system and it can examine the relative effectiveness of possible programs looking to mitigate GHG emissions. From the modeling point of view the complexities of the methane emission sectors and their interactions with the energy system are represented in appropriate detail. The scenarios investigated were exploratory and serve to illustrate the possible technology and policy options that can be investigated with the model; and the continuous and cumulative mitigation cost curves providing insight into programs that might stimulate the market to more quickly adopt the more cost-effective mitigation options.
A New England MARKAL Model (NE-MARKAL) [Gary Kleeman, The Clean Air Association of the Northeast States]

New England States for Coordinated Air Use Management [NESCAUM], with the assistance of the International Resources Group (IRG), has developed a New England-specific version of the MARKAL model based on regional data and in cooperation with energy and air quality divisions of the respective states. This planning tool allows for the analysis of a range of transportation, energy and air quality protection programs with a time horizon of 30 years and a focus on the cost and environmental implications of key program design elements.

This initiative, which began through a collaboration between NESCAUM and the U.S. EPA Office of Research and Development in 2003, has resulted in the development of a MARKet ALlocation (MARKAL) least-cost optimized linear programing (LP) model which is tailored specifically to the energy infrastructure of the New England states. NE-MARKAL is a data-rich analytical framework for examining energy policy options and their resultant impact on energy services in the region. The model serves as the centerpiece of the integrated policy analysis framework developed at NESCAUM which aids in developing a comprehensive understanding of technology, economic, environmental and public health consequences of air quality protection initiatives.

The NE-MARKAL model responds to prescribed demand for regionally based energy services (in this case, energy required to meet the associated energy service demands of the residential, commercial, industrial and transportation sectors) and selects from available technologies – characterized by their costs, efficiencies, lifetimes, and maximum utilization rates, along with any user imposed constraints on market penetration, availability, etc. – to select the least-cost path which satisfies the specified demands. MARKAL is a flexible modeling framework that allows examination of the mid-to-long-term technology choices that shape the evolution of an energy system in meeting specific environmental or other goals. The model allows the implications of specific regional policy options to be examined and compared. Owing to its solid basis in energy economics, MARKAL makes decisions based upon the relative costs of the various technology options and overall system constraints. Thus, it serves to identify the key technologies that will be needed to realize certain GHG- or criteria pollutant-reducing energy/environmental policies and objectives.

The NE-MARKAL model is a linear programming model, similar to DOE’s National Energy Modeling System (NEMS) in that it covers multiple energy demand sectors including residential and commercial buildings, transportation, and the industrial sector, as well as the supply side power generation sector. As NE-MARKAL is expanded to nearby states such as New York, New Jersey and Pennsylvania, resource extraction and conversion technologies (e.g. refineries) can be easily added as well. As opposed to NEMS, however, NE-MARKAL is state-based and regionally specific, with increased regional detail beyond what is currently available in regionalized national energy models. Each New England state is represented as its own region within the model and can be analyzed independently or as a part of the six state collective. Thus, the model is particularly good at demonstrating the benefits of regional cooperation and of flexible implementation of air quality protection programs.

NE-MARKAL is also similar to the Integrated Planning Model (IPM), which has been used for several national regulatory program assessments by the U.S. EPA. IPM does have significant regional detail with respect to the power sector; however, the MARKAL model is multi-sector –
as opposed to IPM which only covers the power generation sector – and, thus, is capable of analyzing inter-sectoral tradeoffs among emission reduction programs which may be more or less cost-effective than single sector focused programs. Furthermore, IPM requires that projections for electricity demand be provided exogenously while MARKAL determines said demand endogenously, weighting it against conservation, fuel switching and other options available to the model.

NESCAUM will ultimately expand this energy/technology model to encompass the 12-state region (extending from Maine to D.C.) working together on several policy fronts that deal with climate change, ozone pollution, and visibility impairment by fine particulates. These activities will be directly linked to regional econometric models and emissions processing, air quality and health benefits assessment tools. Together these activities will result in a diverse regional database and associated models, spanning air quality, climate, technology and economics that are of a quality and dimension not presently available. To this end, NE-MARKAL serves to develop sound regional policy and represents a model for replication in other regions of the U.S.

At the same time, NESCAUM is assisting with a new initiative being led by the Northeast-Midwest Institute to develop an Ohio-MARKAL model employing the NE-MARKAL approach. The prospects are very good that this will expand into a MW-MARKAL model which, when linked with the expanded NE-MARKAL, will provide coverage from the Great Lakes to the Atlantic and facilitate even wider policy discussions and deliberations.

**Project Schedule:** Now in the final stages of development, the NE-MARKAL Reference scenario is undergoing external review, and initial policy analysis is underway focusing on the light-duty transportation sector and implementation of the action steps contained in the New England Governors/Eastern Canadian Premiers 2001 Climate Action Plan.
Systems Analysis and Modeling Tools Research and Development Program

ETSAP continued its now 25 years of tradition advancing the current state-of-the-art with respect to least-cost energy system modeling through the completion of the initial production version of the TIMES model and numerous enhancements to MARKAL. The main features of TIMES and the new features of MARKAL are described in the following sections.

At the same time major strides were made with respect to the data handling systems for both TIMES and MARKAL. With respect to TIMES the initial version of the VERSatile Data Analyst (VEDA) has been completed and is in use for several major TIMES (and MARKAL) undertakings. ANSWER, the stalwart data handling system for MARKAL saw major enhancements as it gained powerful facilities with respect to the multi-region capabilities needed for the IEA-ETP model. Following the update on TIMES and MARKAL information is provided on both the new VEDA system and ANSWER enhancements.

TIMES

Documentation

Extensive and comprehensive documentation for TIMES has been assembled in three volumes:

- Part I: Introduction
- Part II: Sets and Parameters
- Part III: GAMS Implementation

The complete set of TIMES documentation is available for the ETSAP website at www.etsap.org/documentation.asp.

Overview

TIMES (The Integrated MARKAL-EFOM System) is a mathematical modeling scheme for representing, optimizing and analyzing energy systems in a technology rich way on a flexible time and regional scale. The TIMES model generator has been developed under the auspices of the International Energy Agency (IEA) with the Energy Technology Systems Analysis Programme (ETSAP). It has been implemented in the equation-based mathematical modeling language GAMS (General Algebraic Modeling System) /Brooke, et al. 1996/. TIMES has been designed for the long-term analysis of energy, economic and environment issues over a time-horizon of several years to decades. Therefore, the optimization process determines not only the utilization of the existing energy system, but also optimizes the investment in additional capacity or new technologies. Typical questions analyzed with such a model are for example the definition of strategies to reach GHG abatement targets or the analysis of the impacts of policy instruments (e.g. emission trading, green certificates) on the energy system.

The energy system modeling 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 the local energy system of a municipality through to the
national energy system of a country and to the analysis of multi-national energy systems. Therefore, TIMES can be considered as a model generator.

The description of an energy system within TIMES is based on the concept of a **Reference Energy System (RES)** /Beller 1975/. The RES models the energy system as a network of processes and commodities being connected by commodity flows. Depending on the energy system being analyzed, the RES may cover the entire energy system of a country from the primary energy supply through conversion, transport and distribution to the end-use sectors. One characteristic aspect of a RES is that in most cases a process does not depict a single plant or installation, 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 financial products as emission permits. Another feature of a RES is the existence of a stock of technologies that in addition to the technologies used today also contains a portfolio of new technologies that are still under research or are too expensive today but might become competitive in the future. A TIMES model may consist of several regions each of them having their own unique RES. The regions are connected by exchange processes describing the trade activities, e.g. electricity or gas trade.

The time horizon of a TIMES model usually covers several decades and can be flexibly divided into periods each being represented by an average year. The average year can be further divided into sub-annual time segments on up to four levels (annual, seasonal, weekly, daily) to model variations in the energy demand or supply within a year, e.g. load curves for electricity and heat demand or seasonal variations in the inflow of hydro power plants. The number of time segments...
and the choice of processes or commodities having a sub-annual time resolution are fully under user control.

In TIMES, the energy system depicted by processes and commodities is described by a system of equations and variables. Main equations are for example the energy balance for energy commodities, the transformation equation linking the input of a process to the output via the efficiency of the process or capacity-activity constraints limiting the activity of a process by its available capacity. In addition to a predefined standard set of equations, TIMES offers the user a generic equation framework in order to add non-standard user-defined constraints to the model without having to program them. The objective function of TIMES is expressed as the discounted sum of the annual energy system costs. Typical input data are the technical and economic characterization of the technologies, the demand projection for useful energy demand or energy services as well as the extraction costs or the import prices for primary energy carriers. The major decision variables in the optimization process of minimizing the objective function are the flows between the processes and the commodities, the production or activity of a process and the investment variable for adding new capacity to a technology. Thus, the optimization process determines for each energy carrier an equilibrium between supply and demand. While on the supply side of an energy carrier different options are competing with each other according to their costs and production potential, on the demand side of an energy carrier the demand can be adjusted through energy efficiency measures or substitution processes to other fuels. Due to this equilibrium of supply and demand, energy system models can also be characterized as partial equilibrium models. The equilibrium is only partial, since only the energy sector is considered and the equilibrium of the entire economy including other economic sectors is not analyzed.

Mathematically, a TIMES model can be presented as a linear programming optimization problem of the following form:

$$\begin{align}
\text{Min} & \quad \sum_j c_j x_j \\
\text{s.t.} & \quad \sum_j a_{ij} x_j \leq b_i \quad \forall i \in n \\
& \quad x_j \geq 0 \quad \forall j \in m
\end{align} \tag{1}$$

with

- $i$ equation index,
- $j$ variable index,
- $n$ number of equations,
- $m$ number of variables,
- $x_j$ decision variable,
- $c_j$ costs associated with the decision variable $x_j$,
- $a_{ij}$ matrix coefficient of the decision variable $x_j$ in the equations $i$,
- $b_i$ right-hand side constants of the equation $i$.

The objective function $\sum_j c_j x_j$, which should be minimized by choosing appropriate values for the decision variables, is equivalent to the total discounted costs of the energy system over the model horizon.
TIMES features

Compared to MARKAL, TIMES offers the user some new features to model an energy system. In the following a short overview of these features is given.

Variable length time periods
MARKAL has fixed length time periods. However TIMES allows the user to define period lengths in a completely flexible way. This is a major model difference, which indeed required a complete re-definition of the mathematics of most TIMES constraints and of the TIMES objective function. The variable period length feature is very useful in two instances: first if the user wishes to use a single year as initial period (handy for calibration purposes), and second when the user contemplates long horizons, where the first few periods may be described in some detail by relatively short periods (say 5 years), while the longer term may be regrouped into a few periods with long durations (perhaps 20 or more years).

Data decoupling
This somewhat misunderstood feature does not confer additional power to TIMES, but it greatly simplifies the maintenance of the model database and allows the user great flexibility in modifying the new definition of the planning horizon. In TIMES all input data are specified by the user independently from the definition of the time periods employed for a particular model run. All time-dependent input data are specified by the year in which the data applies. The model then takes care of matching the data with the periods, wherever required. If necessary the data is interpolated (or extrapolated) by the model preprocessor code to provide data points at those time periods required for the current model run. In addition, the user has control over the interpolation and extrapolation of each time series.

The general rule of data decoupling applies also to past data: whereas in MARKAL the user had to provide the residual capacity profiles for all existing technologies in the initial period, and over the periods in which the capacity remains available, in TIMES the user provides technical and cost data at those past years when the investments actually took place, and the model takes care of calculating how much capacity remains in the various modeling periods. Thus, past and future data are treated essentially in the same manner in TIMES. One instance when the data decoupling feature immensely simplifies model management is when the user wishes to change the initial period, and/or the lengths of the periods. In TIMES, there is essentially nothing to do, except declaring the dates of the new periods. In MARKAL, such a change represents a much larger effort requiring a substantive revision of the database.

Flexible time slices and storage processes
In MARKAL, only two commodities have time-slices: electricity and low temperature heat, and their time slices are rigidly defined (six time-slices for electricity and three for heat). In TIMES, any commodity and process may have its own, user-chosen time-slices. These flexible time-slices are segregated into three groups, seasonal (or monthly), weekly (weekday vs. weekend), and daily (day/night), where any level may be expanded (contracted) or omitted.

The flexible nature of the TIMES time-slices is supported by storage processes that 'consume' commodities at one time-slice and release them at another. MARKAL only supports night-to-day (electricity) storage.
Note that many TIMES parameters may be time-slice dependent (such as availability factor (AF), basic efficiency (FLO_FUNC), etc).

**Process generality**
In MARKAL processes in different RES sectors are endowed with different (data and mathematical) properties. For instance, end-use processes do not have activity variables (activity is then equated to capacity), and source processes have no investment variables. In TIMES, every process has the same basic features, which are activated or not solely via data specification.

**Flexible processes**
In MARKAL processes are by definition rigid, except for some specialized processes which permit flexible output (such as limit refineries or pass-out turbine CHPs), and thus outputs and inputs are in fixed proportions with one another. In TIMES, the situation is reversed, and each process starts by being entirely flexible, unless the user specifies certain coefficients to rigidly link inputs to outputs. This feature permits better modeling of many real-life processes as a single technology, where MARKAL requires several technologies (as well as dummy commodities) to achieve the same result. A typical example is that of a boiler that accepts any of 3 liquid fuels as input, but whose efficiency depends on the fuel used. In MARKAL, to model this situation requires four processes (one per possible fuel plus one that carries the investment cost and other parameters), plus one dummy fuel. In TIMES one process is sufficient, and no dummy fuel is required. Note also that TIMES has a number of parameters that limit the input share of each fuel, whereas in MARKAL, imposing such limits requires that the user define several user constraints.22

**Investment and dismantling lead-times and costs**
New TIMES parameters allow the user to model the construction phase and dismantling of facilities that have reached their end-of-life. These are: lead times attached to the construction or to the dismantling of facilities, capital cost for dismantling, surveillance costs during the dismantling lead-time. Like in MARKAL, there is also the possibility to define flows of commodities consumed at construction time, or released at dismantling times, thus allowing the representation of life-cycle energy and emission accounting.

**Vintaged processes and age-dependent parameters**
The variables associated with user declared vintaged processes employ both the time period \( p \) and vintage period \( v \) (in which new investments are made and associated input data is obtained). The user indicates that a process is to be modeled as a vintaged process by using a special vintage parameter. Note that in MARKAL vintaging is possible only for demand devices (for which there is no activity variable) or via the definition of several replicas of a process, each replica being a different vintage. In TIMES, the same process name is used for all vintages of the same process.23

In addition, some parameters can be specified to have different values according to the age of the process. In the current version of TIMES, these parameters include the availability factors, the in/out flow ratios (equivalent to efficiencies), and the fixed cost parameters only. Several other

22 In the end the two models use equivalent mathematical expressions to represent a flexible process. Only TIMES reduces the user’s effort to a minimum, while MARKAL requires the user to manually define the multiple processes, dummy fuels and user constraints.

23 The representation of vintage as a separate index helps eliminate a common confusion that existed in MARKAL, namely the confusion of vintage with the age of a process. For instance, if the user defines an annual cost for a car equal to 10 in 2005 and only 8 in 2010, the decrease would not only apply to cars purchased in 2010, but also to cars purchased in 2005 and earlier when they reach the 2010 period.
parameters could, in principle, be defined to be age-dependent, but such extensions have not been implemented yet.

**Commodity related variables**

MARKAL has very few commodity related variables, namely exports/imports, and emissions. TIMES has a large number of commodity-related variables such as: total production, total consumption, but also specific variables representing the flows of commodities entering or exiting each process. This allows the user many “handles” to put limits, and costs on commodities.

**More accurate and realistic depiction of investment cost payments**

In MARKAL each investment is assumed to be paid in its entirety at the beginning of some time period. In TIMES the timing of investment payments is quite detailed. For large facilities (e.g. a nuclear plant), capital is progressively laid out in yearly increments over the facility’s construction time, and furthermore, the payment of each increment is made in installments spread over the economic life of the facility. For small processes (e.g. a car) the capacity expansion is assumed to occur regularly each year rather than in one large lump, and the payments are therefore also spread over time. Furthermore, when a time period is quite long (i.e. longer that the life of the investment), TIMES has an automatic mechanism to repeat the investment more than once over the period. These features allow for a much smoother (and more realistic) representation of the stream of capital outlays in TIMES than in MARKAL.

Moreover, in TIMES all discount rates can be defined to be time-dependent, whereas in MARKAL both the general and technology-specific discount rates are constant over time.

**Climate equations**

TIMES now possesses a set of variables and equations that endogenise the concentration of CO$_2$ and also calculate the radiative forcing and global temperature change resulting from GHG emissions and accumulation in the atmosphere. See the TIMES Climate Module section below for details.

**Enhancements of the TIMES model generator in ANNEX VIII**

Within ANNEX VIII the TIMES model generator has been improved in various ways: the GAMS code has been validated, the computation time and memory usage needed to generate a TIMES model has been drastically reduced and new modeling features have been incorporated in the TIMES framework.

**Maintenance and improvement of the TIMES code**

The GAMS code of TIMES has been tested and validated extensively in ANNEX VIII. The separation between so-called datayears, for which model input data are available, e.g. from the statistics, and the modelyears, which are the years for which the model is to be run, has been enhanced in order to facilitate the change of the definition of the model periods. Various inter- and extrapolations are available. The performance of the code has been improved leading to model generation times being comparable to the ones of MARKAL.

**Reduction algorithm**

The motivation of the reduction algorithm is to reduce the number of equations and variables generated by the TIMES model. Thus, the memory usage can be reduced, which due to the saved memory may improve the computation time needed to solve a model. An example of a situation
where model size can be reduced is a process with one input and one output flow, where the output flow variable can be replaced by the input variable times the efficiency. Thus, the model can be reduced by one variable (output flow variable) and one equation (transformation equation relating input and output flow). Since NLP solvers in contrast to LP solvers do not contain an internal reduction algorithm, the reduction algorithm within TIMES is also useful when either an LP TIMES model is solved with an NLP solver or when nonlinear equations, as in the case of the MACRO model, will be added to TIMES in the future.

*Lumpy investments*
Due to the linear nature of a TIMES model in its standard formulation, capacity can be added in any size. In some applications, e.g. a local model, the granularity of the investment decisions observed in reality may become an important factor. To take into account the discrete nature of capacity additions, a lumpy investment option has been added enabling the modeler to limit the new installed capacity to specific defined unit sizes. Due to the introduction of binary variables the resulting optimization problem becomes a mixed-integer programming problem.

*Market share constraints*
Since not all decisions in the energy sector follow the paradigm of cost minimization, e.g. in the transport sector a car offers additional flexibility to its owner or can be considered as a status symbol, the option exists to specify bounds for the market share of a technology in the overall production of a commodity. Thus, for example it is possible to specify a minimum share for the use gasoline cars in the provision of passenger kilometers.

*Climate module*
The Climate Module starts from global emissions as generated by a TIMES global model, and proceeds to compute successively:
- the changes in CO$_2$ concentrations in three reservoirs,
- the total change (over pre-industrial times) in atmospheric radiative forcing from anthropogenic causes, and
- the temperature changes (over pre-industrial times) in two reservoirs.

Thus, it is possible in a global TIMES model to bound the maximum tolerated carbon concentration in the atmosphere. The Climate Equations used to perform these calculations are adapted from Nordhaus and Boyer (1999), who proposed linear recursive equations for calculating concentrations and temperature changes. These linear equations give results that are good approximations to those obtained from more complex climate models (Drouet et al., 2004; Nordhaus and Boyer, 1999). In addition, the non-linear radiative forcing equation used by these authors is the same as the one used in most models. The climate module is fully described in a later section.

*Applications of TIMES*
The TIMES model generator is currently used by several institutions world-wide. In Germany at IER, besides a national model for Germany, regional energy system models for several federal states (Baden-Württemberg, Bavaria, Saxonia) exist. On the European level, the multi-regional electricity sector model TIMES-EE covering the electricity and district heat generation of 27 countries in Europe has been developed at IER. At the IPP in Germany, a one-regional global TIMES model has been set-up in cooperation with IER to study the long-term perspectives of fusion power. Furthermore, within the EFDA/SERF project a 15-regional global model TIMES model has been developed. In Finland a new TIMES model has been used to assess Greenhouse Gas reduction strategies. At the ERC in South Africa, a TIMES model of a rural village has been
used to analyze options for covering domestic energy needs. Also at ERC, a 12-regional energy supply model has been built to study the energy sector and the electricity trade between the countries within the Southern African Development Community (SADC).

Currently, within the EU-NEEDS Integrated Project a multi-regional TIMES model of the European member states is being developed to analyze strategies in the energy sector under the inclusion of external costs. In Italy a multi-regional TIMES model of the electricity sector is being developed to study the future of this sector in Italy on a detailed regional level; a local energy system model for Piemonte Region has also been made.

The TIMES Climate Module

A new Climate Module option was constructed for the Global TIMES model. The module uses global GHG emissions to calculate CO2 (or CO2-equivalent) concentrations in three reservoirs (atmosphere, upper ocean, deep ocean), then proceeds to calculate the change in atmospheric radiative forcing resulting from the atmospheric CO2 concentration, and finally calculates the changes in mean global temperatures in two layers (atmosphere and deep ocean). The modeler can impose bounds on the concentrations. The climate equations used in the Climate Module are adapted from those in Nordhaus and Boyer (1999). The module was programmed in GAMS and fully tested, and is available as an extension activated by a GAMS parameter.

The new module is the result of a research collaboration between KANLO, VTT, and IER-Stuttgart, supported by ETSAP.

Formulation of the TIMES Climate Module

The Climate Module starts from global emissions as generated by the TIMES global model, and proceeds to compute successively:

- the changes in CO2 concentrations in three reservoirs,
- the total change (over pre-industrial times) in atmospheric radiative forcing from anthropogenic causes, and
- the temperature changes (over pre-industrial times) in two reservoirs.

