



International Energy Agency

Implementing Agreement for a Programme of  
Energy Technology Systems Analysis (ETSAP IA)

***End-of-Term Report***

***(2009-2015)***

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## 1. STRATEGIC DIRECTION

The Contracting Parties of this Implementing Agreement carry out a co-operative Energy Technology Systems Analysis Programme (ETSAP). The objective of ETSAP is to assist decision-makers in the assessment of new energy technologies and policies in meeting the challenges of energy needs and economic development, environmental concerns and technology development.

ETSAP's strategy in achieving the objectives is twofold. Through a common research programme, ETSAP established, maintains and enhances the flexibility of consistent multi-country energy/economy/environment analytical tools and capability (the MARKAL/TIMES family of models). MARKAL (acronym for **Market Allocation**) and TIMES (an acronym for **The Integrated MARKAL-EFOM System**) which is the successor of MARKAL, are developed by ETSAP since 1978. They are economic model generators for local, national or multi-regional energy systems, which provide a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon. They are used for the analysis of the entire energy sector, but may also be applied to study in detail single sectors (e.g. the electricity and district heat sector).

ETSAP members also assist and support government officials and decision-makers by applying these tools for energy technology assessment and analyses of a wide range of energy and environment related policy issues.

The work of ETSAP is by definition focusing on supporting policy making through the analysis of alternative technology pathways in achieving the long term target for a low carbon energy system. All ETSAP members are actively involved with policy making in their own countries and also on an international level. Through their involvement in national energy and environmental policy, the members of ETSAP are in constant communication with policy makers. ETSAP is the first multilateral group to have as a Contracting Party a Caspian and Black Sea region Country: Kazakhstan which joined in 2015. Furthermore the tools of ETSAP are used in many non-IEA countries and the collaboration among ETSAP partners and the institutions in these countries is continuing.

## 2. SCOPE

In the period 2009-15 the main objectives of ETSAP were:

- (a) to develop Coordinated Analysis Tools:  
Developing, improving and making available to the members and the IEA: the global multi-regional TIMES Integrated Assessment Model (TIAM) and the Energy Technology Data Source (E-TechDS).
- (b) to perform coordinated Research and Development:  
Continually advance the state-of-the-art with respect to energy systems analyses, integrated energy/economic/environmental/engineering modelling and long term scenario building through the collaboration of the contracting parties.
- (c) to extend Capacity building activities:  
Best practice examples, manuals, online and actual training opportunities were offered with the aim of maintaining/improving international/national capabilities of energy systems analyses and the use of ETSAP tools.

(d) to maintain and further develop the base tools:

The objective was to maintain and update the ETSAP model generators (MARKAL, TIMES) and users' interfaces (ANSWER, VEDA), and to organize two semi-annual workshops every year.

Numerous activities have been undertaken in the achievement of these objectives. This report summarizes ETSAP advancements, applications, and accomplishments from 2009-2015; more detail on these activities is available in final report of Annex XI<sup>1</sup> and the draft report of Annex XII which is currently being finalised. It lists many examples of policy relevant applications of the MARKAL/TIMES modelling platform and its continued spread to new users through capacity building projects, as well as the ongoing advancement of the methodology to meet the requirements for integrated energy planning in these challenging times. With the knowledge and skills needed to effectively use the methodology now widespread around the world, the framework is positioned to make further important contributions towards identifying policies and pathways that will lead to a low-carbon, secure and affordable future, essential for sustainable development on our planet.

The following contracting parties (countries) have participated in the term under review:

- Belgium through the Belgian Federal Public Planning Service - FPP Science Policy, VITO and University of Leuven
- Canada through Natural Resources Canada
- Denmark through the Danish Energy Authority and RISØE (which later became part of the Technical University of Denmark-DTU),
- European Commission DG RTD through the Joint Research Centre, Institute of Energy and Transport Petten,
- Finland through TEKES and VTT,
- France through ADEME, the Ministère de l'Ecologie, du Développement et de l'Aménagement Durables and Ecole des Mines, Paris – EDMP,
- Germany through the University of Stuttgart, Institute of Energy Economics and the Rational Use of Energy - IER,
- Greece through the Center for Renewable Energy Sources,
- Ireland through the Sustainable Energy Authority of Ireland and University College Cork,
- Italy through ENEA and CNR/IMAA,
- The Netherlands through The Energy Research Center of the Netherlands – ECN,
- Norway through the Institute for Energy Technology – IFE,
- Korea through Korea Energy Management Copr. KEMCO,
- The Russian Federation through ERI RAS,
- Spain through CIEMAT, Spanish Energy Research Center
- Sweden through the Swedish Energy Agency and the University of Chalmers,
- Switzerland through PSI,
- UK through DECC and University College London (UCL),
- United States through DOE and Brookhaven National Laboratories.