The Climate Equations used to perform these calculations are adapted from Nordhaus and Boyer (1999), who proposed linear recursive equations for calculating concentrations and temperature changes. These linear equations give results that are good approximations to those obtained from more complex climate models (Drouet et al., 2004; Nordhaus and Boyer, 1999). In addition, the non-linear radiative forcing equation used by these authors is the same as the one used in most models. The choice of the Nordhaus and Boyer’s climate equations is motivated by the simplicity of their approach and by the fact that their climate module is well-documented and acceptably accurate.

The equations used in the module are theoretically applicable only to the so-called ‘carbon cycle’, and therefore, the correct treatment of other greenhouse gases should be done using different sets of equations for each GHG or aerosol (methane, N2O, ozone, sulfates, etc.). However, following an approach used by many researchers, it is also possible to use the CO2 equations to calculate the impact of other gases on climate. To do so, it is necessary to first convert the emission of each gas into a CO2-equivalent quantity, and to add these CO2-equivalents to form a fictitious emission of total CO2-equivalent, which is then treated as if it were real CO2 emissions. The coefficients used for converting emissions of other gases into CO2-equivalents are those recommended by the IPCC (IPCC 2001), and reproduced in the Appendix of the original report. Therefore, in what follows, the term CO2 should really be thought of as CO2-equivalent.
We now describe the mathematical equations used at each of the three steps of the climate module.

**Concentrations (accumulation of CO2)**

CO2 accumulation is represented as the linear three-reservoir model below: the atmosphere, the quickly mixing upper ocean + biosphere, and the deep ocean. CO2 flows in both directions between adjacent reservoirs. The 3-reservoir model is represented by the following 3 equations when the step of the recursion is equal to one year:

\[
\begin{align*}
M_{atm}(y) &= E(y-1) + (1 - \varphi_{atm-up}) M_{atm}(y-1) + \varphi_{up-atm} M_{up}(y-1) \\
M_{up}(y) &= (1 - \varphi_{atm-up} - \varphi_{up-lo}) M_{up}(y-1) + \varphi_{atm-up} M_{atm}(y-1) + \varphi_{lo-up} M_{lo}(y-1) \\
M_{lo}(y) &= (1- \varphi_{lo-up}) M_{lo}(y-1) + \varphi_{up-lo} M_{up}(y-1)
\end{align*}
\]

with

- \( M_{atm}(y) \), \( M_{up}(y) \), \( M_{lo}(y) \): masses of CO2 in atmosphere, in a quickly mixing reservoir representing the upper level of the ocean and the biosphere, and in deep oceans (GtC), respectively, at period \( t \) (GtC)
- \( E(y-1) \) = CO2 emissions in previous year (GtC)
- \( \varphi_{ij} \), transport rate from reservoir \( i \) to reservoir \( j \) (\( i, j = \text{atm, up, lo} \)) from year \( y-1 \) to \( y \)

**Radiative forcing**

The relationship between GHG accumulations and increased radiative forcing, \( F(t) \), is derived from empirical measurements and climate models.

\[
F(t) = * \frac{\ln(M_{atm}(t)/M_0)}{\ln 2} + O(t)
\]

where:

- \( M_0 \) (i.e.CO2ATM_PRE_IND) is the pre-industrial (circa 1750) reference atmospheric concentration of CO2 = 596.4 GtC
- is the radiative forcing sensitivity to atmospheric CO2 concentration doubling = 4.1 W/m²
- \( O(t) \) (i.e. EXOFORCING(t)), is the increase in total radiative forcing at period \( t \) relative to pre-industrial level due to anthropogenic GHG’s not accounted for in the computation of CO2 emissions. Units = W/m². In Nordhaus and Boyer (1999), only emissions of CO2 were explicitly modeled, and therefore \( O(t) \) accounted for all other GHG’s. In TIMES, only some other gases are fully accounted for, but some are not (e.g. CFC’s, aerosols, ozone). It is the modeler’s responsibility to include in the calculation of \( O(t) \) only those gases not included in the CO2-equivalent emissions.

The parameterization of the forcing equation is not controversial and relies on the IPCC Second Assessment Report by Working Group I (1996). The major assumption made in RICE is also made here: a doubling of CO2 concentrations leads to an increase in radiative forcing \( \gamma = 4.1 \) W/m². The IPCC Third Assessment Report by Working Group I (2001) provides a slightly smaller value of 3.7 W/m² (based on Table 6.2, p.358, chapter 6). Users may want to experiment with other values of the \( \gamma \) parameter.

**Temperature increases**

In the TIMES Climate Module as in many other integrated models, climate change is represented by the global mean surface temperature. The idea behind the two-reservoir model is that a higher radiative forcing warms the atmospheric layer, which then quickly warms the upper ocean. In this
model, the atmosphere and upper ocean form a single layer, which slowly warms the second layer consisting of the deep ocean.

\[ \Delta T_{\text{up}}(y) = \Delta T_{\text{up}}(y-1) + \sigma_1 \left[ F(y-1) - \lambda \Delta T_{\text{up}}(y-1) - \sigma_2 \left[ \Delta T_{\text{up}}(y-1) - \Delta T_{\text{low}}(y-1) \right] \right] \]  

(5)

\[ \Delta T_{\text{low}}(y) = \Delta T_{\text{low}}(y-1) + \sigma_3 \left[ \Delta T_{\text{up}}(y-1) - \Delta T_{\text{low}}(y-1) \right] \]  

(6)

with

- \( \Delta T_{\text{up}} \) = globally averaged surface temperature increase above pre-industrial level,
- \( \Delta T_{\text{low}} \) = deep-ocean temperature increase above pre-industrial level,
- \( \sigma_1 \) = 1-year speed of adjustment parameter for atmospheric temperature,
- \( \sigma_2 \) = coefficient of heat loss from atmosphere to deep oceans,
- \( \sigma_3 \) = 1-year coefficient of heat gain by deep oceans,
- \( \lambda \) = feedback parameter (climatic retroaction) \( (\lambda = 4.1/C_s) \), \( C_s \) being the temperature sensitivity to \( \text{CO}_2 \) concentration doubling.

Remark: in contrast with most other parameters, the value of \( C_s \), the temperature sensitivity to \( \text{CO}_2 \) concentration doubling, is highly uncertain, and may range from 1°C to 10°C. This parameter is therefore a prime candidate for sensitivity analysis, or for treatment by probabilistic methods.

Default values of the climate parameters

Table 7.1 shows the assumed values of all parameters of the Climate Module except exogenous forcing.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td>4.1 W/m²</td>
</tr>
<tr>
<td>PHI_UP_AT</td>
<td>0.0453 per year</td>
</tr>
<tr>
<td>PHI_AT_UP</td>
<td>0.0495 per year</td>
</tr>
<tr>
<td>PHI_LO_UP</td>
<td>0.00053 per year</td>
</tr>
<tr>
<td>PHI_UP_LO</td>
<td>0.0146 per year</td>
</tr>
<tr>
<td>( C_s ), not directly needed</td>
<td>2.91 °C</td>
</tr>
<tr>
<td>LAMBDA</td>
<td>1.41</td>
</tr>
<tr>
<td>SIGMA1</td>
<td>0.024 per year</td>
</tr>
<tr>
<td>SIGMA2</td>
<td>0.44 (no time dimension)</td>
</tr>
<tr>
<td>SIGMA3</td>
<td>0.002 per year</td>
</tr>
<tr>
<td>CO2ATM_PRE_IND</td>
<td>596.4 GtC (pre-industrial equilibrium)</td>
</tr>
<tr>
<td>CO2_ATM_0</td>
<td>735 GtC (in 1995)</td>
</tr>
<tr>
<td>CO2_UP_0</td>
<td>781 GtC (in 1995)</td>
</tr>
<tr>
<td>CO2_LO_0</td>
<td>19230 GtC (in 1995)</td>
</tr>
<tr>
<td>DELTAT_ATM_0</td>
<td>0.43 °C (1995)</td>
</tr>
<tr>
<td>DELTAT_LOW_0</td>
<td>0.06 °C (1995)</td>
</tr>
<tr>
<td>DELTAFORCING_0 not directly needed</td>
<td>1.0395 (1995)</td>
</tr>
</tbody>
</table>

Important Note: The last 6 parameters are given for year 1995. Users whose starting milestone year is different from 1995 must provide appropriate values.

Nordhaus and Boyer use the following formula to calculate the radiative forcing due to all GHG’s except CO2. In the case of the TIMES global model, the energy related methane and N2O
emissions are already accounted for in the calculation of CO2 equivalent emissions. Therefore, the formula below constitutes an upper bound for the radiative forcing due to other gases.

\[
\text{EXOFORCING}(y) = \begin{cases} 
-0.1965 + 0.013465 \times (y-1995), & \text{if } 1995 \leq y \leq 2095 \\
1.15, & \text{if } y > 2095 
\end{cases}
\]

In Nordhaus and Boyer (1999), the forcing of other GHGs (CFCs, CH4, N2O, ozone), and from aerosols are considered to be exogenous. Some of these gases are poorly understood. Moreover, some of them are controlled by non-climate policies (e.g. CFC’s, ozone, aerosols). These values are inspired by the MAGICC model (Wigley et al., 1994). The IPCC TAR (2001) provides estimated ranges of the forcing of non-CO2 GHGs in 1998 (chapter 6) as well as simplified equations (Table 6.2 of chapter 6). However, no average value is provided for several of the gases, which makes it difficult to compare the exogenous forcing proposed by Nordhaus and Boyer (1999) to these updated estimations.

**MARKAL**

*Documentation*

Long overdue, the 1983 Fishbone et al MARKAL Users’ Guide, sometimes previously not so affectionately referred to as “the bible,” has finally been replaced by a 450 page, three volume new set of Documentation for the MARKAL Family of Models, October 2004. The documentation effort was headed by Richard Loulou, with extensive contributions by Gary Goldstein and supported by Ken Noble. The new documentation strives to both provide a substantive background as to the principles embodied in MARKAL, as well as to elaborate the full details associated with both the input data, its relationship to the model structure, and the mathematics itself. The three volumes consist of:

- Part I: **Standard MARKAL**
- Part II: **MARKAL MACRO**
- Part III: **SAGE**

The complete documentation is available for the ETSAP website at [www.etsap.org/documentation.asp](http://www.etsap.org/documentation.asp).

**IEA ETP Enhancements**

The International Energy Agency (IEA) is heavily engaged in a global modeling undertaking as part of the Energy Technology Perspectives (ETP) project. This modeling activity is built on the MARKAL energy system model developed by the Energy Technology Systems Analysis Programme, a long-standing Implementing Agreement under the auspices of the IEA.

In the course of constructing the global model two enhancements to the capabilities embodied in the current MARKAL model have been identified that will improve the task of developing, maintaining and applying the new global modeling framework. The enhancements will immediately benefit the ETP project, as well as the global community of MARKAL users.
An overview and the implementation details, as well as instructions as to use, for each of the enhancements are discussed in an Information Note for MARKAL V5.3 and 5.4.

Overview of New Capabilities and Updates

The major enhancements that have been added to the MARKAL model for ETP are:
An ability to associate emissions directly with commodities;
The “vintaging” of demand devices;
1. A slack formulation of the conventional and heat commodity balance constraints;
2. Multi-region emission constraints;
3. Multi-region user-defined (ADRATIO) constraints; and
4. Resource and technology capacity decay constraints that limit the rate at which capacity can be abandoned.

In the following sections each of the points listed above is addressed to varying degrees.

In addition to these new capabilities and updates, owing to low-level changes in GAMS at GAMS v20.6 and v21.1 some major reworking of the core MARKAL code, particularly with respect to multi-region models, had to be done. However, to the fullest extent possible the MARKAL v5.4 code should work with old and new versions of GAMS.

The Association of Emissions with Commodities (ENV_ENT)

As MARKAL ties the emissions rate to the activity (output) of the process, previously emission factors entered into the database not only needed to reflect the traditional emissions rate, but had to take into consideration the efficiency and other technical characteristics whenever emissions were modeled as a function of the fuel use and not technology output. In addition, since emissions had to be specified technology-by-technology volumes of identical data had to be repeatedly entered by the modeler. The addition of parameter ENV_ENT(env,ent,t) enables the analyst to associate environmental indicators directly with commodities, rather than having to enumerate each technology/emission instance. Where a commodity (energy or material) in the ENV_ENT table is an input then the appropriate calculations are made in the code to determine the amount consumed so that the emissions rate (entered in the ENV_ENT table) can still be applied to the MARKAL production (output) variables, but now properly reflecting the emissions as a function of the quantity of input commodity consumed. When an ENV_ENT commodity is output from the technology, then the emissions rate is applied to the activity variable associated with all technologies producing said commodity but with a negative (-) multiplier. These outputs thus represent emission removal by means of scrubbers, sequestration or other means that reduce the total level of emissions already accounted for by the model owing to the consumption of commodities that release said emission. Note that resource supply options (SRCENCPs) for energy carriers are not included in the ENV_ENT algorithm, though import/export of materials listed as ENV_ENTs are included. A related ENV_ENTr parameter may be used to indicate that SRCENCPs producing or exporting an energy carrier are to be included. Alternately the user can use the ENV_SEP parameter if emissions are to be associated with the resource option.

Furthermore, this enhancement will enable the emissions accounting to be modeled based upon carbon (or sulfur) content, that is material, and thereby better handling the increasing need to examine sequestration and carbon storage in synthetic and natural organic materials. The
accounting is based on Material Flow Accounting (MFA): the technology emissions coefficient is the result of the commodity mass flows in and out of the processes, multiplied by the emissions coefficient per unit of commodity. The ENV_ENT enhancement enables MARKAL to accommodate the MFA approach for carbon and other emissions accounting. This has consequences for the naming of flows, because certain processes (e.g. refineries) convert only a small fraction of the input commodity flows into emissions. Therefore energy use and non-energy use of input commodities must be defined separately. The shares of energy use and non-energy use of input commodities must be based on the total technology carbon balance in order to achieve proper emissions accounting.

As mentioned above, this approach results in the calculation of “net” emissions from a source. That is if a particular tracked emissions indicator is associated with commodities that are both input and output from a technology the code calculates the net release, where the output is assumed to be “sunk” emissions.

Figure 1 lists seven examples of carbon accounting cases. Case 1 is the simple case that will usually occur. An emission coefficient is defined for the fuel “natural gas for power plants”. This particular fuel naming is explained by the refinery case 2. In case an oil emission coefficient was defined, the refinery emission would be overestimated, because the crude oil is not converted into CO2 in the refinery. Only the fuels that are actually burned should be accounted for in the CO2 balance. Therefore the refinery gas upstream input is produced from the refinery gas output in a dummy process. The same holds true for the steam cracker case 4. Case 6 is a methanol production process. Again, only part of the natural gas carbon content is converted into CO2.

The major part ends up in the methanol product. This is accounted for by two natural gas input flows, called natural gas feedstock and natural gas for industry. However in this case, the ratio of natural gas for industry and natural gas feedstock is determined by the carbon content of the methanol and the emission coefficient for the natural gas input. The carbon content of methanol would equal an emissions coefficient of 1.375 t CO2/t methanol. The process uses 30 GJ gas/t methanol (total for natural gas for industry and natural gas feedstock), and the emissions coefficient of natural gas is 56 kg/GJ. The net emission is 1.680-1.375 = 0.305 t CO2/t methanol. This equals 5.4 GJ natural gas for industry. Therefore the feedstock natural gas amounts to 30 – 5.4 = 24.6 GJ. Note that these values are different from an energy balance, which suggests 20 GJ feedstock and 10 GJ energy use. Finally case 7 is a power plant with CO2 capture. The CO2 for storage is modeled as a material flow output (and as an input for the storage process). For material flows, production equals consumption (contrary to energy carriers, for which production equals or is greater than production). As a consequence the CO2 captured must be stored, a second reason for the modeling of such outputs as material flows.

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Figure 1: Accounting examples

There are however circumstances, particularly when moving between accounting sub-sectors, where the ENV_ENT should only be applied to the inputs. For such processes the ENV_ENTXO(tch,env) parameter can be provided to only apply the ENV_ENT calculation against the inputs, that is ignore the outputs from such processes. Similarly there may be circumstances where the INPuts are to be ignored for a particular sector total. In this case ENV_ENTXI(tch,env) can be used to accomplish this.

These examples show there are quite some issues to consider if this approach is applied. It is therefore essential to check the values that are calculated. To assist with this task of “debugging” the ENV_ENT table a small dump utility is available. To use this routine copy the $BATINCLUDE line found at the top of the DUMPEE.INC file as the last line of the <case>.GEN file for single region runs, or the <case>.SLV file for a multi-region run. Doing so results in the creation of a DUMPEE.DMP delimited file suitable for importing into Excel where the individual resource options and technologies involved in the ENV_ENT algorithm, with their associated net coefficients can be found (for each period).

**Vintaging of Demand Devices**

MARKAL has a long-standing shortcoming that requires the user to manually introduce “cloned” technologies if input data, other than the investment cost (INVCOST), change over time. This results in the propagation of like technologies that both increase the model/database size and complicate the management of the input and analysis of the model results. A new facility has
been added to MARKAL to allow the modeler to partially redress this shortcoming for demand devices.

Two new parameters have been added that allow the modeler to specify efficiencies for demand devices (EFF) based upon the year that an investment actually occurs, rather than the current model year which had been the case until now. To accommodate this capability, efficiencies can now be specified explicitly for new investments (IEFF) and residuals (REFF), rather than the overall average for all the capacity in place (EFF). When provided the former is applied to the investment variable (INV) rather than the capacity variable (CAP), which is the case now. For residuals a bounded variable (RESIDV) is introduced (to avoid a very large constant entering the balance equations) that has the REFF applied to it. This enables the same technology name to be employed throughout the modeling horizon, as long as the only input changing over time is INVCOST and/or IEFF/REFF.

*Adjustment of the Energy Balance Equation Permitting a Slack Formulation*

It is now possible for the user to request that the energy carrier balance constraint (EQ/MR/MS_BAL/BALDH) in the MARKAL code for selected energy carriers (ENC/LTH) be formulated as an equality constraint (EQ/MR/MS_BAL/BALDH_S) with a slack variable assigned an appropriate price, rather than the greater than or equal to constraint available until now.

The balance constraint in MARKAL ensures that the total production (plus imports) of each standard (non-electric/heat) energy carrier equals or exceeds the total to be consumed. This inequality is necessary when modeling inflexible processes because it may be the case that overproduction of a particular commodity from such a process may indeed occur when some other commodity is driving the operational level of the process. In such situations infeasibilities would occur if the balance equation was forced to be an equality constraint. Furthermore, the resulting zero marginal cost does properly represent the value of this slack commodity to the energy system. In addition, there may be circumstances where the model may choose to overproduce to meet an imposed limit on carbon emissions (e.g., where biomass is used to sequester carbon).

To deal with these situations it is now possible, as noted above, for the user to request that the conventional balance equation be reformulated as an equality constraint with a newly introduced slack variable (SLKENC/LTH(t,enc/lth)) when needed. To do this, the user provides a value for the slack variable cost parameter (SLKCOST(enc/lth)) on the Energy Carrier tab for each energy carrier (and region) where the equality constraint is to apply.

Note that equations associated with material (MAT) commodities, which are handled as equalities constraints now, as well as renewables for which no SRCENCP exists that employ non-binding equations, will remain the same (that is will not have the SLKENC variable introduced).

*Introduction of the Ability to Limit Emissions from Multiple Regions (Global)*

Introduction of the ability to limit global emissions by adding new parameters (GEMLIM, GEMLIMIT) to the MARKAL code permits the user to limit multiple region, including global, emissions (ENV) either over the entire modeling horizon or by period.

Previously emissions could only be limited by region in a multi-region model. While modeling approaches can be employed to enable global limits to be imposed they are cumbersome to
construct. To permit the ability to easily impose a global limit on any emission new parameters and constraints have been added to the model.

GEMLIM(env) is a new global parameter indicating that the total emission from all regions handling said ENV is to be limited to the specified level. For each such emission indicator a new equation MR_GEMLIM(env) is created summing the individual regional emission variables for each time period and ensuring that that sum is less than or equal to overall limit. A similar parameter, GEMLIMT(env,t) results in equation to impose a global emissions limit in a particular period.

Introduction of the Ability to Model Cross-region User Constraints (ADRATIOs)

Cross-region user-defined equations (MR_XARAT) allow the modeler to construct user-defined constraints (ADRATIOs) that involve multiple regions. They are clearly only relevant for multi-region models. A new ADRATIO qualifier option (Cross-region User-defined Constraint (Set XARAT(adratio))) is used to indicate that an ADRATIO is to be considered multi-region in nature. This indicator is then introduced in each region involved in the cross-region constraint.

Introduction of Decay Constraints

The new capacity “Decay” constraint limits the rate at which resource activity or technology capacity can be reduced between periods.

Previously MARKAL only supported limiting the growth of a resource activity or level of installed capacity by means of an annual growth constraint EQ_GRS/EQ_GRT respectively. This was accomplished by means of the GROWTHr and GROWTH parameters, and associated “seed” TID entries.

For ETP a similar constraint has been added to limit the rate at which a resource activity or technology capacity may be reduced between periods. This is accomplished by the annual decrease rate DECAYr and DECAY in a manner similar to GROWTHr/GROWTH. The resulting constraint for technologies is:

\[ \text{EQ}_\text{TDE}_{i,tch} \cdot \text{CAP}_{i,tch} - \text{CAP}_{i-1,tch} \ast (\text{DECAY}_{i,tch,t} \ast (\text{NYRSPER}) \geq 0 \]

Modeling of Lumpy Investments

To permit more sophisticated modeling in respect of lumpy investments (such as the construction of gas pipelines) an extension to MARKAL was made to handle the all-or-nothing building of new capacity via mixed integer programming (MIP) techniques was done by Dr. Ken Noble, then at ABARE and now running Noble-Soft Systems. Three different facilities for modeling lumpy investments are provided. Each of these facilities requires the user to identify technologies (TCH) where investment in new capacity is ‘lumpy’. The size of the ‘lump’ is specified by the parameter INV_BLOCK, where INV_BLOCK(TCH, YEAR) = minimum positive level of investment in new capacity in technology TCH in period YEAR. The three facilities that are provided allow the user to require that:
(a) Investment in new capacity in each period is either an integer multiple of INV_BLOCK, or zero; or

(b) Investment in new capacity in each period is either INV_BLOCK, or zero; or

(c) Investment in new capacity in each period is either INV_BLOCK, or zero and investment is restricted to occur in at most one period.

The user is cautioned that the computer run time for solving a mixed integer program that involves a large number of integer/binary variables can be many times that for solving a linear program of similar size. Hence use of the new facilities for modeling lumpy investments should be confined to those technologies (such as gas pipelines) where investment is intrinsically lumpy.

Full details on the implementation can be found in the ANSWER-MARKAL Information Note: Lumpy Investments in ANSWER-MARKAL, May 2003.

Modeling to Generate Alternatives

MARKAL is a model that depicts the least-cost evolution of an energy system over time, given assumptions about future demand levels, policies, and technology and fuel characteristics. The model is based on the computation of a dynamic inter-temporal partial equilibrium on energy markets. The modeling framework is very data intensive, and, as one moves further out into the future, the data assumptions are subject to increasing uncertainty. Given these uncertainties, the least-cost pathway that is identified by MARKAL may not be the true optimal pathway. Instead, pathways that appear suboptimal to MARKAL may in fact be optimal when these uncertainties are resolved.

Another consideration is that the least cost solution output by MARKAL provides a single technological pathway toward meeting demands. A MARKAL user may be interested in whether there are alternative pathways at or near the same total cost. If such solutions exist, it may be valuable to know how similar or different these solutions are from the optimal solution, since this information is useful in determining the amount of flexibility available in cost-effectively achieving performance constraints. For example, if all such pathways that meet an emissions target utilize a similar technology, this implies that the technology is required to achieve the target.

Given these issues, it may be desirable to explore the solution space in and around the least-cost solution. One approach for doing this is to employ a technique known as Modeling to Generate Alternatives (MGA). In MGA, a region of space close to the least-cost solution is first specified. Usually this region of space is defined as being within some small fraction from the least cost. Then, optimization is used to identify a set of maximally different (in a sense to be defined) solutions within the region. The solutions are generated sequentially, each new solution being maximally different from all previous solutions. The generation of alternatives ends when a

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25 Note that the MGA formulation has not yet be designated a full variant of Standard MARKAL as it has only be applied by the US EPA to date, and not any ETSAP partners.


specific number of them have been identified or when additional solutions are not sufficiently different (in a sense to be defined) from those already identified.

An advantage of MGA is that, once the least cost model has been formulated, the creation of MGA instances is straightforward. Modifications involve the addition of a small number of constraints and the creation of an objective function that maximizes the ‘distance’ from the previous solutions. There is considerable flexibility in how the distance function can be implemented, allowing a wide range of metrics to be used. For example, a “low-level” distance function may attempt to force out technologies that have appeared in previous solutions. A “high-level” distance function, in contrast, may explicitly seek to identify solutions that differ with respect to some specific dimension, e.g. their impact on pollutant emissions.

We have previously incorporated a preliminary version of MGA into the MARKAL framework. The initial MARKAL-MGA formulation has been expanded to permit constraining the cost by sub-sector, or by some other grouping of technologies, and to provide support for multi-region models. Grouping of technologies may be accomplished by demand sector DM (via MGA_DM) or by explicitly listing the technologies in the MGA group (MGA_Grp). The expenditure on new investments for each specified group is constrained in each time period to be within some fraction of the value from the least-investment cost of that group. The mechanism for limiting sector and group level costs with lower/upper constraints has also been introduced to the Goal Programming formulation of MARKAL (see Goal Programming_MARKAL, Goldstein, Hobbs and Laitner, March 2003).

The MARKAL-MGA procedure will operate as described here.

- Accept the MGA user input data options, discussed below;
- Solve the standard (single/multi-region) MARKAL or MARKAL-PE model;
- Produce <MGA_Runs_1>.ANT/VD* reference case report files;
- Set the MGA_RCst, MGA_DCst, and MGA_GCst levels equal to the “relaxed” total discounted system cost or sector total lump-sum investment expenditure in each period obtained for the standard model run;
- Loop for the MGA_Runs2-n
  - Set the MGA_b coefficient based upon the CAPacity variable (CAP) levels in the previous solution;
  - Establish the new MGA_Obj objective function: summing over using MGA_b * CAP for all technologies;
  - Establish the MGA group cost constraints (EQ_MGADM(dm,year) and EQ_MGAGRPI(mkt_id,year): summing over the total discounted lump-sum investment costs for each MGA_DM and MGA_Grp using the MARKAL investment_coefficient (PRI_INV) * INVestment variable;
  - Solve MGA_Obj;
  - Produce <MGA_Runs_1>.ANT/VD* report files;

This approach enables the series of MARKAL/MARKAL-PE and (n-1) MGA runs to be performed very quickly.

For full details on the MARKAL-MGA formulation and use see the MARKAL Information Note: MARKAL-MGA+Reg, January 2005.
**Data Management and Analysis Systems ("Shells")**

**VEDA**

The VErsatile Data Analyst (VEDA) software came to fruition during Annex VIII, with support from ETSAP and other key institutions. VEDA supports both MARKAL and TIMES, opening (?) where the latter has made the use of TIMES a real possibility by the wider ETSAP and energy system modeling community. VEDA consists of two independent but closely related software, VEDA-Front-End (VEDA-FE), which oversees the management of the input data and submitting of model runs, and VEDA-Back-End (VEDA-BE) used to analyze the results of the model runs. Besides its fundamental requirement to support MARKAL and TIMES, VEDA was explicitly developed to support the demands imposed by large multi-region models.

VEDA is now being used for major multi-region modeling initiatives including the Energy Information Administration SAGE, European Union NEEDS, and European Fusion Development Agreement (EFDA), and New England MARKAL undertakings.

The main features of VEDA-FE (front-end) are:

- a heavy reliance on flexible region-aware Excel spreadsheets integrated with a core database;
- a direct linkage to existing regional data sources (e.g., IEA energy balance statistics, USEPA eGRID, EuroStat);
- employing a customizable n-dimensional Data Cube component for displaying tables;
- a demand projection module tied to regional economic indicators, fine-tuned with analyst insight;
- a technology repository “inheritance” matrix with regional adjustment factors;
- a trade matrix with multiple views;
- RES diagramming with region filtering and data views (including results via VEDA-BE);
- rule-based user-defined constraint creation “assistant,” and
- powerful filter and search facilities.

The overall layout and integration of VEDA-FE is depicted in Figure 1 below.
Figure 1: VEDA-FE System Components and Integration

The basic VEDA-FE data form and its search engine are shown in Figure 2.

Figure 2: Data View & Search Forms
VEDA-FE support extensive graphing capabilities, including RES diagramming, as shown in Figures 3 and 4.

Figure 3: RES Diagrams and Search/Data Windows

Figure 4: Input Data Graphs
The demand projection facility enables the reference year demand for energy services to be easily extrapolated for the modeling horizon based upon economic, demographic, and/or other drivers, refined by expert judgment, as depicted in Figure 5.

Figure 5: Demand project sub-system

The VEDA-FE technology repository, or sub-RES, allows for a common set of technology descriptions to be “inherited” into a multi-region model by simply indicating which technologies are available to a region, and what adjustment factor, if any, are to be applied for the various technical parameters (e.g., operating cost, year of availability). The inheritance matrix is shown in Figure 6.
The handling of specification of trade in large multi-region models is complex. VEDA-FE facilities this by means of a simple trade matrix and various means of qualifying the trade information, as shown in Figure 7.
Every MARKAL/TIMES modeler is aware of the daunting task of properly enumerating (and maintaining, whenever new technologies are added or some existing ones are removed) the various user-defined constraints that need to be imposed on a model in order to “guide” the model into a reasonable and acceptable solution space (e.g., rate of fuel switching in the residential sector) and represent policies (e.g., renewable portfolio standards). VEDA facilitates this by turning to a rule-based approach, where the analyst can identify the candidate technologies either by name/description maps or commodity in/out flows, which are enumerated on demand to extrapolate to the actual entries required by the model. The user-constraint template is shown in Figure 8.

As already noted, VEDA-BE (back-end) is a powerful model post-processor used to examine the return of model runs. The main features of VEDA-BE are:

- management of (GAMS) sets, parameters and model results for the purpose of dynamic viewing and re-organizing, and presentation to others;
- support for the construction of user-defined sets, definition of new tables, and manipulation of tables;
- providing for powerful filtering capabilities on both elements names and descriptions;
- employment of customizable n-dimensional data cube component for displaying tables and graphing of them;
- a batch REPORT mode for easy generation of a set of standard tables, and
- a Web-enabled facility, allowing model results to be made available over the web in user-friendly, reconfigurable tables.

The VEDA-BE dynamic data cube, and the options for further customizing it beyond the fundamental drag-and-drop facility at its core, are shown in Figure 8.
VEDA-BE allows for any number of tables to be brought into the viewer at any time, and provides for both context (e.g., component name) and content (e.g., data value, non-0) filtering to facilitate determining what is happening in a series of model runs. Figure 9 illustrates the multi-table viewing and data filtering.

Figure 9: Multiple Tables and Value Filtering

The information presented in any table may be quickly graphed, as shown in Figure 10, and exported to Excel or other MS-Office components.

Figure 10: Quick Graph of Model Results
The diagramming facility of VEDA (both FE and BE) also for a single dimension of the data or model results to be displayed on the RES, as shown in Figure 11.

![Figure 11: RES with Model Results](image)

As mentioned previously a special instance of VEDA-BE, VEDA-Viewer, is web enabled permitting cube tables to be downloaded from the web for viewing and manipulation locally. A sample application main page is shown in Figure 12.
Figure 12: Web Menu of VEDA-Viewer

VEDA is the brainchild of Amit Kanudia and is under continual development by KanORS Consulting Inc, with substantive input in terms of requirements and functionality injected by Gary Goldstein, ETSAP’s Primary Systems coordinator. For more information about VEDA interested parties may contact Amit (amit@KanORS.com) or Gary (ggoldstein@irgltd.com).

**ANSWER**

During Annex VIII, the ANSWER Windows-based user interface for working with the MARKAL family of models continued to be developed to meet the needs of the expanding MARKAL user community. The single most important development was the creation of a special version of ANSWER tailored to meet the needs of the International Energy Agency’s Energy Technology Perspectives (IEA-ETP) Model, as discussed below.

The current ANSWER user base includes about 90 institutions in some 35 countries.

*General ANSWER enhancements*

During Annex VIII, the ANSWER software continued to be enhanced so that it could handle (almost) all of the enhancements that were made to the ETSAP GAMS-MARKAL code. In most cases, the task of ensuring that the ANSWER database template remains aware of new data/results parameters is a fairly routine one. But adapting the ANSWER paradigm to accommodate the introduction into the GAMS-MARKAL code of cross-region emission and user constraint parameters required considerable ingenuity.
Otherwise, there was a general focus on improving user-friendliness of ANSWER, and of speeding up the operation of ANSWER in areas where users reported performance problems. Amongst these improvements were the creation of a significantly simplified batch run facility, and the speeding up of the time taken to generate the GAMS data dictionary files by a factor of about 25.

Special Enhancement to ANSWER for IEA-ETP Model

The IEA-ETP model is a 15-region MARKAL model with a lot of technology detail for each region, so is a huge model. Some of the important characteristics of the model include:

- A common naming convention across regions for many technologies and commodities (so for example ESISBFG005 is “Industrial Cogen unit, Iron and Steel, RFG” in each region).
- Common numeric values across regions for many parameter instances associated with technologies.
- For some parameter instances, instead of a common numeric value across regions, regional numeric value = common numeric value * regional multiplier, where the same regional multiplier applies for many technologies. (Or, regional numeric value = common numeric value + regional adder, where the same regional adder applies for many technologies.)

The special version of ANSWER that was created to meet the needs of the IEA-ETP Model has the following main characteristics:

- Use of a special _LIBRARY region within an ANSWER database to store information and data associated with technologies and commodities that will be common to each of the 15 regions.
- The provision of extensive bulk copying and 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.
The creation of an “Operator Parameter” mechanism to allow the user to specify regional multiplier (or regional adder) to be applied to _LIBRARY region parameter numeric values.
The achievement of acceptable performance notwithstanding the huge size of the IEA-ETP model.

The maintenance of data integrity between “Child” technologies and commodities in the 15 regions with their “Parents” in the _LIBRARY region, a task made considerably more complicated by the need to take account of the “Operator Parameter” mechanism mentioned above.

Ownership of ANSWER

Near the end of 2003, the ownership of the ANSWER software changed. The software was originally developed and marketed over the period 1996 to late 2003 by former Australian ETSAP Partner ABARE (the Australian Bureau of Agricultural and Resource Economics) – an independent economic and policy research agency of the Government of Australia. During this period, primary system design, programming and support and maintenance were undertaken by then ABARE staff member, Dr Ken Noble. In late 2003 Ken Noble retired from ABARE, established Noble-Soft Systems Pty Ltd and purchased the ANSWER software from ABARE, thereby ensuring continuing development and support for the software.

Noble-Soft Systems is a company whose sole business is providing development and support for the ANSWER software, and for the MARKAL/TIMES energy modeling framework. It maintains a close collaborative relationship with ETSAP and in particular with the ETSAP Primary Systems Coordinator, Gary Goldstein, with the aim of ensuring that the software continues to be developed in beneficial directions. For more information on ANSWER interested parties may contact Ken (noblesoft@netspeed.com.au) or Gary (ggoldstein@irgltd.com).
INTERNATIONAL ENERGY AGENCY

IMPLEMENTING AGREEMENT FOR A PROGRAMME OF ENERGY TECHNOLOGY SYSTEMS ANALYSIS

The Contracting Parties

CONSIDERING that the Contracting Parties, being either governments of International Energy Agency ("Agency") Countries, governments of other countries invited by the Governing Board of the Agency to be Contracting Parties, international organizations or parties designated by their respective governments, wish to take part in the establishment and operation of a Programme of Energy Technology Systems Analysis (the "Programme") as provided in this Agreement;

CONSIDERING that the Contracting Parties which are governments of Agency Countries and the governments of Agency Countries which have designated Contracting Parties (referred to collectively as the "Governments") have agreed in Article 41 of the Agreement on an International Energy Program (the "I.E.P. Agreement") to undertake national programmes in the areas set out in Article 42 of the I.E.P. Agreement, including energy research and development, on overall energy systems analysis and general studies in which field the Programme will be carried out;

CONSIDERING that in the Governing Board of the Agency on 21st October 1980, the Governments approved the Programme as a special activity under Article 65 of the I.E.P. Agreement;

CONSIDERING that the Agency has recognized the establishment of the Programme as an important component of international co-operation in the field of thermal energy research and development;

HAVE AGREED as follows:

Article 1
OBJECTIVES

(a) Scope of Activity. The Programme to be carried out by the Contracting Parties within the framework of this Agreement shall consist of co-operative energy technology systems analysis.

(b) Method of Implementation. The Contracting Parties shall implement the Programme by undertaking one or more tasks (the "Task" or "Tasks") each of which will be open to participation by two or more Contracting Parties as provided in Article 2 hereof. The Contracting Parties,
which participate in a particular Task, are, for the purposes of that Task, referred to in this Agreement as "Participants".

(c) Task Co-ordination and Co-operation. The Contracting Parties shall co-operate in co-ordinating the work of the various Tasks and shall endeavour, on the basis of an appropriate sharing of burdens and benefits, to encourage co-operation among Participants engaged in the various Tasks with the objective of advancing the activities of all Contracting Parties in the field of energy technology systems analysis.

Article 2

IDENTIFICATION AND INITIATION OF TASKS

(a) Identification. The Tasks undertaken by Participants are identified in the Annexes to this Agreement. At the time of signing this Agreement, each Contracting Party shall confirm its intention to participate in one or more Tasks by giving the Executive Director of the Agency a Notice of Participation in the relevant Annex or Annexes and the Operating Agent for each Task shall give the Executive Director of the Agency a Notice of Acceptance of the Task Annex. Thereafter, each Task shall be carried out in accordance with the procedures set forth in Articles 2 to 11 hereof, unless otherwise specifically provided in the applicable Annex.

(b) Initiation of Additional Tasks. Additional Tasks may be initiated by any Contracting Party according to the following procedures:

(1) A Contracting Party wishing to initiate a new Task shall present to one or more Contracting Parties for approval a draft Annex, similar in form to the Annexes attached hereto, containing a description of the scope of work and conditions of the Task proposed to be performed;

(2) Whenever two or more Contracting Parties agree to undertake a new Task, they shall submit the draft Annex for approval by the Executive Committee pursuant to Article 3 (e) (2) hereof; the approved draft Annex shall become part of this Agreement; Notice of Participation in the Task by Contracting Parties and acceptance by the Operating Agent shall be communicated to the Executive Director in the manner provided in paragraph (a) above;

(3) In carrying out the various Tasks, Participants shall co-ordinate their activities in order to avoid duplication of activities.

(c) Application of Task Annexes. Each Annex shall be binding only upon the Participants therein and upon the Operating Agent for that Task, and shall not affect the rights or obligations of other Contracting Parties.

Article 3

THE EXECUTIVE COMMITTEE

(a) Supervisory Control. Control of the Programme shall be vested in the Executive Committee constituted under this Article.
(b) Membership. The Executive Committee shall consist of one member designated by each Contracting Party; each Contracting Party shall also designate an alternate member to serve on the Executive Committee in the event that its designated member is unable to do so.

(c) Responsibilities. The Executive Committee shall:

(1) Adopt for each year, acting by unanimity, the Programme of Work, and Budget if foreseen, for each Task, together with an indicative Programme of Work and Budget for the following year; the Executive Committee may, as required, make adjustments within the framework of the Programme of Work and Budget;

(2) Make such rules and regulations as may be required for the sound, management of the Tasks, including financial rules as provided in Article 6 hereof;

(3) Carry out the other functions conferred upon it by this Agreement and the Annexes hereto; and

(4) Consider any matters submitted to it by any of the Operating Agents or by any Contracting Party.

(d) Procedure. The Executive Committee shall carry out its responsibilities in accordance with the following procedures:

(1) The Executive Committee shall each year elect a Chairman and one or more Vice-Chairmen;

(2) The Executive Committee may establish such subsidiary bodies and rules of procedure as are required for its proper functioning. A representative of the Agency and a representative of each Operating Agent (in its capacity as such) may attend meetings of the Executive Committee and its subsidiary bodies in an advisory capacity;

(3) The Executive Committee shall meet in regular session twice each year; a special meeting shall be convened upon the request of any Contracting Party, which can demonstrate the need therefore;

(4) Meetings of the Executive Committee shall be held at such time and in such office or offices as may be designated by the Committee;

(5) At least twenty-eight days before each meeting of the Executive Committee, notice of the time, place and purpose of the meeting shall be given to each Contracting Party and to other persons or entities entitled to attend the meeting; notice need not be given to any person or entity otherwise entitled thereto if notice is waived before or after the meeting;

(6) The quorum for the transaction of business in meetings of the Executive Committee shall be one-half of the members plus one (less any resulting fraction) provided that any action relating to a particular Task shall require a quorum as aforesaid of members or alternate members designated by the Participants in that Task.

(e) Voting.
(1) When the Executive Committee adopts a decision or recommendation for or concerning a particular Task, the Executive Committee shall act:

(i) When unanimity is required under this Agreement: by agreement of those members or alternate members, which were designated by the Participants in that Task and which are present and voting;

(ii) When no express voting provision is made in this Agreement: by majority vote of those members or alternate members, which were designated by the Participants in that Task and which are present and voting.

(2) In all other cases in which this Agreement expressly requires the Executive Committee to act by unanimity, this shall require the agreement of each member or alternate member present and voting, and in respect of all other decisions and recommendations for which no express voting provision is made in this Agreement, the Executive Committee shall act by a majority vote of the members or alternate members present and voting. If a government has designated more than one Contracting Party to this agreement, those Contracting Parties may cast only one vote under this paragraph.

(3) The decisions and recommendations referred to in sub-paragraphs (1) and (2) above may, with the agreement of each member or alternate member entitled to act thereon, be made by mail, telefax, telex, cable or other electronic means, without the necessity of calling a meeting. Such action shall be taken by unanimity or majority of such members as in a meeting. The Chairman of the Executive Committee shall ensure that all members are informed of each decision or recommendation made pursuant to this sub-paragraph.

(f) Reports. The Executive Committee shall, at least semi-annually, provide the Agency and the Committee on Energy Research and Development with periodic reports on the progress of the Programme.

Article 4

THE OPERATING AGENTS

(a) Designation. Participants shall designate in the relevant Annex an Operating Agent for each Task. References in this Agreement to the Operating Agent shall apply to each Operating Agent in respect of the Task for which it is responsible.

(b) Scope of Authority to Act on Behalf of Participants. Subject to the provisions of the applicable Annex:

(1) All legal acts required to carry out each Task shall be performed on behalf of the Participants by the Operating Agent for the Task;

(2) The Operating Agent shall hold, for the benefit of the Participants, the legal title to all property rights, which may accrue to or be acquired for the Task.
The Operating Agent shall operate the Task under its supervision and responsibility, subject to this Agreement, in accordance with the law of the country of the Operating Agent.

(c) **Reimbursements of Costs.** The Executive Committee may provide that expenses and costs incurred by an Operating Agent in acting as such pursuant to this Agreement shall be reimbursed to the Operating Agent from funds made available by the Participants pursuant to Article 6 hereof.

(d) **Replacement.** Should the Executive Committee wish to replace an Operating Agent with another government or entity, the Executive Committee may, acting by unanimity and with the consent of such government or entity, replace the initial Operating Agent. References in this Agreement to the "Operating Agent" shall include any government or entity appointed to replace the original Operating Agent under this paragraph.

(e) **Resignation.** An Operating Agent shall have the right to resign at any time, by giving six months written notice to that effect to the Executive Committee, provided that:

1. A Participant, or entity designated by a Participant, is at such time willing to assume the duties and obligations of the Operating Agent and so notifies the Executive Committee and the other Participants to that effect, in writing, not less than three months in advance of the effective date of such resignation; and

2. Such Participant or entity is approved by the Executive Committee, acting by unanimity.

(f) **Accounting.** An Operating Agent which is replaced or which resigns as Operating Agent shall provide the Executive Committee with an accounting of any monies and other assets which it may have collected or acquired for the Task in the course of carrying out its responsibilities as Operating Agent.