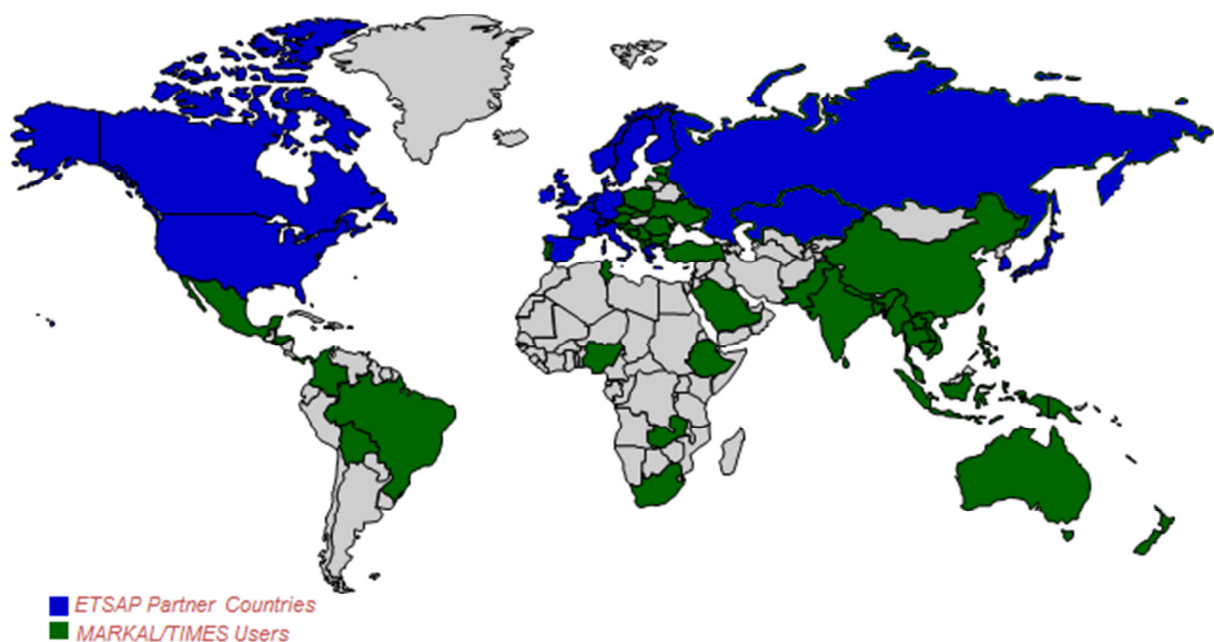
Furthermore in 2014 Japan re-engaged in the activities of ETSAP. In addition ETSAP secured for the first time a sponsor, the ENEL Foundation based in Italy. In February 2015 Kazakhstan joined ETSAP

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<sup>1</sup> Available at <http://www.iea-etsap.org/web/FinReport/ETSAP-Annex-XI-final-report-final%20version-June-2012-v03.pdf>

represented by Nazarbayev University. Kazakhstan is the first country of the Caspian and Black Sea region to participate in an Energy Technology Initiative.

With the support of the IEA several other organizations in Turkey, China, India, Mexico, South Africa, Brazil, Australia, Austria, Indonesia, Portugal, Croatia, Ukraine, Czech Rep., and Singapore were approached and have been invited by the Executive Committee to join the Implementing Agreement. The invited institutions are already users of ETSAP's tools and their participation in ETSAP would enhance the modelling community. By the end of 2014, there were more than 250 MARKAL-TIMES licensed institutions, of which nearly 180 are active in 69 countries, including the current 19 Contracting Parties in the ETSAP Implementing Agreement (Figure 1). Details about the dates of participation for each contracting party are given in Annex I.