(g) **Transfer of Rights.** In the event that another Operating Agent is appointed under paragraph (d) or (e) above, the Operating Agent shall transfer to such replacement Operating Agent any property rights which it may hold on behalf of the Task.

(h) **Information and Reports.** Each Operating Agent shall furnish to the Executive Committee such information concerning the Task as the Committee may request and shall each year submit, not later than two months after the end of the financial year, a report on the status of the Task.

**Article 5**

**ADMINISTRATION AND STAFF**

(a) **Administration of Tasks.** Each Operating Agent shall be responsible to the Executive Committee for implementing its designated Task in accordance with this Agreement, the applicable Task Annex, and the decisions of the Executive Committee.

(b) **Staff.** It shall be the responsibility of the Operating Agent to retain such staff as may be required to carry out its designated Task in accordance with rules determined by the Executive Committee.
Committee. The Operating Agent may also, as required, utilize the services of personnel employed by other Participants (or organizations or other entities designated by Contracting Parties) and made available to the Operating Agent by secondment or otherwise. Such personnel shall be remunerated by their respective employers and shall, except as provided in this Article, be subject to their employers' conditions of service. The Contracting Parties shall be entitled to claim the appropriate cost of such remuneration or to receive an appropriate credit for such cost as part of the Budget of the Task, in accordance with Article 6 (f) (6) hereof.

Article 6
FINANCE

(a) Individual Obligations. Each Contracting Party shall bear the costs it incurs in carrying out this Agreement, including the costs of formulating or transmitting reports and of reimbursing its employees for travel and other per diem expenses incurred in connection with work carried out on the respective Tasks, unless provision is made for such costs to be reimbursed from common funds as provided in paragraph (g) below.

(b) Common Financial Obligations. Participants wishing to share the costs of a particular Task shall agree in the appropriate Task Annex to do so. The apportionment of contributions to such costs (whether in the form of cash, services rendered, intellectual property or the supply of materials) and the use of such contributions shall be governed by the regulations and decisions made pursuant to this Article by the Executive Committee.

(c) Financial Rules, Expenditure. The Executive Committee, acting by unanimity, may make such regulations as are required for the sound financial management of each Task including, where necessary:

1. Establishment of budgetary and procurement procedures to be used by the Operating Agent in making payments from any common funds which may be maintained by Participants for the account of the Task or in making contracts on behalf of the Participants;

2. Establishment of minimum levels of expenditure for which Executive Committee approval shall be required, including expenditure involving payment of monies to the Operating Agent for other than routine salary and administrative expenses previously approved by the Executive Committee in the budget process.

In the expenditure of common funds, the Operating Agent shall take into account the necessity of ensuring a fair distribution of such expenditure in the Participants' countries, where this is fully compatible with the most efficient technical and financial management of the Task.

(d) Crediting of Income to Budget. Any income, which accrues from a Task, shall be credited to the Budget of that Task.

(e) Accounting. The system of accounts employed by the Operating Agent shall be in accordance with accounting principles generally accepted in the country of the Operating Agent and consistently applied.
(f) Programme of Work and Budget, Keeping of Accounts. Should Participants agree to maintain common funds for the payment of obligations under a Programme of Work and Budget of the Task, the following provisions shall be applicable unless the Executive Committee, acting by unanimity, decides otherwise:

1. The financial year of the Task shall correspond to the financial year of the Operating Agent;

2. The Operating Agent shall each year prepare and submit to the Executive Committee for approval a draft Programme of Work and Budget, together with an indicative Programme of Work and Budget for the following year, not later than three months before the beginning of each financial year;

3. The Operating Agent shall maintain complete, separate financial records, which shall clearly account for all funds and property coming into the custody or possession of the Operating Agent in connection with the Task;

4. Not later than three months after the close of each financial year the Operating Agent shall submit to auditors selected by the Executive Committee for audit the annual accounts maintained for the Task; upon completion of the annual audit, the Operating Agent shall present the accounts together with the auditors' report to the Executive Committee for approval;

5. All books of account and records maintained by the Operating Agent shall be preserved for at least three years from the date of termination of the Task;

6. Where provided in the relevant Annex, a Participant supplying services, materials or intellectual property to the Task shall be entitled to a credit, determined by the Executive Committee, acting by unanimity, against its contribution (or to compensation, if the value of such services, materials or intellectual property exceeds the amount of the Participant's contribution); such credits for services of staff shall be calculated on an agreed scale approved by the Executive Committee and include all payroll-related costs.

(g) Contribution to Common Funds. Should Participants agree to establish common funds under the annual Programme of Work and Budget for a Task, any financial contributions due from Participants in a Task shall be paid to the Operating Agent in the currency of the country of the Operating Agent at such times and upon such other conditions as the Executive Committee, acting by unanimity, shall determine, provided however that:

1. Contributions received by the Operating Agent shall be used solely in accordance with the Programme of Work and Budget for the Task;

2. The Operating Agent shall be under no obligation to carry out any work on the Task until contributions amounting to at least fifty per cent (in cash terms) of the total due at anyone time have been received.

(h) Ancillary Services. Ancillary services may, as agreed between the Executive Committee and the Operating Agent, be provided by that Operating Agent for the operation of a Task and the cost of such services, including overheads connected therewith, may be met from budgeted funds of that Task.
(i) **Taxes.** The Operating Agent shall pay all taxes and similar impositions (other than taxes on income) imposed by national or local governments and incurred by it in connection with a Task, as expenditure incurred in the operation of that Task under the Budget; the Operating Agent shall, however, endeavour to obtain all possible exemptions from such taxes.

(j) **Audit.** Each Participant shall have the right, at its sole cost, to audit the accounts of any work in a Task for which common funds are maintained, on the following terms:

1. The Operating Agent shall provide the other Participants with an opportunity to participate in such audits on a cost-shared basis;
2. Accounts and records relating to activities of the Operating Agent other than those conducted for the Task shall be excluded from such audit, but if the Participant concerned requires verification of charges to the Budget representing services rendered to the Task by the Operating Agent, it may at its own cost request and obtain an audit certificate in this respect from the auditors of the Operating Agent;
3. Not more than one such audit shall be required in any financial year;
4. Any such audit shall be carried out by not more than three representatives of the Participants.

**Article 7**

**INFORMATION AND INTELLECTUAL PROPERTY**

It is expected that for each Task agreed to pursuant to this Agreement, the applicable Annex will contain information and intellectual property provisions. The General Guidelines Concerning Information and Intellectual Property, approved by the Governing Board of the Agency on 21st November 1975, shall be taken into account in developing such provisions.

**Article 8**

**LEGAL RESPONSIBILITY AND INSURANCE**

(a) **Liability of Operating Agent.** The Operating Agent shall use all reasonable skill and care in carrying out its duties under this Agreement in accordance with all applicable laws and regulations. Except as otherwise provided in this Article, the cost of all damage to property, and all expenses associated with claims, actions and other costs arising from work undertaken with common funds for a Task shall be charged to the Budget of that Task; such costs and expenses arising from other work undertaken for a Task shall be charged to the Budget of that Task as the Task Annex so provides or the Executive Committee, acting by unanimity, so decides.

(b) **Insurance.** The Operating Agent shall propose to the Executive Committee all necessary liability, fire and other insurance, and shall carry such insurance as the Executive Committee may direct. The cost of obtaining and maintaining insurance shall be charged to the Budget of the Task.
(c) **Indemnification of Contracting Parties.** The Operating Agent shall be liable, in its capacity as such, to indemnify Participants against the cost of any damage to property and all legal liabilities, actions, claims, costs and expenses connected therewith to the extent that they:

1. Result from the failure of the Operating Agent to maintain such insurance as it may be required to maintain under paragraph (b) above; or

2. Result from the gross negligence or willful misconduct of any officers or employees of the Operating Agent in carrying out their duties under this Agreement.

**Article 9**

**LEGISLATIVE PROVISIONS**

(a) **Accomplishment of Formalities.** Each Participant shall request the appropriate authorities of its country (or its Member States in the case of an international organization) to use their best endeavours, within the framework of applicable legislation, to facilitate the accomplishment of formalities involved in the movement of persons, the importation of materials and equipment and the transfer of currency which shall be required to conduct the Task in which it is engaged.

(b) **Applicable Laws.** In carrying out this Agreement and its Annexes, the Contracting Parties shall be subject to the appropriation of funds by the appropriate governmental authority, where necessary, and to the constitution, laws and regulations applicable to the respective Contracting Parties, including, but not limited to, laws establishing prohibitions upon the payment of commissions, percentages, brokerage or contingent fees to persons retained to solicit governmental contracts and upon any share of such contracts accruing to governmental officials.

(c) **Decisions of Agency Governing Board.** Notwithstanding Article 7 of the Framework for International Energy Technology Co-operation, adopted by the IEA Governing Board on 3 April, 2003, the Framework shall apply, and be an integral Part of, this Agreement from November 26, 2004. A copy of the Framework is attached as Exhibit A to this Implementing Agreement.”

(d) **Settlement of Disputes.** Any dispute among the Contracting Parties concerning the interpretation or the application of this Agreement which is not settled by negotiation or other agreed mode of settlement shall be referred to a tribunal of three arbitrators to be chosen by the Contracting Parties concerned who shall also choose the Chairman of the tribunal. Should the Contracting Parties concerned fail to agree upon the composition of the tribunal or the selection of its Chairman, the President of the International Court of Justice shall, at the request of any of the Contracting Parties concerned, exercise those responsibilities. The tribunal shall decide any such dispute by reference to the terms of this Agreement and any applicable laws and regulations, and its decision on a question of fact shall be final and binding on the Contracting Parties concerned. Operating Agents, which are not Contracting Parties, shall be regarded as Contracting Parties for the purpose of this paragraph.

**Article 10**

**ADMISSION AND WITHDRAWAL OF CONTRACTING PARTIES**

(a) **Admission of New Contracting Parties: OECD Member Countries.** Upon the invitation of the Executive Committee, acting by unanimity, admission to this Agreement shall be open to the government of any OECD Member Country (or a national agency, public organization,
private corporation, company or other entity designated by such government), which signs or
accedes to this Agreement, accepts the rights and obligations of a Contracting Party, and is
accepted for participation in at least one Task by the Participants in that Task, acting by
unanimity. Such admission of a Contracting Party shall become effective upon the signature of
this Agreement by the new Contracting Party or its accession thereto and its giving Notice of
Participation in one or more Annexes and the adoption of any consequential amendments thereto.

(b) Admission of New Contracting Parties: OECD Non-Member Countries. The government
of any country which is not a Member of the OECD may, on the approval of the Executive
Committee, acting by unanimity, and, where required, with the approval of the Committee for
Energy Research and Technology, be invited to participate as a Contracting Party in this
Agreement (or to designate a national agency, public organization, private corporation, company
or other entity to do so), under the conditions stated in paragraph (a) above.

(c) Participation by the European Communities. The European Communities may
participate in this Agreement in accordance with arrangements to be made by the Executive
Committee, acting by unanimity.

(d) Admission of New Participants in Tasks. Any Contracting Party may, with the agreement
of the Participants in a Task, acting by unanimity, become a Participant in that Task. Such
participation shall become effective upon the Contracting Party's giving the Executive Director of
the Agency a Notice of Participation in the appropriate Task Annex and the adoption of
consequential amendments thereto.

(e) Contributions. The Executive Committee may require, as a condition to admission to
participation, that the new Contracting Party or new Participant shall con- tribute (in the form of
cash, services or materials) an appropriate proportion of the prior budget expenditure of any Task
in which it participates.

(f) Replacement of Contracting Parties. With the agreement of the Executive Committee,
acting by unanimity, and upon the request of a government, a Contracting Party designated by
that government may be replaced by another party. In the event of such replacement, the
replacement party shall assume the rights and obligations of a Contracting Party as provided in
paragraph (a) above and in accordance with the procedure provided therein.

(g) Withdrawal. Any Contracting Party may withdraw from this Agreement or from any
Task either with the agreement of the Executive Committee, acting by unanimity, or by giving
twelve months written Notice of Withdrawal to the Executive Director of the Agency, such
Notice to be given not less than one year after the date hereof. The withdrawal of a Contracting
Party under this paragraph shall not affect the rights and obligations of the other Contracting
Parties; except that, where the other Contracting Parties have contributed to common funds for a
Task, their proportionate shares in the Task Budget shall be adjusted to take account of such
withdrawal.

(h) Changes of Status of Contracting Party. A Contracting Party other than a government or
an international organization shall forthwith notify the Executive Committee of any significant
change in its status or ownership, or of its becoming bankrupt or entering into liquidation. The
Executive Committee shall determine whether any such change in status of a Contracting Party
significantly affects the interests of the other Contracting Parties; if the Executive Committee so
determines, then, unless the Executive Committee, acting upon the unanimous decision of the
other Contracting Parties, otherwise agrees:
(1) That Contracting Party shall be deemed to have withdrawn from the Agreement under paragraph (g) above on a date to be fixed by the Executive Committee; and

(2) The Executive Committee shall invite the government which designated that Contracting Party to designate, within a period of three months of the withdrawal of that Contracting Party, a different entity to become a Contracting Party; if approved by the Executive Committee, acting by unanimity, such entity shall become a Contracting Party with effect from the date on which it signs or accedes to this Agreement and gives the Executive Director of the Agency a Notice of Participation in one or more Annexes.

(i) Failure to Fulfil Contractual Obligations. Any Contracting Party which fails to fulfil its obligations under this Agreement within sixty days after its receipt of notice specifying the nature of such failure and invoking this paragraph, may be deemed by the Executive Committee, acting by unanimity, to have withdrawn from this Agreement.

Article 11
FINAL PROVISIONS

(a) Term of Agreement. This Agreement shall remain in force for an initial period of two years and, thereafter, may be extended for additional periods not greater than five years as may be determined by the Executive Committee, acting by unanimity and subject to the approval of the Committee for Energy Research and Technology (CERT) of the Agency. The Executive Committee, acting by unanimity, may terminate this Agreement at any time.

(b) Legal Relationship of Contracting Parties and Participants. Nothing in this Agreement shall be regarded as constituting a partnership between any of the Contracting Parties or Participants.

(c) Termination. Upon termination of this Agreement or any Annex to this Agreement, the Executive Committee, acting by unanimity, shall arrange for the liquidation of the assets of the Task or Tasks. In the event of such liquidation, the Executive Committee shall, so far as practicable, distribute the assets of the Task, or the proceeds therefrom, in proportion to the contributions which the Participants have made from the beginning of the operation of the Task, and for that purpose shall take into account the contributions and any outstanding obligations of former Contracting Parties. Disputes with a former Contracting Party about the proportion allocated to it under this paragraph shall be settled under Article 9 (d) hereof, for which purpose a former Contracting Party shall be regarded as a Contracting Party.

(d) Amendment. This Agreement may be amended at any time by the Executive Committee, acting by unanimity, and any Annex to this Agreement may be amended at any time by the Executive Committee, acting by unanimity of the Participants in the Task to which the Annex refers. Such amendments shall come into force in a manner determined by the Executive Committee, acting under the voting rule applicable to the decision to adopt the amendment.

(e) Deposit. The original of this Agreement shall be deposited with the Executive Director of the Agency and a certified copy thereof shall be furnished to each Contracting Party. A copy of this Agreement shall be furnished to each Agency Participating Country, to each Member country
of the Organisation for Economic Co-operation and Development and to the European Communities.

Done in Paris, this 13th day of November 1980.
As amended by the Executive Committee, held in Paris on 10 October 2001.
As amended by the Executive Committee by written procedure on March 15, 2004.
As further amended by the Executive Committee, held in Florence on 26 November 2004.

Contracting Parties

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date of Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energieverwertungsagentur (Austria)</td>
<td>19.12.80.</td>
</tr>
<tr>
<td>The Department of National Development and Energy (Australia)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>succeeded by the Australian Bureau of Agriculture and Resource Economics</td>
<td></td>
</tr>
<tr>
<td>Kernforschungsanlage Jülich GmbH (Germany)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>name changed to Forschungszentrum Jülich GmbH, replaced by the Institute</td>
<td></td>
</tr>
<tr>
<td>Energy Economics and Rational Use of Energy (IER) of the University of</td>
<td></td>
</tr>
<tr>
<td>Stuttgart 12.05.97.</td>
<td></td>
</tr>
<tr>
<td>The Commission of the European Communities</td>
<td>11.01.82.</td>
</tr>
<tr>
<td>The National Technology Agency of Finland (TEKES)</td>
<td>09.01.02</td>
</tr>
<tr>
<td>The Stichting Energieonderzoek Centrum Nederland (ECN) (Netherlands)</td>
<td>02.04.82.</td>
</tr>
<tr>
<td>The Royal Ministry of Petroleum and Energy (Norway)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>(name changed to the Royal Norwegian Ministry of Industry and Energy, then</td>
<td></td>
</tr>
<tr>
<td>reverted back to the Royal Norwegian Ministry of Petroleum and Energy)</td>
<td></td>
</tr>
<tr>
<td>The Centro de Estudios de la Energía (Spain)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>The Energy Research and Development Commission (Sweden)</td>
<td>18.11.80.</td>
</tr>
<tr>
<td>(subsequently succeeded by the Energy Research Commission</td>
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<td>then by the Swedish National Board for Industrial and Technical Development (NUTEK)</td>
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<tr>
<td>and later by the Swedish Energy Agency)</td>
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<td>The Office Fédéral de l'Energie (Switzerland)</td>
<td>01.04.81.</td>
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<td>(replaced by the Paul Scherrer Institute) 19.12.91.</td>
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<td>The Kocaeli University (Turkey)</td>
<td>22.03.96.</td>
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<tr>
<td>The Secretary of State for Energy (United Kingdom)</td>
<td>09.06.81.</td>
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<tr>
<td>(succeeded by the Secretary of State for Trade and Industry)</td>
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<tr>
<td>The United States Department of Energy</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>(replaced by The Government of the United States of America; then again</td>
<td></td>
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<td>by the United States Department of Energy)</td>
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EXHIBIT A

IEA FRAMEWORK FOR INTERNATIONAL ENERGY TECHNOLOGY CO-OPERATION

I. General Principles

Article 1
Mandate

1.1 In fulfilment of Chapter VII of the Agreement on an International Energy Program and in light of the Shared Goals of the IEA, the IEA operates Implementing Agreements to enable IEA Member countries to carry out programmes and projects on energy technology research, development and deployment.

1.2 An Implementing Agreement is a contractual relationship established by at least two IEA Member countries, and approved by the Governing Board, for the purpose set out in Article 1.1.

1.3 Participants in an Implementing Agreement shall contribute as fully as possible to the achievement of its objectives and shall endeavour to secure, through public and private support, the necessary scientific, technical and financial resources for the programmes and projects carried out under such an Implementing Agreement.

1.4 Each Implementing Agreement shall have an Executive Committee composed of representatives of all participants.

Article 2
Nature of Implementing Agreements

2.1 The activities of an Implementing Agreement may include, inter alia:
(a) co-ordination and planning of specific energy technology research, development and deployment studies, works or experiments carried out at a national or international level, with subsequent exchange, joint evaluation and pooling of the scientific and technical results acquired through such activities;
(b) participation in the operation of special research or pilot facilities and equipment provided by a participant, or the joint design, construction and operation of such facilities and equipment;
(c) exchange of information on (i) national programmes and policies, (ii) scientific and technological developments and (iii) energy legislation, regulations and practices;
(d) exchanges of scientists, technicians or other experts;
(e) joint development of energy related technologies; and
(f) any other energy technology related activity.

2.2 Participation in an Implementing Agreement shall be based on equitable sharing of obligations, contributions, rights and benefits. Participants in an Implementing Agreement shall undertake to make constructive contributions, whether technical, financial or otherwise, as may be agreed by the Executive Committee.
2.3 Some or all of the participants in an Implementing Agreement may choose to execute specific projects and/or programmes through Annexes to the Implementing Agreement.

II. Rules Applicable to IEA Implementing Agreements

Article 3
Participation, Admission and Withdrawal

3.1 An Implementing Agreement can be established by two or more IEA Member countries subject to approval of the Committee on Energy Research and Technology (CERT) and of the Governing Board. There are two possible categories of participants in Implementing Agreements: Contracting Parties and Sponsors.

3.2 Contracting Parties may be

(a) the governments of both OECD member or OECD non-member countries;
(b) the European Communities;
(c) international organisations in which the governments of OECD member countries and/or OECD non-member countries participate; and
(d) any national agency, public organisation, private corporation or other entity designated by the government of an OECD member country or an OECD non-member country, or by the European Communities.

3.2.1 Participation in any Implementing Agreement for OECD non-member countries or for international organisations requires prior approval by the CERT. However, should the CERT consider a first time application by an OECD non-member country or an international organisation to be sensitive, it may refer the decision to the Governing Board as it deems appropriate.

3.2.2 Prior to CERT approval of participation of OECD non-member countries or international organisations in any Implementing Agreement, the Executive Committee shall:

(a) have voted in favour of the applicant to join the Implementing Agreement and provide evidence of the same to the CERT;
(b) provide the CERT with a copy of the terms and conditions of the applicant’s participation in the Implementing Agreement; and
(c) provide the CERT with a letter from the applicant expressing the applicant’s desire to join the Implementing Agreement and specifying which Annexes it wishes to join; its acceptance of the terms and conditions of the Implementing Agreement; the name of its designated entity if it is not the applicant itself; and the name of the entity that will sign the Implementing Agreement.

3.2.3 The terms and conditions for the admission, participation and withdrawal of Contracting Parties, including their rights and obligations, in Implementing Agreements and their Annexes, if any, shall be established by the Executive Committee of each Implementing Agreement.
3.2.4 Notwithstanding Article 3.2.3, no Contracting Party from an OECD non-member country or international organisation shall have greater rights or benefits than Contracting Parties from OECD member countries.

3.3 Sponsors may be

(a) entities of OECD member countries or OECD non-member countries who are not designated by the governments of their respective countries to participate in a particular Implementing Agreement; and
(b) non-intergovernmental international entities in which one or more entities of OECD member countries or OECD non-member countries participate.

3.3.1 Participation of Sponsors in Implementing Agreements requires prior approval by the CERT.

3.3.2 Prior to CERT approval of Sponsor participation in any Implementing Agreement, the Executive Committee shall:

(a) have voted in favour of the applicant to join the Implementing Agreement and provide evidence of the same to the CERT;
(b) provide the CERT with a copy of the terms and conditions of the applicant’s participation in the Implementing Agreement; and
(c) provide the CERT with a letter from the applicant expressing the applicant’s desire to join the Implementing Agreement and specifying which Annexes it wishes to join; its acceptance of the terms and conditions of the Implementing Agreement; and the name of the entity that will sign the Implementing Agreement.

3.3.3 The terms and conditions for the admission, participation and withdrawal of Sponsors, including rights and obligations, in Implementing Agreements and their Annexes, if any, shall be established by the Executive Committee of each Implementing Agreement.

3.3.4 Notwithstanding Article 3.3.3, no Sponsor shall have greater rights or benefits than Contracting Parties from OECD non-member countries and no Sponsor shall be designated Chair or Vice-chair of an Implementing Agreement.

3.3.5 The CERT shall have the right to not approve participation of a Sponsor if the terms and conditions of such participation do not comply with this Framework, any Decisions of the CERT or the Governing Board and the Shared Goals of the IEA.

Article 4
Specific Provisions

4.1 Unless the CERT otherwise agrees, based on exceptional circumstance and sufficient justification, Implementing Agreements shall be for an initial term of up to, but no more than, five years.

4.2 An Implementing Agreement may be extended for such additional periods as may be determined by its Executive Committee, subject to approval of the CERT. Any single
extension period shall not be greater than five years unless the CERT otherwise decides, based on exceptional circumstances and sufficient justification.

4.3 Notwithstanding Paragraph 4.2, should the duration of the programme of work of an Annex exceed the term of the Implementing Agreement to which it relates, the CERT shall not unreasonably withhold approval to extend the Implementing Agreement for such additional period to permit the conclusion of the work then being conducted under the Annex.

4.4 Either the Contracting Parties or the Executive Committee of each Implementing Agreement shall:

4.4.1 approve the programme activities and the annual programme of work and budget for the relevant Implementing Agreement;

4.4.2 establish the terms of the contribution for scientific and technical information, know-how and studies, manpower, capital investment or other forms of financing to be provided by each participant in the Implementing Agreement;

4.4.3 establish the necessary provisions on information and intellectual property and ensure the protection of IEA copyrights, logos and other intellectual property rights as established by the IEA;

4.4.4 assign the responsibility for the operational management of the programme or project to an entity accountable to the Executive Committee of the relevant Implementing Agreement;

4.4.5 establish the initial term of the Implementing Agreement and its Annexes;

4.4.6 approve amendments to the text of the Implementing Agreement and Annexes;

and

4.4.7 invite a representative of the IEA Secretariat to its Executive Committee meetings in an advisory capacity and, sufficiently in advance of the meeting, provide the Secretariat with all documentation made available to the Executive Committee members for purposes of the meeting.

Article 5
Copyright

5.1 Notwithstanding the use of the IEA name in the title of Implementing Agreements, the Implementing Agreements, the Executive Committee or the entity responsible for the operational management of the programme or project may use the name, acronym and emblem of the IEA as notified to the World Intellectual Property Organisation (WIPO) only upon prior written authorisation of the IEA and solely for the purposes of executing the Implementing Agreements.

5.2 The IEA shall retain the copyright to all IEA deliverables and published or unpublished IEA material. Implementing Agreements wishing to use, copy or print such IEA
deliverables and/or material shall submit a prior written request of authorisation to the IEA.

**Article 6**

*Reports to the IEA*

6.1 Each Executive Committee shall submit to the IEA:

6.1.1 as soon as such events occur, notifications of any admissions and withdrawals of Contracting Parties and Sponsors, any changes in the names or status of Contracting Parties or Sponsors, any changes in the Members of the Executive Committee or of the entity responsible for the operational management of the programme or project, or any amendments to an Implementing Agreement and Annex thereto;

6.1.2 annual reports on the progress of programmes and projects of the Implementing Agreement and any Annex;

6.1.3 notwithstanding Article 6.1.1, in addition to and with the Annual Report, annually provide the IEA with the following information:

(a) the names and contact details of all current Contracting Parties and Sponsors;
(b) the names and contact details of all Contracting Parties and Sponsors who may have withdrawn from the Implementing Agreement or any Annex in the year covered by the Annual Report;
(c) the names and contact details of all new Contracting Parties and Sponsors who may have joined the Implementing Agreement or any Annex in the year covered by the Annual Report;
(d) any changes in the names or status of any Contracting Parties or Sponsors;
(e) the names and contact details of the Executive Committee members and the entity responsible for the operational management of the programme or project; and
(f) any amendments to the text of an Implementing Agreement and any Annex thereto.

6.1.4 End of Term Reports, which shall include all the information and documentation required by Decisions of the CERT then in effect and relating thereto; and

6.1.5 at the request of the IEA, any other non-proprietary information as may be requested by the IEA in connection with the IEA’s mandate.

**Article 7**

*Effective Date*

This Framework shall take effect and become binding on all participants in the Implementing Agreements and Annexes from the date of its approval as a decision by the Governing Board.
APPENDIX B: ANNEX VIII - Exploring Energy Technology Perspectives

Implementing Agreement
for a Programme of
Energy Technology Systems Analysis

ANNEX VIII - *Exploring Energy Technology Perspectives*

Learning Strategies for Technological Development toward Sustainable Futures

**FINAL VERSION**

*Drafted according to the minutes of the Executive Committee meeting held in Paris, 10.10.2001
Completed by means of 2 written procedures*
1. Aims

Building on the results of Annex VII, comprising a new generation of assessment tools and first generation global energy technology models, Annex VIII will make a substantial contribution to the work conducted by the International Energy Agency, national governments, the IPCC and other international organizations on global strategies for sustainable development. Guided by on longer term ambitions, specific attention will be for shorter term initiatives and actions, e.g. of Parties to the Kyoto Protocol seeking to meet the commitments made in December 1997 and plan the next stages of their work in climate change and other sustainability concerns. This will include:

(a) the widespread and successful use of ETSAP tools, methodologies, data services and knowledge by the governments of the ETSAP Contracting Parties;

(b) the use of ETSAP tools, data services and analytical capacity to perform scenario analysis for the IEA Energy Technology Perspectives Project [IEA/CERT(2001)25];

(c) the constructive use of ETSAP tools by other countries - OECD Member and non-Member countries - as well as international organizations, in multi-lateral collaboration, discussions, and negotiations;

(d) the establishment of linkages with economic and environmental models and approaches that complement the work of ETSAP;

(e) the maintenance and ongoing use of ETSAP networks for analytical support;

(f) the demonstration and deployment of new methods, with increased flexibility to depict complex energy systems:

(1) to evaluate common or joint actions implemented by groups of countries, including emission trading in the Kyoto Protocol or trade in energy commodities;

(2) to treat evolution in the costs of new technologies endogenously, including spill-over effects of international collaboration; and

(3) to explicitly deal with strategic planning under uncertainty.

The overall goal of this Annex is thus to serve national governments, the IEA and other international fora like the IPCC, the Kyoto Protocol, and the Subsidiary Bodies of the FCCC, by fostering and supporting the assessment of constructive policy options for the development and deployment of energy technologies that are compatible with long-term sustainable development goals.

2. Background

There is widespread recognition that the global challenges of climate change and other sustainable development issues call for concerted and coordinated response strategies. At the same time the notion that technological change is a key factor in shaping future economic, energy and emission trajectories has become common wisdom. For example, the most recent Third Assessment Report of the IPCC indicates that costs to meet greenhouse gas stabilization targets can probably be lower than previously estimated as a result of targeted and effective technological development pathways. What pathways to pursue and how to initiate and foster promising technological development processes is however due to significant uncertainties. Short term policy interventions in the fields of R,D&D (“technology supply push”) and market stimulation (“technology demand pull”) will be required to enhance the prospects for longer term solutions to reduce emissions while meeting economic and social aspirations, an important
contribution to the practical realization of sustainable development. For example, the United Nations Framework Convention on Climate Change (FCCC) acknowledges that the global nature of climate change calls for the widest possible co-operation by all countries and their participation in effective and appropriate international response. The Kyoto Protocol reflects this approach by adopting flexible policy instruments aiming at worldwide participation to meet binding targets to reduce the emission of six greenhouse gases. During Annex VII the first steps were made to explore the mutually linked issues of international policy measures (Kyoto Mechanisms) and spill-over of technological improvements.

The ETSAP tools are available not only in most OECD countries, but in many other countries in Eastern Europe and the developing world. Alternative proposals for differentiated national targets have already been evaluated with respect to cost-effectiveness and equity indicators. ETSAP has the capability to estimate the cost savings of common actions implemented by wider groups of nations - within the industrialized world or developing countries, or between them as provided for by the Clean Development Mechanism in the Kyoto Protocol. It is also able to address an important emerging issue, namely, dealing with uncertainties in many factors that bear on the international economic activities, including emission trading in the Kyoto Protocol or trade in energy commodities.

ETSAP provides powerful support to the users of its methodologies and tools. It has established, and continues to nurture, a network of nations and expert analysts who co-operate in developing sound, technologically-informed options and in calculating the cost of restricting emissions of greenhouse gases and other pollutants. The family of ETSAP models use consistent formulations and data on technologies that consume, transform, or produce energy commodities. The ability to calculate the marginal costs of increasingly stringent reductions in emissions makes it possible to propose distributions of agreed levels of emissions among the countries that minimize the total costs, including optional mechanisms to partially meet national emission reduction commitments by exchanges with other countries.

The evolution of the research conducted during Annex VII by the ETSAP research partnership includes the development of hard-linked multi-country models to assess joint actions including issues of international emissions trading in the Kyoto Protocol or trade in energy commodities, and stochastic formulations to take uncertainties into full account. Simultaneously the endogenous treatment of technological progress ("learning") was consolidated as an operational feature in the ETSAP tools.

During Annex VII, ETSAP developed the next generation of its main tools, inter alia, to enhance adoption of further methodological developments and linkages in many different areas in the next decade. Within Annex VIII these instruments are to be developed further into products for operational and widespread use. The core tool is the TIMES model (The Integrated MARKAL-EFOM System).

3. **Services and Objectives**

(a) The principal services that ETSAP provides to its Participants are:

(1) an analytical facility for constructively studying:

   (i) energy technology strategy

   (ii) greenhouse gas abatement policy;
(2) a worldwide network of systems analysts and users that fully supports the use of the methodologies employed by ETSAP and related tools, resulting in the establishment of national technology and energy demand databases that can be used to promote the understanding of technologies in climate change analysis.

(b) The specific objectives of this Annex are:

(1) Analysis of regionalized global energy systems:
   To maintain consistent databases and to develop methodologies for combined optimization of regional models, together providing global coverage, in order to analyze the role of energy demand, conversion and supply technologies, and trade in balancing national or multi-national energy budgets while collectively meeting broad economic and environmental requirements;

(2) Analysis of national energy systems:
   To develop and control the quality of data needed by ETSAP tools used in support of decision-making; to make these data available for use in other applications as may serve the goal of this Annex; and to improve linkages between technological and non-technological factors in ETSAP tools;

(3) Expansion:
   To expand the availability and application of ETSAP methodologies in countries that are party to the FCCC or the Kyoto Protocol, or other countries that are considering becoming a party to either instrument;

(4) Establish operational links with other complementary approaches:
   To ensure a mutually beneficial exchange with economic and environmental models, such as general equilibrium and integrated assessment models, and other approaches with different scope and resolution;

(5) Develop advanced tools:
   To continue to foster the advancement of tools to enable local, regional, national and international authorities to better address the complex questions associated with energy and environmental issues. This includes both extension of the framework within which complex energy systems are represented, as well as the means for managing and fostering the effective use of such tools.

4. Means

The objectives shall be achieved by:

(a) Regionalized, Global Technology Models:
   Further development and application of internally consistent global technology models, consisting of interlinked regional datasets to cover co-operative policies and measures toward sustainable development and appropriate technological development strategies;

(b) Links with Other Approaches:
   Establishing links with other approaches, in particular, integrated assessment models to ensure a consistent background for ETSAP analyses and to provide results back to such models; support combined applications with other models at local and regional level;

(c) Technology Dynamics:
Introduction of technological change in ETSAP analyses as a function of policy and market developments or plans;

(d) Data Sets:
  Discussing and jointly validating data developed by the ETSAP Contracting Parties, by making non-proprietary data available to others, and by developing default data sets to facilitate initial application of ETSAP methods in new countries;

(e) Internal Peer Review:
  Doing internal peer review of each other’s model formulations and data bases to ensure that combined results are consistent among countries;

(f) External Review:
  Inviting outside experts, including policy analysts and those who use other methods, to discuss methodologies and to review results before the Annex is completed;

(g) Reference Groups:
  Using national and multi-national reference groups for the development and analysis of the models and linkage to users;

(h) Workshops:
  Organizing workshops and seminars to exchange information and experience in the areas of work covered by this Task, participating in joint meetings with related international projects, making a concerted effort to communicate with the wider professional community, and by otherwise involving decision-makers;

(i) Twinning:
  Twinning established ETSAP Contracting Parties with new countries; providing materials to guide new and recent users of ETSAP methodologies;

(j) Other Activities:
  Carrying out such other activities as may be agreed in the Annual Programme of Work.

5. Programs

There will be four principal programs in this Annex:

5.1 National Programs
  National programs of work, appropriate to and funded by the individual Participants, aimed at supporting the objectives of Annex VIII, with guidance from national reference groups;

5.2 Common Program
  A common program of work, funded by the core ETSAP budget and any other financial support from IEA Member Countries, directly or through the IEA Secretariat, in which the international and global analyses will be integrated to draw conclusions regarding cooperation in technological development strategies toward sustainable development;

5.3 Ongoing Research and Development Program
  A program, funded by the core ETSAP budget, to complete the development of the new generation of ETSAP tools to fully tested and operational versions for general use. These tools include Windows-based analyst’s Shells and the new core energy model TIMES designed to facilitate wider ranges of application areas, provide a platform for ongoing
research and evolution and improve integration with other approaches such as Integrated Assessment Models and Geographical Information Systems.

6. Operating Agent

The Operating Agent is the Politecnico di Torino (Italy), acting through the Dipartimento di Energetica.

7. Specific Obligations and Responsibilities of the Operating Agent

In addition to the obligations and responsibilities enumerated in Article 4 of the Implementing Agreement the Operating Agent shall establish:

(a) Project Staff

For the purpose of carrying out the above objectives the Operating Agent shall establish, within sixty days after the Annex has entered into force, a Project Staff composed of a Project Head and such additional assistance as may be required, including external staff, to fulfill the Task. Activities requiring common work may include quality assurance review, development of the procedure for comparing and integrating the national models, preparing the final conclusions and report of the Task, and other activities that may be decided upon by the Operating Agent or the Executive Committee. The common work may be performed by the Project Head, by other Operating Agent staff, or by organizations or professionals from the participating countries following the plans determined from time to time by the Executive Committee.

The person who will act as Project Head, and the members of the Project Staff, will be appointed by the Operating Agent, acting upon the unanimous approval of the Executive Committee.

(b) Executive Responsibilities

The Operating Agent shall be responsible for overall co-ordination of the Task. The main responsibilities will be:

(1) To manage the common program;

(2) To assure appropriate communication among the Participants;

(3) With the approval of the Executive Committee, to represent ETSAP in various international conferences, bodies, and groups, and

(4) To prepare and distribute material on the work of ETSAP for distribution through a newsletter or the World Wide Web.

(c) Workshops and seminars

At the request of the Executive Committee, the Operating Agent shall organize workshops and seminars.

(d) Validation

At the request of the Executive Committee, the Operating Agent shall co-ordinate the work of a small group of experts charged with reviewing the consistency and accuracy of input data, national models, and the main findings.

(e) Preparation of Draft Programme of Work and Reports

The Operating Agent shall prepare and submit to the Executive Committee, prior to its first meeting, a draft Programme of Work for the three-year period of the Task. The Operating Agent
shall report to the Executive Committee at least once a year on the progress of the activities under this Task. Upon termination of this Annex, the Operating Agent shall prepare and submit to the Executive Committee for approval, a draft final report on the activities carried out during the period of this Annex. Following approval, the Operating Agent shall transmit the report to the Agency and to the members of the IEA Committee on Energy Research and Technology. The Committee on Energy Research and Technology may, during this Task, propose additions to the Programme of Work. The Executive Committee shall decide whether these proposals will be added to the Programme of Work, provided such additional work can be carried out within the resource levels set out in paragraph 9 below.

(f) Secretarial and Administrative Support to Task Sharing Activities
Following guidance and instructions from the Executive Committee, the Operating Agent shall give secretarial and administrative support to establishing activities of Contracting Parties on a task-sharing basis, subject to specific budgets made available for those purposes by the Executive Committee.

8. Specific Obligations, Responsibilities and Rights of the Participants

Participants shall carry out, to the extent possible, the following activities and communicate the results to the Operating Agent:

(a) Collection of national data on emission release and emissions control technologies;
(b) Collection of information on energy system structure and related data;
(c) Establishment and validation of data on technology characterizations and related data;
(d) Performance of national and co-operative, multi-national scenario analyses using energy systems models;
(e) Establishment of national and multi-national reference groups to discuss and advise on data bases, assumptions, methodology, model results and their application to the development of policy, especially under the auspices of the FCCC;
(f) Contribute to the development of ETSAP models and tools, including testing of newly developed versions of software.

Participants have special rights to the results of the joint work, not available to non-participants, as may be decided by the Executive Committee from time to time, subject only to the limitations laid out in paragraph 11 below. This includes privileged access to the support systems and related services contracted on behalf of ETSAP or made available to Participants by the Operating Agent acting on decisions made by the Executive Committee.

9. Funding

(a) Common Financial Obligations

The Common Program will be funded through the Operating Agent. The actual costs of the Operating Agent's activities during this Annex will be divided equally among all Participants. If the number of Participants changes, the Executive Committee will decide whether or not to adjust the budget and fees. New Participants will pay a full share of the costs beginning in the Task year in which they become Participants.

The 2002 budget of the Operating Agent will be EURO 312,000; based on 13 Participants at EURO 24,000 each. The Executive Committee will decide the annual budget for subsequent years.
based on this amount, and taking into account the actual number of Participants, inflation and any agreed changes in the work of the Operating Agent.

(b) Individual Financial Obligations

In addition to the contributions set out in subparagraph (a) above, each Participant shall bear all costs it incurs in carrying out this Task, including the costs of its National Program and participation in workshops and seminars.

10. Time Schedule

This Annex will enter into force on the 1st of January, 2002 and will remain in force for a period of three years and seven months. It may be extended by agreement of two or more Participants acting in the Executive Committee and taking into account any recommendation of the Agency's Committee on Energy Research and Technology concerning the term of this Annex which shall thereafter apply only to those Participants.

11. Information and Intellectual Property

In addition to the provisions of Article 7 of the Implementing Agreement:

(a) Executive Committee Powers

The publication, distribution, handling, protection and ownership of information and intellectual property arising from this Annex shall be determined by the Executive Committee acting by unanimity in conformity with this Agreement, and the laws of the countries of the Participants and of the Operating Agent.

(b) Right to Publish

Subject only to copyright restrictions, the Participants shall have the right to publish all information provided to or arising from this Annex except proprietary information, but they shall not publish it with a view to profit, except as agreed by the Executive Committee, acting by unanimity.

(c) Proprietary Information

The Operating Agent and the Participants shall take all necessary measures in accordance with this Annex, the laws of their respective countries, and international law to protect proprietary information. For the purposes of this Annex proprietary information shall mean information of a confidential nature such as trade secrets and know-how (for example, computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) that is appropriately marked, provided such information:

(1) Is not generally known or publicly available from other sources;

(2) Has not previously been made available by the owners to others without obligation concerning its confidentiality; and

(3) Is not already in the possession of the recipient Participant without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information to identify the information as such and to ensure that it is appropriately marked.

(d) Production of Relevant Information by Governments

The Operating Agent should encourage the governments of all Agency Participating Countries to make available or to identify to the Operating Agent all published or otherwise freely available information known to them that is relevant to the Task. The Participants should notify the
Operating Agent of all pre-existing information, and information developed independently of the Task known to them which is relevant to the Task and which can be made available to the Task without contractual or legal limitations.

(e) Production of Available Information by Participants

Each Participant agrees to provide to the Operating Agent all previously existing information and information developed independently of the Annex which is needed by the Operating Agent to carry out its function in this Task and which is freely at the disposal of the Participant and the transmission of which is not subject to any contractual and/or legal limitations:

(1) If no substantial cost is incurred by the Participant in making such information available, at no charge to the Task;

(2) If substantial costs must be incurred by the Participant to make such information available, at such charge to the Task as shall be agreed between the Operating Agent and the Participant with the approval of the Executive Committee.

(f) Use of Proprietary Information

If a Participant has access to proprietary information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent in accordance with an agreement between the Operating Agent and the specific Participant setting forth the terms and conditions for such acceptance, but the proprietary information shall not become part of reports, handbooks, or other documentation, nor be communicated to the other Participants except as may be agreed in writing between the Operating Agent and the Participant which supplied such information.

(g) Acquisition of Information for the Task

Each Participant shall inform the Operating Agent of the existence of information known to the Participant that can be of value to the Task, but which is not freely available, and the Participant shall endeavor to make the information available to the Task under reasonable conditions, in which event the Executive Committee may, acting unanimously, decide to acquire such information.

(h) Reports on Work Performed under the Task

The Operating Agent shall provide reports on all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information, to the Participants.

(i) Copyright

The Operating Agent may take appropriate measures necessary to protect copyrightable material generated under this Task. Copyrights obtained shall be the property of the Operating Agent in trust for and for the benefit of the Participants, provided, however, that Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee.