**Figure 1:** ETSAP contracting parties and MARKA/TIMES users around the world.

ETSAP members work closely with users of its analytical tools and benefits are mutual. New model users learn to understand the capability of the model in addressing issues related to energy, the environment, innovative technologies and the economy. ETSAP experts learn from new model users wider energy and environmental issues that need to be addressed in a way that is tractable analytically. ETSAP members have been working with the following organizations over the past years:

- the International Energy Agency (IEA), for its Energy Technology Perspective (ETP) and Nordic Energy Technology Perspective (NETP) projects;
- the U.S. Environmental Protection Agency (EPA) for the nine region US MARKAL;
- the European Commission, where several contracting parties participate to various research and policy studies, including REACCESS, ATeT and the development of the JRC European TIMES model, which will be used in the framework of the SETPlan for analyzing future technological options;
- The European Fusion Development Association (EFDA);

- IRENA for the common development of the Energy Technology Data Sources (ETechDS) and the analysis of renewable energy penetration by 2030 (REMAP) among other topics;
- the Energy Research Institute of National Development and Reform Commission of China, the Tsinghua University and other Chinese institutes for the development of China energy models with ETSAP tools;
- the South African National Energy Research Institute and the University of Cape Town for analyses related to long term energy scenarios for Africa;
- user's groups in South East Europe (Albania, Bosnia & Herzegovina, Bulgaria, Croatia, Kosovo, FYRO Macedonia, Montenegro, Romania and Serbia), supported by USAID, for multiyear capability building undertaking in energy modelling and policy assessment, and
- the International Energy Workshop (IEW) which ETSAP sponsors every year.

### 3. CONTRACTUAL AND MANAGEMENT REQUIREMENTS

In the period from 2009 until 2015 the following activities took place in the framework of ETSAP

Meeting	Quantity	Participants
Workshops	12	50-80
Training course for ETSAP's tools	14	15-20
Executive Committee meetings	2/year	80%
ETSAP is holding a workshop once per year back to back with the International Energy Workshop (IEW) and is one of the partners of IEW <sup>2</sup> .	6	200-300

A detailed list of publications is given in Section 5 and can be found in the Final reports of the Annexes on the ETSAP website (<http://www.iea-etsap.org/web/official.asp#ImpAgr>)

ETSAP is a cost sharing Implementing Agreement. An annual participation fee which is currently set at €20,000 is used to cover the expenses of the development of the modeling tools (MARKAL/TIMES) and the related shells (ANSWER/VEDA). Furthermore the fees are used to fund research activities by ETSAP members through common collaborative projects. The level of participation fees is discussed and agreed unanimously in the Executive Committee every year.

The Executive committee of ETSAP meets twice per year and on average the participation is around 80%. Since ETSAP operates only one Annex, the Executive Committee meetings serve as Annex meetings and are always accompanied by workshops where the results of common projects are presented. Workshops with specific thematic content are also organized at different times during the year.

ETSAP does not produce annual reports but produces Final Reports at the end of each Annex, which lasts for three years. The final reports are detailed documents of several hundred pages, presenting a review of all the common scientific and policy related work that is done by the ETSAP partners. Funds are allocated for the write up and publication of the final reports.

<sup>2</sup> <http://www.internationalenergyworkshop.org/>

The legal text of the Implementing Agreement was amended for the last time in 2004. The text is available on the website.

### 3. CONTRIBUTION TO TECHNOLOGY EVOLUTION / PROGRESS

ETSAP is not directly related to specific technologies, therefore its contribution to technological evolution or technology deployment and market facilitation are difficult to quantify. But, the tools developed by ETSAP allow to analyse the role of technologies and their possible development pathways on the energy system, thus supporting decision makers in defining policies or technology strategies. Furthermore, the recent addition of ENEL Foundation as a sponsor and the engagement with IRENA, do demonstrate also industry relevance.

During the term under review, the work of ETSAP evolved in several important directions.