(j) Authors

Each Participant shall, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation with its authors required to carry out the provisions of this paragraph. Each Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the laws of its country.

12. Products

The products of this Task shall be:
Maintenance and improvement of an international capability for the analysis of energy technologies and their future prospects and extension of such a capability within the context of energy and the environment, and in particular climatic change post Kyoto;

Periodic reports on workshops or seminars and on analytical studies undertaken in connection with the Task; and

A final report on the activities carried out under this Annex.

13. PARTICIPANTS

The Contracting Parties that are Participants in the Task are the following:
(list of parties to be added following their notification to the Executive Director of the IEA and to be selected from the following list)

<table>
<thead>
<tr>
<th>Contracting Parties</th>
<th>Date of Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energieverwertungsagentur (Austria)</td>
<td>19.12.80.</td>
</tr>
<tr>
<td>The Department of National Development and Energy (Australia)  succeeded by the Australian Bureau of Agriculture and Resource Economics (ABARE)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>The Government of Belgium</td>
<td>08.09.81.</td>
</tr>
<tr>
<td>The Department of Energy, Mines and Resources (Canada)</td>
<td>07.07.82.</td>
</tr>
<tr>
<td>succeeded by the Department of Natural Resources</td>
<td></td>
</tr>
<tr>
<td>The Ministry of Energy (Denmark), replaced by the Ministry of Environment and Energy, Danish Energy Agency</td>
<td>04.12.80.</td>
</tr>
<tr>
<td>The Commission of the European Communities</td>
<td>01.01.82.</td>
</tr>
<tr>
<td>The Government of Finland</td>
<td>09.01.02</td>
</tr>
<tr>
<td>Kernforschungsanlage Jülich GmbH (Germany) name changed to Forschungszentrum Jülich GmbH replaced by the Institute for Energy Economics and Rational Use of Energy (IER) of the University of Stuttgart</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>The Scientific Research and Technology Service of the Ministry of Coordination (Greece)</td>
<td>01.12.80.</td>
</tr>
<tr>
<td>The National Board for Science and Technology (Ireland)</td>
<td>17.07.81.</td>
</tr>
<tr>
<td>The Ente Nazionale Idrocarburi (Italy) 13.11.80. replaced by the National Agency for New Technologies Energy and Environment (ENEA)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>The Government of Japan</td>
<td>17.09.81.</td>
</tr>
<tr>
<td>The Korea Institute of Energy Research (KIER)*</td>
<td>15.05.96.</td>
</tr>
<tr>
<td>The Stichting Energieonderzoek Centrum Nederland (ECN, Netherlands)</td>
<td>02.04.82.</td>
</tr>
<tr>
<td>The Royal Ministry of Petroleum and Energy (Norway) 13.11.80. name changed to the Royal Norwegian Ministry of Industry and Energy</td>
<td>02.04.82.</td>
</tr>
<tr>
<td>The Centro de Estudios de la Energia (Spain)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>The Energy Research and Development Commission (Sweden)</td>
<td>18.11.80.</td>
</tr>
<tr>
<td>(subsequently succeeded by the Energy Research Commission and later by the Swedish National Board for Industrial and Technical Development (NUTEK))</td>
<td>18.11.80.</td>
</tr>
<tr>
<td>The Office Fédéral de l'Energie (Switzerland) replaced by the Paul Scherrer Institute</td>
<td>01.04.81.</td>
</tr>
<tr>
<td>The Kocaeli University (Turkey)</td>
<td>22.03.96.</td>
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<tr>
<td>The Secretary of State for Energy (United Kingdom)</td>
<td>09.06.81.</td>
</tr>
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</table>
(succeeded by the Secretary of State for Trade and Industry)
The United States Department of Energy 13.11.80.
(replaced by The Government of the United States of America; then again by the United States Department of Energy)
1. **Description of the Technical Sector**

**Background**

Which are the economic consequences of the new research and achievements in the field of energy supply, end uses and materials onto the energy systems and their emissions? How far is the present technological level from the desired long-term environment and economic goals? Is the present level of effort in the research for new energy technologies in the supply sector, in the end use markets and in the material uses going to fill the gap? What amount of resources is needed to reach a mitigation of the climate changes to the level suggested by the projections over the next century? What technology options look most promising? What policies and measures are most effective?

Decision makers of energy sectors, global environment, related RD&D, some end-use sectors such as transport and electric appliances require quantitative analyses and scenarios as base material to support their decisions. The traditional macroeconomic and aggregated general equilibrium modelling analyses provide same economic policy indications but cannot indicate the technological and organizational options through which the policies have to be implemented. These indications are provided by analyses carried out with the help of technology characterisation data bases, together with national and regional energy balances and scenario analyses based upon technical economic models of the energy technology systems, integrating supply of energy vectors with the demand of energy services by the end-users. To assist decision makers, an assessment of costs and benefits is essential.

The experts working together under this Agreement aim to provide analyses of and solutions to such problems.

**History and Achievements**
Since 1976 ETSAP has been building a bridge among the specialists of energy sectors, energy technologies, environment and economy in order to carry out joint system modelling analyses. With a relatively low budget – less than 200 k€ in the last few years – this Agreement achieved impressive results. As an international group of systems analysts, ETSAP has been among the first to analyse the energy related environmental issues. It contributed to the acid deposition debate in the 1980s, to climate change ETSAP partners evaluated mitigation costs before the Rio conference, provided environmental policy analysis instrumental to preparation of the Kyoto Protocol, are analysing different international mitigation schemes, have contributed to the Third Assessment Report of the IPCC (Working Group III) and to the Special Report on Emission Scenarios, and in several countries contribute to the preparation of domestic mitigation programmes reported in the Second and Third National Communications to UNFCCC.

Scope and Programmes

The scope of this Agreement is central to the activities of the secretariat, carried out by the Energy Efficiency, Technology and R&D office as well as the Long Term Co-operation and Policy Analysis office. The modelling tools and expertises of ETSAP are presently being used for the Energy Technology Perspective Project of the Energy Technology Policy Division, as well as by the US Energy Information Administration in the “System for the Analysis of Global Energy markets” (SAGE Project) for the preparation of the International Energy Outlook.

The technical sector of this Agreement is different from and non homogeneous to most other Agreements. It has developed and continuously improves large economic programming model generators of the energy technologies systems, it implements the modelling software, it uses both to model global, regional, national and local energy systems, it runs the models to build long term energy environment scenarios, it compares different technologies and clusters, and it evaluates cost and benefits of policies and measures.

Among the programmes of this Agreement are multi-regional bottom up models of the global energy environment system with a strong technological connotation; advanced local energy – environmental planning integrated with Graphical Information Systems (GIS) and life cycle analyses (LCA), along the lines of Annex 33 of the IEA Implementing Agreement on Energy Conservation in Buildings and Community Systems, integration of such global technical-economic models with climate change scientific models; the preparation of an international Data Base characterising from the technical-economic point of view existing and new energy environment supply and end use technologies; diffusion of the methodology to non member countries.

Objectives

The main objective of this Task is to support the objectives of this Agreement, diffusing its methodologies to:
(a) New national groups operating in the countries of the Contracting Parties;
(b) Organizations active in other IEA Member countries;
(c) Organizations active in non Member countries;
(d) Governmental and non-governmental international groups and organizations;
(e) Universities and educational bodies.
Means

The Participants shall share the co-ordinated work necessary to carry out this Task. The Objectives shall be achieved by:

(a) Facilitating the widespread dissemination and adoption of ETSAP methodologies and analysis in different regions, countries, local areas; an example of such activities is the organization of training courses to form new experts or to widen the analytic capabilities of existing experts domestically, locally and in outreach activities;

(b) Carrying out coordinated analyses of energy technologies systems, energy efficiencies studies on technology options, impact of Policies and Measures, effects of deregulation in energy sub-sectors, RD&D ranking by means of cost/benefit analyses, guidelines for modelling, documentation, etc.;

(c) Collecting, analyzing and disseminating information and data related to energy systems, energy technologies, energy and environment models and scenarios;

(d) Improving the modelling tools, by means of integration with other existing tools, developing new research ideas, testing new solutions, fine tuning experimental models and software (e.g. to foresee links to spatial variables and local GIS, to compare partial/local optima to global optima, to test stepwise or hierarchical approaches and sensitivity);

(e) Organizing annual meetings of experts, as appropriate, to exchange information and experience in the area of work covered by the Agreement; and

(f) Exchanging specialists, experts and students active in the sector.

Results

The results of work performed under this Annex will be designed for use by all Participants, and will include:

(a) Proceedings of annual meetings to exchange information on the status of the analyses of active teams in the Participants’ countries and international groups;

(b) Reports and summary assessments on progress in analyses, in methodological research and development, and in the general priorities in the field; and

(c) A description of programmes to promote process oriented systems analyses applied to energy environment and related sectors.

Time Schedule

This Annex shall enter into force on September 1, 2002 and shall remain in force till July 31, 2005. Within the limits of the term of the Agreement, this Annex may be extended by two or more Participants, acting in the Executive Committee, and shall thereafter apply only to those Participants.

Specific Obligations and Responsibilities of the Participants

In addition to the obligations enumerated in Article 7 of this Agreement:

(a) Each Participant shall provide the Operating Agent with reports on the results of the work carried out;
Each Participant shall collect, assess and report to the Operating Agent data and information on the use of models according to the Objectives and Means as described in paragraph 2 and 3 above;

each Participant shall exchange the material related to, and reviews on the work for, quality improvement;
each Participant shall participate in the editing and review of draft reports on the Task; and
each Participant shall support the Operating Agent in efforts to disseminate the methodologies and their use in assessing local or regional systems, offering lessons and courses, carrying out outreach activities.

Specific Obligations and Responsibilities of the Operating Agent

In addition to the obligations enumerated in Articles 4 and 7 of this Agreement, the Operating Agent shall:

(a) Prepare and distribute the results described in paragraph 4 above;
(b) At the request of the Executive Committee, organize workshops, seminars, conferences and other meetings;
(c) In co-ordination with the Participants, use its best effort to avoid duplication with activities of other related programmes and projects implemented by or under the auspices of the Agency or of other competent bodies;
(d) Provide the Participants with the necessary guidance for the work they carry out, assuring minimum duplication of effort;
(e) Perform such additional services and actions as may be decided by the Executive Committee, acting by unanimity.

Funding

The Programme of Work is carried out on a task sharing basis. A wide use of the web will increase the opportunities of exchanges at low cost.

(a) Annual Meetings. The annual meetings pursuant in paragraph 3 above shall be hosted in turn by the Participants. The cost of organizing and hosting the meetings shall be borne by the host Participant.

(b) Publications. The cost of publishing the reports and summary assessments described in paragraph 4 above shall be met by the Operating Agent.

(c) Individual Financial Obligations. Each Participant shall bear all the costs it incurs in carrying out its activities, including the purchase of the proprietary software necessary to run the models, reporting and travel expenses.

(d) Task-Sharing Requirements. The level of work to perform the programme specified in this Annex is estimated at 3 person-months per year for the Operating Agent, 2 additional person-months for each Participant in the first year that the Annex is in force, and an additional person-month per year for each Participant during the remainder of the term of the Annex. Part of the above activities will be funded by Annex VIII budget, with unanimous decision of the Executive Committee.
Operating Agent

The Politecnico di Torino (Italy), acting through the Dipartimento di Energetica, is designated as Operating Agent

Information and Intellectual Property

(b) Executive Committee Powers
The publication, distribution, handling, protection and ownership of information and intellectual property arising from this Annex shall be determined by the Executive Committee, acting by unanimity, in conformity with this Agreement.

(c) Right to Publish
Subject only to copyright restrictions, the Participants shall have the right to publish all information provided to or arising from this Annex except proprietary information, but they shall not publish it with a view to profit, except as agreed by the Executive Committee, acting by unanimity.

(d) Proprietary Information
The Operating Agent and the Participants shall take all necessary measures in accordance with this Annex, the laws of their respective countries, and international law to protect proprietary information. For the purposes of this Annex proprietary information shall mean information of a confidential nature such as trade secrets and know-how (for example, computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) that is appropriately marked, provided such information:
  ➢ Is not generally known or publicly available from other sources;
  ➢ Has not previously been made available by the owners to others without obligation concerning its confidentiality; and
  ➢ Is not already in the possession of the recipient Participant without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information to identify the information as such and to ensure that it is appropriately marked.

(e) Production of Relevant Information by Governments
The Operating Agent should encourage the governments of all Agency Participating Countries to make available or to identify to the Operating Agent all published or otherwise freely available information known to them that is relevant to the Task. The Participants should notify the Operating Agent of all pre-existing information, and information developed independently of the Task known to them which is relevant to the Task and which can be made available to the Task without contractual or legal limitations.

(f) Production of Available Information by Participants
Each Participant agrees to provide to the Operating Agent all previously existing information and information developed independently of the Annex which is needed by the Operating Agent to carry out its function in this Task and which is freely at the disposal of the Participant and the transmission of which is not subject to any contractual and/or legal limitations:
  ➢ If no substantial cost is incurred by the Participant in making such information available, at no charge to the Task;
If substantial costs must be incurred by the Participant to make such information available, at such charge to the Task as shall be agreed between the Operating Agent and the Participant with the approval of the Executive Committee.

(g) Use of Proprietary Information
If a Participant has access to proprietary information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent in accordance with an agreement between the Operating Agent and the specific Participant setting forth the terms and conditions for such acceptance, but the proprietary information shall not become part of reports, handbooks, or other documentation, nor be communicated to the other Participants except as may be agreed in writing between the Operating Agent and the Participant which supplied such information.

(h) Acquisition of Information for the Task
Each Participant shall inform the Operating Agent of the existence of information known to the Participant that can be of value to the Task, but which is not freely available, and the Participant shall endeavor to make the information available to the Task under reasonable conditions, in which event the Executive Committee may, acting unanimously, decide to acquire such information.

(i) Reports on Work Performed under the Task
The Operating Agent shall provide reports to the Participants and to the Executive Committee on all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information.

(j) Copyright
The Operating Agent may take appropriate measures necessary to protect copyrightable material generated under this Task. Copyrights obtained shall be the property of the Operating Agent in trust for and for the benefit of the Participants, provided, however, that Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee.

(k) Authors
Each Participant shall, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation with its authors required to carry out the provisions of this paragraph. Each Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the laws of its country.

Participants in this Task

The Contracting Parties which are Participants in this Task are the following:
(list of parties to be added following their notification to the Executive Director of the IEA and to be selected from the following list + new accessions)

<table>
<thead>
<tr>
<th>Contracting Parties</th>
<th>Date of Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energieverwertungsagentur (Austria)</td>
<td>19.12.80.</td>
</tr>
<tr>
<td>The Department of National Development and Energy (Australia)</td>
<td>13.11.80.</td>
</tr>
<tr>
<td>succeeded by the Australian Bureau of Agriculture</td>
<td></td>
</tr>
<tr>
<td>and Resource Economics (ABARE)</td>
<td></td>
</tr>
<tr>
<td>The Government of Belgium</td>
<td>08.09.81.</td>
</tr>
</tbody>
</table>
The Department of Energy, Mines and Resources (Canada) succeeded by the Department of Natural Resources
The Ministry of Energy (Denmark), replaced by the Ministry of Environment and Energy, Danish Energy Agency
The Commission of the European Communities
The Government of Finland
Kernforschungsanlage Jülich GmbH (Germany) name changed to Forschungszentrum Jülich GmbH replaced by the Institute for Energy Economics and Rational Use of Energy (IER) of the University of Stuttgart
The Scientific Research and Technology Service of the Ministry of Coordination (Greece)
The National Board for Science and Technology (Ireland) replaced by the National Agency for New Technologies Energy and Environment (ENEA)
The Government of Japan
The Korea Institute of Energy Research (KIER)*
The Stichting Energieonderzoek Centrum Nederland (ECN, Netherlands) 2004.02.
The Royal Ministry of Petroleum and Energy (Norway) 13.11.80. (name changed to the Royal Norwegian Ministry of Industry and Energy)
The Centro de Estudios de la Energia (Spain)
The Energy Research and Development Commission (Sweden) 18.11.80. (subsequently succeeded by the Energy Research Commission and later by the Swedish National Board for Industrial and Technical Development (NUTEK))
The Office Fédéral de l'Energie (Switzerland) replaced by the Paul Scherrer Institute
The Kocaeli University (Turkey) 22.03.96.
The Secretary of State for Energy (United Kingdom) (succeeded by the Secretary of State for Trade and Industry)
The United States Department of Energy replaced by The Government of the United States of America; then again by the United States Department of Energy

July 29, 2005

171
APPENDIX D: Contracting Parties/Members of the Executive Committee, Annex VIII

Chairs: P. Tseng, H. Labib
Vice-Chairs: M. Ishigami, T. Yano, P. Taylor

Belgium: Federal Public Planning Service Science Policy / A. Fierens
Canada: Natural Resources Canada/ H. Labib
European Union: European Commission/ D. Rossetti di Valdalbero
Finland: TEKES / R. Pikku-Pyhältö
Germany: University of Stuttgart - IER / A. Voss
Greece: Centre for Renewable Energy Sources / G. Giannakidis
Italy: Consiglio Nazionale delle Ricerche
Istituto per le Metodologie Ambientali Avanzate / Vincenzo Cuomo
Japan: Ministry of Education, Culture, Sports, Science and Technology, Planning and Evaluation Division, Science and Technology Policy Bureau / Masao Tanaka
Korea: Korea Energy Management Corporation, Center for Climate Change Mitigation Projects / J-W Noh
The Netherlands: Energy Research Center of the Netherlands / K. Smekens
Sweden: Swedish Energy Agency / E. Centeno Lopéz
Switzerland: Paul Scherrer Institute / S. Kypreos
Turkey: Marmara University / T.S. Uyar
United Kingdom: AEA Technology / P. Taylor
U.S.A. Department of Energy / P. Tseng, B. Unruh

Project Head
GC. Tosato

Operating Agent
Politecnico di Torino, Italy
APPENDIX E: Annex VIII SCHEDULE OF WORKSHOPS

May 2002
Canberra, Australia
Host: Australian Bureau of Agricultural and Resource Economics

October 2002
Torino, Italy
Host: Politecnico di Torino

June 2003
Laxenburg, Austria
Host: International Institute for Applied Systems Analysis (IIASA), held in conjunction with the International Energy Workshop (IEW)

October 2003
Beijing, China

June 2004
Paris, France
Host: International Energy Agency (IEA), held in conjunction with the International Energy Workshop (IEW)

November 2004
Florence, Italy
Host: Politecnico di Torino, held in conjunction with New Energy Externalities Developments for Sustainability (NEEDS), European Commission project
APPENDIX F: The MARKAL-TIMES Family of Model Generators

TIMES: The Integrated MARKAL-EFOM System, which is the evolutionary replacement of MARKAL. It offers the analyst greater flexibility and additional features including:

- fully flexible time periods/years, variable length and data/model year independence;
- fully flexible time slices, annual/seasional/weekly/day-night levels all (but annual) user defined;
- more accurate cost representation, annual with construction and incremental investments;
- all “processes” represented uniformly, plus vintaging and aging;
- representation of intra-process commodity flows;
- more flexible user constraints, including inter-temporal;
- time dependent discount/hurdle rates;
- flexible units: energy, material, economic values;
- a climate module, and
- GAMS code that is simpler to understand, maintain and upgrade.

MARKAL is a family of models that represent energy systems by the set of technologies used to extract, transport or transmit, convert, and use energy to meet projected future energy service demands. The basic MARKAL is a bottom-up linear programming model, but its variants include coupling with top-down economic models and nonlinear solution algorithms. The solution to a MARKAL model represents the optimum set of technologies that, with perfect foresight, meet the projected energy demands within the constraints that are specified, for example, the maximum level of carbon dioxide emissions permitted.

The various versions of MARKAL have generally been developed by individual participants in ETSAP to meet their specific needs. However, with the exceptions noted below by an asterisk, they are now incorporated in a common model. The user activates these features by providing the appropriate data and/or switches. Most of the MARKAL versions can be coupled to combine desired features.

MARKAL-ED: MARKAL with elastic demands. In this “partial equilibrium” approach, the projected energy demands, rather than being fixed for future years, are modified as part of the solution of the program in response to the changing cost of energy. The energy demands are represented with a stepwise linear approximation, where the user provides own-price elasticities for each “flexible” demand sector. There is also an extension to MARKAL-ED that permits income elasticities (MEDI) also to be provided by sector.

MARKAL-ETL: A nonlinear version of MARKAL in which the unit costs of technologies may decline with increasing total capacity as a result of endogenous technological learning, that is, down the learning curve.

MARKAL-EV: A version that includes environmental damage calculations, or nonlinear optimization of an objective function that includes the damage calculation.

MARKAL–MACRO: A nonlinear, dynamic optimization model that links MARKAL with MACRO, a top-down macroeconomic growth model. Multiple MARKAL-MACRO models may be linked to represent trade among countries in energy and emission permits.
**MARKAL-MACRO-MERGE***: An integration of MARKAL-MACRO with MERGE, a global trade model.

**MARKAL-MGA/GP***: A variant of MARKAL support Modeling to Generate Alternatives (MGA) and Goal Programming. The former can be used to generate a series of maximally different solutions within a constrained (by limited change in total and sector costs) solution space. The latter permitting weights to be assigned to multiple objectives (e.g., least-cost and emission goals) and a set of Pareto-efficient solutions found to enable decision-makers to examine a range of solutions taking into consideration different perspectives.

**MARKAL-MICRO**: Like MARKAL-ED, a partial equilibrium approach. In this case, projected energy demands are represented as nonlinear functions, and the solution is obtained using nonlinear programming techniques.

**MARKAL-Stochastics**: A version that allows for uncertainty in such input values as the permitted future level of carbon dioxide emissions, prices of energy and technologies, and levels of demand. Probabilities are assigned to alternative future scenarios. The model calculates the hedging strategy: the singular optimal mix of technologies for the near term until the uncertainty is resolved at an assumed future date.

**SAGE**: System for Analysis of Global Energy markets, a version of MARKAL that permits stepped (or “myopic”) solutions in successive time periods to the model horizon, and employed a market share algorithm and inter-temporal technology learning.

* - experimental versions not part of the ETSAP Standard MARKAL/TIMES model generators
APPENDIX G: Selected Non-ETSAP User’s of the ETSAP Tools

**G.1 - AusAID/ASEAN EPSAP**

<table>
<thead>
<tr>
<th>“Country”</th>
<th>Participating Institution</th>
<th>Study Description/Status</th>
</tr>
</thead>
</table>
| ASEAN     | ASEAN Centre for Energy   | • The Trans-ASEAN Energy Network - Analysis of gas pipelines and electricity interconnections  
|           |                          | • ASEAN Energy Market Integration |
| Cambodia  | Ministry of Industry, Mines and Energy | • National Energy Policy - Analysis of Options |
| Indonesia | Badan Pengkajian Dan Penerapan Teknoiogi | • Gas Utilization: National Gas Pipelines, Alternative Fuel Mix for Power Plant and Demand Sectors  
|           |                          | • The Future Demand for Natural Gas in Indonesian Regions with Particular Reference to the Use of CNG in Transport  
|           |                          | • Future Technologies for Power Plants in Indonesian Regions with Particular Reference to the Use of Renewable Energy and Small Scale Coal Steam Plant |
| Laos      | Ministry of Industry and Handicrafts, Electricity | • Energy Security and Diversity. |
| Myanmar   | Ministry of Energy        | • Energy Self-Sufficiency - Options and Strategies |
| Malaysia  | PTM Malaysia Energy Centre | • Fuel Diversification - Economic and Environmental Impact of Alternative Fuel Mix  
|           |                          | • Cost and Environmental Impact of Renewable Energy Technologies  
|           |                          | • GHG Mitigation Options with Emphasis on Energy Efficiency and Renewable Energy Strategies |
| Philippines | Department of Energy      | • Impact of Natural Gas Expansion  
|           |                          | • Promoting Renewable Energy in a Restructured Electricity Market  
|           |                          | • Increasing Renewable Energy Utilization by Full Cost Accounting of Electricity Supply |
| Thailand  | National Energy Policy Office | • Removing the Subsidy on LPG and Implementing a Policy to Increase the Use of CNG in Transport  
|           |                          | • Fuel Options for Power Generation  
|           |                          | • Renewable Energy |
| Vietnam   | Ministry of Industry | • The Strategy Orientation for Electricity Supply  
|           |                          | • Analysis of Power Development Strategies in Compliance with Environmental and Energy Security Issues  
|           |                          | • Energy Pricing and its Implication for Energy Efficiency and Environment |

**G.1.1. Myanmar**

PROJECT BACKGROUND
Australian Managing Contractor - SMEC invited Myanmar to participate in EPSAP Project under the AADCP-RPS in September 2003.

Myanmar joined the Project in September 2003.


PROJECT ACTIVITIES
- The National Coordinating Committee and National Project Team were established in October 2003 comprising the members from the major energy sector in Myanmar (Oil & Gas Sector, Electric Power Sector, and Coal sector).
- The Project was commenced in late 2003 when Australian Coordinating Partner (ACP) conducted MARKAL training program for all CLM National Project Team members in Phnom Penh, Cambodia and main activities of program are listed below chronologically:
  - MARKAL Database design, data collection, database development and enhancement (January to April 2004).
  - Discussion and finalizing of the topic for national energy policy and report planning (June to July 2004).
  - Further training over the period of Myanmar team member work attachment to the ASEAN Centre for Energy (ACE) during July 2004.
  - Formulate scenarios and cases for the policy analysis over the period from November through December 2004.
  - Completion of model runs and draft report by January followed by report editing by ACE, ACP and reviewing by ABARE.

NATIONAL POLICY STUDY TOPIC
"Self Sufficiency in Liquid Fuels-Options and Strategies"
The topic is of considerable interest to Myanmar which is endowed with substantial primary energy resource in the petroleum and gas sector, however is forced to import petroleum products.

G.1.2. The Philippines

Increasing Renewable Energy Utilization by Full Cost Accounting of Electricity Supply is the third of the energy policy studies conducted by the Philippines under ASEAN-Australia Energy Cooperation Project’s (AAECP) Energy Policy and Systems Analysis Project.

This policy study looks into the potential role of renewable energy (RE) under given circumstances such as: (a) provision of fiscal and non-fiscal incentives; (b) application of emission fees; and (c) setting of a Renewable Portfolio Standard (RPS) using the MARKAL Model.

The study explored seven scenarios for comparative analysis. These are the base case, reference case, renewable portfolio standard case, self-sufficiency case, CO2 reduction case, tax emission case and the cost benefit case.

A review of existing policies on financial incentives, emission tax and the RPS requirement was undertaken with the end view of measuring the impact of emission taxes and financial incentives vis-à-vis the RPS. This was undertaken to also determine other initiatives that may be necessary under a given RPS.
Several variations of RPS levels were examined in the study including that of a case where fossil fuel prices are high and another, where a carbon tax is imposed simultaneously with the minimum RPS.

Based on the MARKAL simulations, coal and CCGT are the cheapest option for power generation. While this finding is subject to the availability of the fuel and stability of its prices and may also infringe on the environmental criteria, mine-mouth coal can really be competitive cost-wise in times of high oil price and can contribute substantially to the goal of energy self-sufficiency.

On the same breadth, geothermal and mini-hydro remains fairly competitive having the lowest average generation cost among RE sources. Notwithstanding their significant contribution to self-sufficiency, geothermal and mini-hydro are strong candidates in the power market owing to their being ‘clean energy sources’. On a general accounting, the Reference case which is the ‘business-as-usual case’ provides the most economic outcome in the study.

All of the identified policies and mechanisms examined in the study are projected to incur additional costs, as follows:

- The policy to achieve 60 percent energy self-sufficiency will need an extra $3.5 billion over the Reference case
- With the implementation of an RPS, a minimum 40 percent RE share will have an incremental cost of $0.54 billion while a 50 percent share will need an additional $0.95 billion over the Reference case
- Obligating fossil generators to pay emission taxes will also incur an additional cost of $0.25 billion

As regards environmental aspect, all cases showed corresponding incremental costs with the reduction of CO2 emission. Of all the CO2 reduction cases examined, the 10 percent reduction emerged most practical as the ratio of marginal costs to the level of reduction is much lower than the other cases.

An assessment of the viability of RE technologies showed that geothermal and hydro are already economic while wind, solar and biomass are near-economic. The competitiveness of the latter three technologies is apparent in their annual benefit-cost ratios which can be enhanced through the provision of fiscal and non-fiscal incentives. Aside from the incentives already stated in the EPIRA, the passage of the RE Bill is expected to facilitate the development of RE electricity market. The proposed incentives in the Bill could reduce investment cost by around 20 percent while a significant cut in operating and maintenance costs will accrue from income tax holidays, exclusion from payment of ancillary services and interconnection and wheeling charges, and exemption from universal charge. While the specific amount cannot be readily deduced as the cost of technologies and electricity production varies, these incentives will generally spur investments in RE.

Another mechanism represented by the RPS cases, i.e. 40% and 50% RPS levels, were examined in this study. Results of the simulations showed that while both will increase RE utilization, a higher target will entail a substantial amount of investment in the estimated value of green certificates which may range from $5/MWh to $32/MWh in RPS50 and $5/MWh to $19/MWh in RPS40. In addition to this, consumers will have to bear more expensive electricity should generators be obliged with higher RE output.
One of the limitations of the study, however, relates to the assumptions which had to be improved from the second policy study. As assumptions were changed, some of the results also changed particularly affecting the economic viability of RE technologies. For future related studies, attention should be drawn to the improvement of assumptions to fully reflect the real situation in the country’s energy sector.

G.2 - China

The costs of mitigating carbon emissions in China: Findings from China MARKAL-MACRO modeling
[Wenying Chen, Global Climate Change Institute, Tsinghua University, Beijing, China]

In 2000, China emitted around 800 million tons of carbon from fuel combustion, accounting for about 13% of the world total and being the second largest CO$_2$ emitter in the world. China is facing mounting pressure such as “voluntary commitment of GHG reduction” from the developed countries in international negotiation on global climate change issue although China has done and will continue to do considerable efforts to cut carbon emission. Is China really a nation with quite low carbon abatement costs as widely regarded by the developed countries? Can China afford to commit itself a carbon emission cap? This paper attempts to analyze China’s marginal abatement cost of carbon and potential impacts of carbon mitigation on GDP with application of China MARKAL-MACRO model, an integrated energy, environment and economy non-linear dynamic programming model.

In this study, MARKAL-MACRO, an integrated energy-environment-economy model, is used to generate China’s reference scenario for future energy development and carbon emission through the year 2050. The results show that with great efforts on structure adjustment, energy efficiency improvement and energy substitution, China’s primary energy consumption is expected to be 4818Mtce and carbon emission 2394MtC by 2050 with annual decrease rate of 3% for the carbon intensity per GDP during the period 2000-2050. On the basis of this reference scenario, China’s marginal abatement cost curves of carbon for the year 2010, 2020 and 2030 are derived from the model, and the impacts of carbon emission abatement on GDP are also simulated. The results are compared with those from other sources. The research shows that the marginal abatement costs vary from 12US$/tC to 216US$/tC and the rates of GDP losses relative to reference range from 0.1% to 2.54% for the reduction rates between 5% and 45%. Both the marginal abatement costs and the rates of GDP losses further enlarge on condition that the maximum capacity of nuclear power is constrained to 240GW or 160GW by 2050. The paper concludes that China’s costs of carbon abatement is rather high in case of carbon emissions are further cut beyond the reference scenario, and China’s carbon abatement room is limited due to her coal-dominant energy resource characteristic. As economic development still remains the priority and per capita income as well as per capita carbon emission are far below the world average, it will be more realistic for China to make continuous contributions to combating global climate change by implementing sustainable development strategy domestically and playing an active role in the international carbon mitigation cooperation mechanisms rather than accepting a carbon emission ceiling.
G.3 - Colombia

G.3.1. Carbon Sequestration Marginal Cost Curb for Colombia
[Angela Duque, Angela Cadena - University of Los Andes]

A methodological approach to estimate the marginal cost curve (supply curve of Certified Reduction Units (CER)) originated in the Land Use, Land Use Change and Forestry (LULUFC) for Colombia is proposed. We developed a model to identify and evaluate carbon sequestration projects under a linear programming platform. The model follows the principles and formulation of the MARKAL models (cost minimization objective function and available area, agriculture and forest products demands and sequestration constraints). In this way, it is possible to compare Colombian sequestration cost with those obtained by one of the authors of this work when estimating CO₂ reduction cost originated in energy projects by using the MARKAL family of models. We applied the methodology to evaluate several kinds of forestry projects in five regions of the country.

In the future we aim to formulate a LULUFC model version using the MARKAL family of models. For the time being we are getting the absorption index or curves for different species harvested in Colombia. At the end, we would be able to compare competitiveness of LULUFC projects versus reduction projects not only within the country but with other countries that use the same modelling approach, like those countries participating in ETSAP.

G.3.2. Modelling the Natural Gas System by using the MARKAL model
[Juan Bernardo Moreno, Angela Cadena – University of Los Andes]

In this project we model the Colombian Natural Gas System in order to identify expansion requirements and options as well as to calculate efficient cost and tariffs for natural gas transportation. The natural gas industry, like the electricity industry sector, followed a reform process. It has unbundled production, transportation and distribution. It is aimed that production prices results from the introduction of competition. Transportation and distribution prices are defined by regulatory authorities. In this context, transportation and distribution companies must ask for efficient tariffs according with demands forecasts and investment and operation and maintenance cost required to supplying the foreseen consumption.

We represent the different sections of the pipeline and assign local energy demand by redefining national energy demands according to those pipeline sections. Competition among energy carries to supply energy services takes place in a regional or local way. Natural gas (shadow) prices in each node allow us to estimate efficient tariffs for transportation and operation and maintenance cost of the national pipeline. These calculations are a good reference (price-floors) for ECOGAS, the national natural gas transportation company, to ask the regulator for prices definition.

In the future we shall represent the electric transmission grid to evaluate competitiveness of natural gas vs. electricity expansion.

G.3.3. Integrated Environment - Energy – Economy (EEE) Evaluation for the Sustainable Local Planning of the Aburrá Valley Metropolitan
[Ricardo Smith Quintero, Angela Cadena, Claudia Rave - Group of Energy Studies, National University of Colombia]
An application was made with the MARKAL model for the Metropolitan Area of the Aburrá Valley, where the city of Medellin is located. This application aims to identify a sustainable development patterns of the Metropolitan Area according to environmental and energy policies. The project that is already in its final phase, required an extensive search, collection, processing and analysis of information for the assembly of the data base for the model, being the first time that a model of this type is applied locally in the Metropolitan Area. Thus one of the most important results of the project is the consolidation of an EEE data base for the Metropolitan Area.

The main objectives of the project are the revision of the mobility macro projects and massive natural gas penetration in the residential, commercial and industrial sectors.

- The mobility project for the region pretends to implement an integrated network of buses between the existing Metro lines and the non served zones, to complete the massive transportation system. The fuel consumption and the required technologies to implement the system, supported in the results of emissions and costs, have been analyzed for this macro project.
- The substitution of fuel oil and electricity by natural gas in the industrial and ‘residential – commercial’ sectors respectively, has been evaluated under restrictions of fuel availability, emission of pollutants (CO, CO2, MP, NOx, SO2) and costs.

In this final phase some preliminary results have been analyzed and according to them, other development directions have been established following the model. A strong refinement of the transportation sector is proposed, to evaluate in greater detail the technological options for the mobility project and the environmental effects of the general transportation system of the Metropolitan Area. Also a refinement project of the technological information at the industrial level is envisioned for the decision making on the improvement of efficiencies and processes and its environmental and economic impacts.

The project is developed by the Group of Energy Studies, National University of Colombia – Medellin, and co-financed by the following organizations: AMVA - Environmental Regulating and Planning Organization- and EEPPM – Electricity and Natural Gas Regional Utility. The participation of both organizations is a key factor in the implantation of the EEE scheme for the analysis of policies in the region and the interest of both is to rely upon the model for the decision making processes through joint work with the University.

**G.4 - Croatia**

During 2004 at the Energy Institute Hrvoje Požar MARKAL is being used for a Ph.D. (Helena Bozic) thesis study: “Compilation, valuation and building of the model for long term energy system planning in Croatia. The thesis have to show the difference between the simulation vs. optimization models for the long term energy system planning in Croatia (national case), where for simulations the ENPEP (BALANCE) model is used. This simulation approach helps in modeling the technology market share potential for demand sectors of the MARKAL national model. This approach will be used to examine some specific issues in Croatia with regard to the energy system including building an expanded natural gas network in the country, new capacity investments in the power system (with some data input derived using WASP) and how best to meet the Kyoto Protocol obligations for emissions reduction. The analysis will also examine the impacts of specific measures for emission reduction.
A key issue centers on the fact that only one part of the country is covered by natural gas transmission and distribution network while there is a need in other parts of the country as well. To examine whether this is economical and possible (having in mind domestic gas reserves and possible inputs in the future time), a multi-region MARKAL model has to be build for the 4 regions in Croatia. It is expected that this approach will give better answer for capacities in gas sector, as well as more accurate representation of the power sector, in connection with regional demands.

The second application of MARKAL in Croatia is as part of the Southeast Regional Energy Market Support initiative sponsored by USAID. EIHP will serve as the in-region technical support team, and be a key contributor to the development the Regional Energy Demand Planning (REDP) framework, which will draw heavily on the approach being employed for the EU NEEDS project. The task aims at creating a regional energy demand/energy efficiency planning capability (as discussed in the International Studies, Collaboration and Contributions section of this report.

**G.5 - Estonia**

The MARKAL model was first introduced in Estonia in 1994 under financial grant of NUTEK (Sweden) and guidance from Energy Systems Technology Division of Chalmers University of Technology. Since the same year Estonia has cooperated with the IEA ETSAP programme as an observer.

The ETSAP tools used in Estonia (including MARKAL) are licensed to the Department of Electrical Power Engineering of Tallinn University of Technology (DEPE TUT). During past 10 years several national and international modelling exercises have been carried out.

On the national level, MARKAL has been used mainly for investigation of development options of Estonian energy system and projecting of greenhouse gas emissions. The most urgent problem has been and is the long-term development of power sector. When joining the EU Estonia agreed to fulfil major challenge: to replace 95% of its power generation capacity (compared to 2002) before 2016. The main factors that influence the decisions are:

- sustainability of presently dominating oil shale power engineering (indigenous solid fossil fuel with secure supply and controllable price used for power plants and for oil and gas production in refineries, but with high CO$_2$ content and other environmental concerns);
- availability, supply security and price of natural gas imports from Russia;
- CO$_2$ reduction targets and emissions trading;
- targets for renewables;
- energy efficiency and conservation;
- opening of electricity market.

Aside research projects the results of MARKAL modelling have been used in developing several important documents:

- Estonia’s Second National Communication under UN FCCC (1998),
- Development Plan of Estonian Power Engineering until 2030 (strategy for national energy company Eesti Energia Ltd., 2002),
• National Long-Term Development Plan for Fuel and Energy Sector until 2015 (adopted in the Parliament in December 2004),

MARKAL will be used in the development of Estonia’s Fourth National Communication under UN FCCC during the second half of year 2005.

International projects have largely based on good relations under ETSAP cooperation network:
• Energy Strategy for Estonia (EU PHARE project, 1996-1997),
• Economics of GHG Limitations - Phase 1: Establishment of a Methodological Framework for Climate Change Mitigation Assessment (UNEP/GEF project, 1996-1998),
• Modelling of Energy Trading and CO₂ Mitigation in the Nordic and Baltic Countries (grant of Research Council of Norway, 1999-2000),
• Contract research for IEA ETSAP and US EIA “Development of SAGE Model by EIA: Regional Models for Eastern Europe and Former Soviet Union” (2003),


Relatively long experience of using MARKAL model from one side and decades-long experience of the development of methods and software for optimal operation planning and control of power system and its elements under incomplete information has initiated lately in DEPE TUT interest for combining these research fields. Paper on the new topic (Keel M., Liik O., Tammoja H., Valdma M. Optimal planning of electric power generation in thermal power system.) will be published in the international conference IEEE PowerTech 2005, St. Petersburg, 27-30 June 2005.

**G.6 – Nigeria**

**ESTIMATING THE ECONOMIC BENEFITS OF THE KYOTO PROTOCOL FOR THE NIGERIAN ECONOMY**
[Felix B. Dayo, Anthony O. Adegbulugbe, Francis Ibitoye, A. Adeninkinju, and Alfred Voss, Published by United Nations Industrial and Development Organization (UNIDO), Vienna, 2004.]

This study employs a suite of models to explore the economic benefits of the Kyoto Protocol for Nigeria’s economy. In order to achieve this the MARKAL modeling tool was used to study the energy system’s response to the Kyoto Protocol (KP) while a computable general equilibrium (CGE) model is used to assess the economic implications of various KP impacts on the energy sector.

In this report, MARKAL has been employed to provide answers to the following questions:
• What is the likely optimal structure of Nigeria’s energy sector under the Kyoto Protocol?
• What will be the effects of the Kyoto Protocol on key economic and environmental indicators? For example:
• Capital costs (cost of investment on supply and demand technologies)
Expenditure on fuels
- Primary energy intensity (primary energy consumed per GDP)
- CO₂ intensity of primary energy consumption

- Oil export is the backbone of Nigeria’s economy. If and when the Kyoto Protocol comes into effect, it is likely there will be a global reduction in the demand for oil, and consequently a reduction in the country’s earnings from oil. What will be the effects, on the above indicators, of a reduction in global oil demand or a fall in oil prices, as a result of the implementation of the Kyoto Protocol?

- What will be the likely effects of CDM projects on Nigeria’s energy system?

The study estimates that the cumulative CO₂ reduction in the Nigerian energy sector will be about 55 MT during 1995-2020 by comparison with the Business-As-Usual (BAU) scenario, because of CDM projects and energy efficiency improvement if the Kyoto Protocol comes into force. A reduction of about 12% in revenue from crude oil exports, by comparison with the BAU scenario, is projected during 2002-20 under the Kyoto Protocol since a large number of importers worldwide will switch from crude oil to other cleaner fuels. Given that revenue from crude oil exports is the mainstay of the Nigerian economy future economic growth will slow down. In the same scenario the revenue from gas exports is projected to increase by 38% over the BAU scenario, which to some extent compensates for the fall in oil export revenues and tempers the economic slowdown. Apart from an increase in gas exports an increase in energy efficiency and inflows of foreign direct investment under the CDM are identified as other positive impacts of the KP. The study estimates that increased energy efficiency would lead to a 4.8% increase in GDP and a 2.3% fall in the price index over the BAU scenario during 2000-20. During the same period, GDP will increase by 3.8% and the price index will fall by 0.9% as a result of CDM activities. However, these results should be interpreted with caution since they are based on a number of assumptions such as GDP growth rate, fuel prices, efficiency improvement and number and type of CDM projects.

On the whole, the study identifies and quantifies a number of positive and negative impacts of the KP on the Nigerian energy sector and the economy. Despite some limitations, the study is a useful first step towards a comprehensive analysis of the various complex issues related to the impact of global greenhouse gas control actions on the Nigerian energy sector and the economy with the aim of contributing towards better-informed decision making on the subject in Nigeria.