(a) Use of the MARKAL-TIMES model enabled expert groups conducting integrated energy systems to reach new targets in quality, scope and numbers. Groups have formed in countries that are considering joining ETSAP (Croatia, Ukraine, Portugal, Singapore, Turkey). In addition, extremely competent teams have been established and expanded in the developing countries (South Africa, China, Pakistan), while key countries such as Russia have also turned to the ETSAP tools. Russia joined ETSAP as a contracting party in 2011.

As a result of ongoing training and internationally financed capacity building activities new groups are being established in other countries, such as Kazakhstan (which finally joined ETSAP in 2015), the Balkan countries, and countries in Asia.

(c) The original tools developed by ETSAP continue to improve. The Integrated MARKAL EFOM SYSTEM (the TIMES model generator), an advanced successor to MARKAL, is now replacing MARKAL in most of the countries. Two user interfaces, (VEDA and ANSWER), fully support both the MARKAL and TIMES models generators, which oversee all aspects of working with the models. The underlying strength of the technical-economic partial equilibrium paradigm, complimented by the ease-of-use of the interfaces, is the primary reason for the heightened interest and thereby growing user community.

(d) ETSAP developed and maintains technology briefs on relevant technologies in the energy supply and demand sectors (see also Section 9). Though primarily intended for providing technology characterizations to be used in energy models, they also provide a brief overview on technology status, performance and costs and discuss future potentials and barriers.

(e) Dozens of energy models have been built with ETSAP tools, at the global, regional, national and local scale.

Another indication of the relevance of ETSAP community is reflected by the number of articles that appeared in the scientific literature which increased from an average of 14 papers per year during the 2002-2007 to 24 papers per year in the period 2009-2015.

Those interested in ETSAP accomplishments include:

- The IEA CERT representatives, particularly from representing countries currently participating in ETSAP, along with those who have expressed interest in joining ETSAP;
- The government sponsors of the various institutions involved directly in ETSAP, and those that are using ETSAP's tools without being a contracting party of ETSAP; in both cases, ETSAP's tools are often used to inform
  - Parties to other IEA Implementing Agreements<sup>3</sup>;
  - The wider energy and Global Climate Change (GCC) policy community, researchers and modelers;
  - MARKAL/TIMES modellers around the world;
  - University professors and their students interested in growing programs that may employ the ETSAP Tools to groom the new generation of energy experts.

#### 4. POLICY RELEVANCE

The work of ETSAP is directly linked with policy making. The ETSAP tools are currently used by the JRC to analyse future technology development, by the IEA in the ETP series and related energy technology roadmaps and by national governments since most of the contracting parties of ETSAP contribute to national policy making, formulating energy and environmental policies. MARKAL/TIMES is listed as one of the four selected modelling tools in the UNFCCC guide for preparing the national communications for non-Annex I parties.

ETSAP's tools have been used to provide advice in policy making at different geographical scales. Global Models, (IEA Energy Technology Perspective model, the original TIMES Integrated Assessment Model (TIAM), several derived TIAM models from different modelling teams, the Global TIMES Model of the European Fusion Development Agreement, the TIMES G5 model and the Global Multi-regional MARKAL Model), regional models (the Pan-European TIMES model, MARKAL-TIMES Models for Europe, Asia and North America), a large number of applications from national models of 32 countries and applications of Sub-National Models (Western China, Reunion Island, Lombardy, Pavia, Southwest region of Sweden, Kathmandu Valley) and local models for rural areas and cities are presented in detail in the Final Report of Annex XI and Annex XII that cover the period from 2009 until 2015. An overview of the activities of ETSAP members, related projects and applications of ETSAP tools, is presented in Section 9.

The IET/JRC in Petten is using a TIMES model for all the EU member states which is used in the assessment of future technology options in the path to a low carbon economy in Europe. The Energy Modelling Forum researchers are examining robust transition policies towards climate sustainable systems after 2100 using ETSAP-TIAM. Several groups use global, multi-regional and national models to explore the impact of different post-Kyoto regimes. Pan European and member states' models are used to identify the least expensive combination of measures that satisfy the demanding EC targets for 2020.