The effects of the KP on capital investment on energy infrastructure, expenditure on fuel consumed within the economy, and other associated costs are shown in Table 1

**Table 1: Economic Indicators**

<table>
<thead>
<tr>
<th>Investment</th>
<th>KPScenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discounted Capital Cost, all energy infrastructure</td>
<td>9.76%</td>
</tr>
<tr>
<td>Discounted Capital Cost, excluding cost of projects designed for energy export (e.g. West African Gas Pipeline, LNG and other NGL plants)</td>
<td>-24.63%</td>
</tr>
<tr>
<td>Discounted fuel cost</td>
<td>-4.21%</td>
</tr>
<tr>
<td>Discounted other expenditure</td>
<td>0.81%</td>
</tr>
<tr>
<td>Discounted total energy system cost</td>
<td>1.54%</td>
</tr>
<tr>
<td>Discounted energy system cost, excluding cost of projects designed for energy export (e.g. West African Gas Pipeline, LNG and other NGL plants)</td>
<td>-6.04%</td>
</tr>
<tr>
<td>Revenue from Oil Export</td>
<td>-11.67%</td>
</tr>
<tr>
<td>Revenue from Gas Export</td>
<td>37.72%</td>
</tr>
<tr>
<td>Combined revenue from Oil and Gas</td>
<td>-6.97%</td>
</tr>
</tbody>
</table>
From the table we notice that, over the study horizon, capital costs decrease by about 25% under the Kyoto Protocol, that is if we do not consider the costs of those energy infrastructures solely designed to service the export market (e.g. the West African Gas Pipeline, LNG and other NGL plants, etc.). As expected, there is a slight decrease of about 4.21% in fuel costs as a result of increased use of renewable technologies and improvements in energy efficiency under the Kyoto Protocol. Furthermore, analyses show that, over the study period, earnings from oil exports could decline by 11.67% under the KP, while on the other hand revenue from increased gas exports could go up by 37.72%. In total, however, the combined revenue earnings from oil and gas exports will decrease only marginally, by about 7%.

**G.7 - Poland**

At Gdansk University of Technology (Poland), a MARKAL model for Pomerian region\(^\text{28}\) is underway. The analysis concentrates on future development of energy systems (power and heat) using renewable energy, mainly biomass. Modeling of processes allowing for biomass co-firing in existing coal boilers have been elaborated, which is of principal importance in a coal-based country like Poland. Additionally, different options of meeting quota obligation for electricity from renewable energy production and from cogeneration are investigated. Since renewable energy resources occur locally, the analysis focuses on optimization in regional scale.

According to most recent Polish regulations, in 2010 the share of electricity from renewables should amount to 9% of total electricity sold to the final consumers. According to the amendment of Polish Energy Act, each company producing electricity will have to choose between: 1) generation of own renewable-based systems (e.g. installation of wind turbines, biomass boilers or conversion of existing coal boilers into biomass co-firing ones); and 2) purchase of “green” electricity from other producers having an excess of this commodity.

The trade of “green” electricity is based on the “certificates of origin” – an idea proposed in European Parliament and Council Directive 2001/77/EC. Company that fails to meet the obligation will have to pay a fine.

Different options of meeting quota obligation for electricity from renewables and electricity from cogeneration are studied in MARKAL model for Pomerian region. Although the obligation does not concern a region, the appropriate constraint has been imposed on it. The share of electricity produced in renewable energy sources in total amount of electricity produced inside region plus electricity purchased from other regions should be as stated in regulation or even higher in case of regions with high renewable energy potential. In case of investigated region, the obligation concerns mainly producers of electricity rather than power distribution companies operating on this area, since these are consolidated and have geographical borders wider than borders of one region and do not necessarily have to meet the obligation in each region they operate.

The trade of “green” electricity between regions is taken into account. However, in case of single-region model, a limitation of the amount of electricity from renewable energy sources available for purchase should be considered. In addition, the methodology allowing for the trade of “green” electricity between producers is investigated. In long-term analyses the uncertainties concern the

\(^{28}\) Pomerian region (pol. Województwo Pomorskie) - North of Poland, Gdańsk is the capital city of the region.
number and type of companies producing electricity. Similar scheme has been elaborated for electricity from cogeneration and as well as for emission permit allocation and trade.

To assess possibilities of meeting quota obligations in Poland, a model for one region is insufficient. In regional model, professional power plants are not included and these are potentially big producers of “green” electricity due to their capability of co-firing coal and biomass. Therefore, MARKAL model of power sector in Poland will be elaborated and the mechanisms of supporting the development of renewable energy sources will be studied. Additionally, the results of model for Poland i.e. marginal cost of electricity will be used in the model for Pomerian region. Linkage of these models is considered. Quota obligations and emission constraints are modeled using additional equations. The fine for not meeting obligation as well as for exceeding the allocated amount of CO$_2$ emissions has been included in the objective function. This enables to evaluate the cost of succeeding in and failing to meet quota obligations and emission constraints.

**G.8 - South Africa**

M.I. Howells, T. Alfstad, D.G. Victor, G. Goldstein and U. Remme presented a description, an analysis and projections of a South African village. Based on a survey, it was determined that the majority of respondents used wood in an *imbula* (an informal wood stove, often constructed from a 25l metal paint can) as fuel. Most respondents used the fuel because it was easily available or they were familiar with it. There was also an absence of alternatives other than high cost kerosene. Of the people who used wood, many preferred kerosene as a secondary fuel, the least expensive fuel after wood. Paraffin was used in rain when it was difficult to gather wood. Many households reported coughing, smoke and smelliness as problems with wood. In some households, different appliances were used for water heating and cooking. Typically one would find that space heating and cooking are carried out in an *imbula*, while water heating is done with Paraffin. Lighting was by candles or kerosene wick-devices. Most households owned a radio and about one-third had a TV; one-fifth reported having a cell phone.

Several future scenarios were run. In the base case, wood dominated. Open fires contribute roughly 75% to final energy demand. LPG and paraffin serve as backup fuels. Water heating and cooking are similar. Over the modeling period total final energy consumption for lighting drops significant due to a technology transition from kerosene wicks to more efficient paraffin pressure lantern. By the end of the period (2017) pressurized paraffin lanterns provide half of the useful energy, but consume less than 25% of the fuel that is burned for lighting.

In the “Stand Alone” scenario, the most significant change from the Base Case was that the model selects diesel generator, but only with the capacity for lighting, where they replace paraffin and for radio and TV.

In the “Grid Electrification” Scenario the model calculates that supplying these low volumes of electricity from a new grid connection would be less costly than purchasing or charging of batteries. This strategy with only low volume consumption has been followed in other countries. While this is an economic option, it does not promote a more complete move to electricity.

**G.9 - Southeast Europe Regional Energy Demand Planning (SEE-REDP)**

The countries of Southeast Europe are developing regional approaches to energy cooperation. The Athens Memoranda of Understanding (MOUs) of November 2002 and December 2003
encourage creating regional electricity and gas markets for integration into the European Union (EU) Internal Energy Market. Countries in the region are in varying stages of transition to competitive markets, and accession to the European Union. There are several core issues that need to be examined as countries in the region transition to liberalized energy markets while simultaneously addressing EU directives and fostering development of globally competitive economies. These include: the relationship between economic growth and energy demand, the effects of disproportionate tariffs on energy use patterns and competitiveness, the potential for energy efficiency gains, the possibility of an increased role for natural gas and renewables, and the social implications of restructuring of the energy system and markets.

The recently concluded Generation Investment Study (GIS), sponsored by the EU adopted a regional approach to meeting electric generation capacity requirements over the next 15 years. This Study focused on the supply picture in the power sector, tying projections of future electricity needs directly to economic growth. Building on the GIS to expand analysis to encompass comprehensive energy system planning for the region is a continuing effort. Under USAID sponsorship, this activity will foster additional modeling and analysis capabilities to complement the GIS by establishing a framework to evaluate alternatives that may influence future electricity use patterns, such as tariffs, use of renewable energy sources, demand side management and fuel substitution issues, as noted above.

This project will employ MARKAL adopting and adapting the NEEDS project Reference Energy System structure and conventions. MARKAL is comprehensive enough to accommodate the complex nature of the entire energy system, as well as the options and alternatives for shaping its evolution over time. It allows the technology components and demand activities of the entire energy system to be represented at an appropriate level of detail, while enabling these systems (countries) to be integrated into a single planning apparatus that can provide clear evidence of the benefits of cooperative approaches. Initially this project will focus strictly on the detailed representation of the demand sectors, along the nature gas, district heat, and renewables within the energy system, and us as input assumptions and results of the GIS study for the power sector.

Demand Planning Working Group: The work plan features the full involvement and cooperation of regional counterparts in planning the future development of regional energy systems. The countries participating include Albania, Bosnia, Bulgaria, Croatia, Kosovo, Macedonia, Montenegro Romania, and Serbia. The approach to be followed will mirror USAID’s successful experience in supporting the SEE Regional Electricity Transmission Planning Project that has developed a consistent transmission model for the region and has evaluated the implications of transmission investment projects on load flows.

A Regional Demand Energy Planning (REDP) Working Group has been established with representatives from each participating country; these representatives are users of energy planning analysis designated by the High Level Working Group who in turn will involve a technical counterpart familiar with energy system modeling principles and usage in their country.

The REDP Working Group will develop individual country models and conduct analyses for their respective countries under IRG’s guidance. Working Group members will be fully engaged in all aspects of developing the data, modeling the underlying energy system, and applying the framework.

The REDP Work Group experts will be provided with local technical assistance with respect to data needs and use of MARKAL by Energy Institute Hrvoje Požar, under the direction of IRG. A
second local institution highly familiar with the core aspects of energy system modeling, though not necessarily MARKAL, will be engaged as a regional coordinator for project related activities.

The comprehensive framework will be employed to examine the impacts on electricity demand and load owing to demand side management actions including: improvements in building envelopes, introduction of more efficient demand devices, availability of renewable energy options, and co-generation. In addition, the framework will handle other issues outside of the electric power sector that are likely to affect future electricity use patterns, most notably fuel switching with respect to natural gas (outside the power sector), the changing pattern of district heating in the region, and the impact of changes in tariffs and cross-subsidization.

The REDP RES will have a simplified representation of the (upstream) energy supply system.

- The power sector, refineries and the like will not be explicitly modeled.
- Rather supply step curves (indicating the ability to deliver a given amount of energy at some stated price) will be employed, as the emphasis of this initial undertaking is to examine the demand for energy not its supply.
- Electricity data (step curve and unit fuel consumption for each step) will be drawn from the GIS+RETPP studies, with provisions for sensitivity analysis.
- Supply curves for most other finally energy forms (e.g., coal, refined products) will be derived from international sources (e.g., IEA), augmented by local knowledge.
- Natural gas and district heat will be given more detailed treatment, including the modeling of pipeline and plant/grid investments respectively.

The REDP will be organized into four phases, with the core activities as noted here.

- Phase I - Data gathering and calibration [Dec 2005]
- Phase II - Development of Reference scenario(s) [June 2006]
- Phase III - Preliminary analysis [Sept 2006]
- Phase IV - Sensitivity analysis and integration into a [TBD]
APPENDIX H: MARKAL/TIMES Institutions
(April '05)

Over the past 15 years, MARKAL/TIMES has been introduced to over 162 institutions in more than 57 countries. The current list of active users of the ETSAP Tools is provided in the table below.

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<td>Lorna Greening</td>
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<td>Northeast States for Coordinated Air Use Management (NESCAUM)</td>
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<td>US Department of Energy (EERE)</td>
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<td>US Environmental Protection Agency (ORD)</td>
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<td>Vietnam</td>
<td>Ministry of Industry</td>
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<td>116</td>
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The Status column indicates M=MARKAL/T=TIMES in use, to the best of ETSAP's knowledge.
APPENDIX I: Annex IX, Energy Models Users’ Group

ETSAP has been building a bridge among specialists of energy sectors, energy technologies, environment and economy to carry out joint system modeling analyses.

The prime aim of this Agreement is to diffuse the MARKAL methodologies to new national groups operating in the countries of the Contracting Parties, organizations active in other IEA Member countries, organizations active in non-Member countries, governmental and non-governmental international groups and organizations, and universities and educational bodies.

The means by which it works:

The participants shall share the coordinated work necessary to carry out this task. The objectives shall be achieved by:

(a) Facilitating the widespread dissemination and adoption of ETSAP methodologies and analysis in different regions, countries, and local areas;
(b) Carrying out coordinated analyses of energy technologies systems, such as energy efficiencies, deregulation, RD&D ranking;
(c) Collecting, analyzing and disseminating information and data related to energy systems, energy technologies, energy and environment models and scenarios;
(d) Improving the modeling tools, by means of integration with other existing tools, developing new research ideas, testing new solutions, fine tuning experimental models and software, e.g., to foresee links to spatial variables and local GIS;
(e) Organizing annual meeting of experts, as appropriate to exchange information and experience in the areas of work covered in the agreement;
(f) Exchanging specialists, experts, and students active in the sector.

Specific Obligations and Responsibilities of the Participants:

(a) Participants shall provide the Operating Agent with reports on the results of the work carried out;
(b) Participants shall exchange the material related to and reviews on the work for, quality improvement;
(c) Participants shall participate in the editing and review of draft reports on the task; and
(d) Participants shall support the Operating Agent in efforts to disseminate the methodologies and their use in assessing local or regional systems.

Funding:

(a) Annual meeting shall be hosted in turn by the Participants. The cost of organizing and hosting the meetings shall be borne by the host Participant.
(b) The Program of work is carried out in a task sharing basis. A wide use of the web will increase the opportunities of exchange at low cost;
(c) The cost of publishing reports and summary assessments shall be met by the Operating Agent;
(d) Each Participant shall bear all the costs it incurs in carrying out its activities, including the purchase of the proprietary software necessary to run the models;
(e) The level of work to perform the program specified in this Annex is estimated at 3 person-months per year for the Operating Agent, 2 additional person-months for each Participant in the first year, and an additional person-month per year for each participant during the remainder of the Annex.

193
While the goal of promoting and disseminating the ETSAP Tools continue to evolve on a bilateral or donor institution basis, Annex IX itself only carried out one activity, the "Global and Regional Energy Modelling", held in Taipei April 4-7, 2005. The conference was co-sponsored by ETSAP and the Taiwan Environmental Protection Agency. It was very well attended, with some 32 technical presentations (listed below) given by the participants.

Programme

April 4, Morning  Welcoming Session

Opening: **Dr. GianCarlo Tosato**, Conference Committee Chair
Welcome Speech
**Dr. Rong-i Wu**, Vice Premier, Executive Yuan
**Dr. Jiunn-rong Yeh**, Executive Director, National Sustainable Development Council, Executive Yuan
**Dr. Juu-en Chang**, Minister, TEPA
Welcome and Introduction of ETSAP
Speaker: **Dr. Hertsel Labib**, Chairman of ETSAP

Keynote Speech
Speaker: **Dr. Robert Dixon**, Council on Environmental Quality Executive Office of the United States President

Special Topics

*Private Financing for Certified Emission Reductions*
**Owen Carroll**, SUNY Stony Brook and Magnet Group, US
John Lee, Brookhaven National laboratory, US

*Regional Energy and Environmental Issues In Central America*
**Marco Gonzalez**, Central American Commission on Energy and Development, CA

*Technology dynamics, Energy Scenarios and Social perspectives*
**GianCarlo Tosato**, IEA/ETSAP, Project head, Italy

*The Effect of Carbon Tax on CO2 Emission and the Economy of Taiwan - An Application of DGEMT Model*
**Chi-Yuan Liang**, Institute of Economics, Academia Sinica, Taiwan

*CARIBELATE: An Organizational Template for Incubation and Diffusion of GHG Emissions Reduction Technologies*
**Edward Linky**, US Environmental Protection Agency
John Lee, Brookhaven National laboratory, US

April 4, Afternoon  Global and Regional Modeling

*Energy Policy Analysis Using MARKAL in the ASEAN Region*
**Hugh Bannister**, EPSAP, Australia

*Regionalization of US DOE MARKAL*
**Paul Friley**, Firas Barazi, and John Lee
Brookhaven National laboratory, US

*Modelling of Regional Energy Collaboration in the Nordic Countries*
**Erik Ahlgren**, Anna Krook Riekkola, and Thomas Unger, Sweden

*NE-MARKAL: An Energy/Economic/Environment Framework for Exploring Regional Policy Options in the Northeast United States*
Gary Kleiman and Ren-Tseng Young
Northeast States for Coordinated Air Use Management, US

Recent developments of World MARKAL/TIMES Scenarios Done at GERAD
Maryse Labriet, Group for Research in Decision Analysis, Canada

Integrated Energy Planning and GHG Emission Reduction in Central America: Development of a Regional MARKAL Model
Ta-hsiung Lin, Soon-Ching Ho, Hui-Chen Chien, TEPA Taiwan, James Lu and Marsha Tsai, ITRI, John Lee and Vatsal Bhatt, and Ann Reisman
Brookhaven National Laboratory, US

April 5, Morning National and Local Modeling
The strategies of TEPA for Climate Change and the role Markal Model plays
Fung-Luh Yeh, Soon-Ching Ho, Hui-Chen Chien, TEPA Taiwan

An Assessment of the China Power-Generation Sector
Socrates Kypreos and Robert Krakowski, Paul Scherrer Institute, Switzerland

Analysis of Taiwan's Future Energy Structure under the Clean Energy Development Goal, Bureau of Energy, Taiwan

A Model Analysis of Energy Network in Zero Emission Industrial Park
Shimazaki Yoichi, University of Yamanashi, Japan

Current MARKAL Applications in Taiwan
Jhy-Ming Lu, Miao-Shan Tsai, Kuei-Lan Chou and Yu-Feng Chou, ERL, ITRI, Taiwan

A Portfolio Approach in Local Energy Planning: The Case of New York City
John Lee, Vatsal Bhatt, Edward Linky, and Owen Carroll, US.

An Economy-wide Analysis of Policy Responses of Taiwan to Stabilize CO2 Emissions
Shih-Hsun Hsu, Han-Pang Su, Hsing-Chun Lin, and Du-Hwa Li, National Taiwan University, Taiwan

MARKAL Modeling in Vietnam

April 5, Afternoon National and Local Modeling (Continued)

MARKAL Modeling in Cambodia
MARKAL Modeling in Myanmar

Issues in Energy and Environmental Planning
Issues in Energy and Environmental Planning
Luis Ake, Belize

Issues in Energy and Environmental Planning
Fernando Alvarado, Costa Rico

Issues in Energy and Environmental Planning
Salvador Rivas, El Salvador

Issues in Energy and Environmental Planning
Gerardo Salgado, Honduras

Issues in Energy and Environmental Planning
Carlos Mansilla, Guatemala

April 6, Morning Modeling Tools
Issues in Energy and Environmental Planning
Marina Stadthagen, Nicaragua

Issues in Energy and Environmental Planning
Eduardo Reyes, Panama

Issues in Energy and Environmental Planning
Tumentsogt Tsevegmid, Mongolia

ETSAP Tools Data Handling Systems for Multi-Region Models
Ken Noble, Australia, Amit Kanudia, Canada, and Gary Goldstein, US

GianCarlo Tosato, IEA/ETSAP and, Alain Haurie, Switzerland

Panel Discussion: Issues on Modelling Needs and International Cooperation, Concluding Remarks

April 6,
Afternoon

Optional Site Visit to Hsinchu Science Park (HSP) (Host: ITRI)
APPENDIX J: Selected References

The material assembled in this report was gathered from diverse sources provided by the various ETSAP Partners. In some cases these were summaries of the institution’s ETSAP and/or MARKAL related activities, and in other cases reports or journal articles were provided. In either case extensive references to other material and sources of related information were provided. These references are collected here.

International Studies, Collaborations and Contributions

International Energy Agency - Energy Technology Perspective Project

Publications


Working papers, conference proceedings etc.


Global Multi-Regional MARKAL Model (GMM)


**Decomposing the Global MARKAL-MACRO Model GMM**


**Marginal Abatement Curves in the Energy-System GMM Model**


Impacts of R&D on Carbon Mitigation Costs


**Toward a Nash Equilibrium MARKAL?**


**Assessment of Abatement Costs and Permit Allocations Using World-MARKAL**


*The European Fusion Development Agreement (EFDA) Consortium to Examine the Long-term Global Potential for Nuclear Fusion: The World TIMES Project*
ETSAP Partner Activities

Belgium

Impact of opening the Belgian electricity market: an analysis with MARKAL

Stef Proost and Denise Van Regemorter, How to achieve the Kyoto Target in Belgium – modeling metholody and some results – Working paper, n° 2000-09, 2000


Stef Proost and Denise Van Regemorter, How to achieve the Kyoto Target in Belgium – modeling methodology and some results – Working paper, n° 2000-09, 2000


Adrian Wals and Fieke Rijkers, How will a CO₂ price affect the playing field in the Northwest European power sector?, Research Symposium European Electricity Markets, The Hague, September 2003


Germany


University of Stuttgart, 2004 (report in German under www.ier.uni-stuttgart.de/sachsen) /Fahl, et. al. 2004a/

Fahl, Ulrich ; Bickel, Peter ; Blesl, Markus ; Droste-Franke, Bert ; Ellersdorfer, Ingo ; Rehrl, Tobias ; Remme, Uwe ; Rout, Ullash Kumar ; Voß, Alfred: "Development and application of an integrated assessment modeling system for the analysis of sustainable development strategies of energy supply in Germany ", Institute for Energy Economics and the Rationale Use of Energy (IER), University of Stuttgart, Final report in German under http://elib.uni-stuttgart.de/opus/volltexte/2004/1740/ /Fahl, et. al. 2004b/


Italy


Contaldi M., Tosato G.C., 1995, Data and scenarios for Italian national program to limit GHG gases emissions from energy system, ENEA Technical Report.


D. MAP, 2001: Ministerial Decree of April 24, 2001 on energy efficiency; Proposal for the implementation of the Ministerial Decree of April 24, 2001 etc., consultation document issued by the Authority for Electric and Gas market in Italy, April 2002; Proposal or technical characterization tables to quantify primary energy savings of interventions related to Ministerial Decree of April 24, 2001 on energy efficiency, consultation document issued by AEG, January 2003.


ENEA, 1999, Libro Bianco per la valorizzazione energetica delle fonti rinnovabili.


Ministero dell’Ambiente, 2003, *Programma nazionale per la progressiva riduzione delle emissioni nazionali annue di SO2, NOx e VOC e NH3*, Direttiva 2001/81/CE.


**United Kingdom**


Goulder, L H (2004), Induced Technological Change and Climate Policy, Prepared for the Pew Center on Global Climate Change


PCAST (1997). Recommendations of the President's Committee of Advisors on Science and Technology, Panel on Energy R&D for the 21st Century, November


TIMES