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<sup>3</sup> For example collaboration with RETD: [http://iea-retd.org/wp-content/uploads/2011/09/SC4\\_IEA-RETD\\_Climate\\_Stabilization\\_and\\_Renewable\\_Energy\\_July2010.pdf](http://iea-retd.org/wp-content/uploads/2011/09/SC4_IEA-RETD_Climate_Stabilization_and_Renewable_Energy_July2010.pdf)

Synergies achieved as a result of advanced methodology, tools and applications have raised the importance of ETSAP and its mission. The IEA ETP publications advise the decision-makers on the role of energy technologies for a sustainable energy future. The results of ETSAP-TIAM studies are being included among the groups that assess climate mitigation policies through the Energy Modelling Forum (EMF) and IPCC and the different derived TIAM models are used by institutions in projects funded by the European Union. The expert groups using the ETSAP tools that work for the Ministries in various countries are informing decision-makers on the merits and impacts of different measures for achieving the increasingly essential objectives of the energy security, climate change mitigation, and economic affordability in response to national policies and measures.

Interest in ETSAP was reflected by participation in the biannual workshops where the number of attendees ranged between fifty and one hundred experts, giving between twenty and fifty presentations per workshop (the presentations are available at <http://www.iea-etsap.org/web/Workshop.asp>).

## **5. CONTRIBUTION TO ENVIRONMENTAL PROTECTION**

ETSAP tools are examining energy-environment-economy interactions in a medium to long term horizon using a least cost approach methodology, so by definition the issue of environmental protection is included in all the analysis performed. As was mentioned above, the results of ETSAP-TIAM studies are being included among the groups that assess climate mitigation policies through the Energy Modelling Forum (EMF) and IPCC. More specifically, MARKAL/TIMES is listed as one of the four selected modelling tools in the UNFCCC guide for preparing the national communications for non-Annex I parties.

## **6. CONTRIBUTION TO INFORMATION DISSEMINATION**

ETSAP's website (<http://www.iea-etsap.org>) presents updated information on the tools and the activities, reports on the common research and analysis project held among partners, and a forum for tool users. The Annex reports published every three years, at the end of each Annex, provides a comprehensive guide for the work done by ETSAP partners and the work done using ETSAP's tools in general. ETSAP contributes regularly to the IEA secretariat promotion activities.

The results of the analysis done by the ETSAP members are always disseminated through publications and reports, in addition to extensive journal and conference publications. In May 2015 a book will be published by Springer International Publishing, in the series "Lecture Notes in Energy", with the title "Informing Energy and Climate Policies Using Energy Systems Models". This book presents the applications of ETSAP's tools in a number of energy and environmental policy issues. The majority of the contributors come from ETSAP contracting parties and all the chapters refer to the use of ETSAP's tools. The foreword of the book is written by the Chair of CERT, Ms Alicia Mignone.

## **7. OUTREACH TO IEA NON-MEMBER COUNTRIES**

As was mentioned in the previous sections, the Russian Federation and Kazakhstan are contracting parties of ETSAP. Furthermore, ETSAP tools are used in countries around the world including Brazil, China, India, Mexico, Pakistan, South Africa and Ukraine, just to name a few. ETSAP is continuously trying to expand the use of its tools in more countries through training sessions offered during the bi-annual workshops as well as targeted training sessions in specific countries which request for

these (training in Curitiba Brazil in October 2012, training in Cape Town in 2012, in Beijing 2014). ETSAP hosted a recent Workshop in China (2014) and participated in an IEA MOST NEET Workshop on Integrate Approaches to Energy Technologies in China in 2012.

## 8. ADDED VALUE

The added value of participation in ETSAP is achieved through the following activities:

- Common research projects and tools development. ETSAP members engage in research activities in common areas of interest, exchanging experiences and expertise. ETSAP tools are continuously improved in order to include the results of the research projects, enhancing their modeling capabilities to include issues that are relevant to current policy making (high penetration of renewables, flexibility of the electricity system etc.)
- Analysis of low carbon energy system development through collaboration of different institutes with different expertise and different focus (renewable energy, macro economic development, technological development options etc.). One of the strong points of ETSAP is the participation of Institutes with different focuses in the energy, environment, economy interaction analysis. This creates a unique platform for the combination of expertise in answering the complex issues of future energy systems.
- Interaction with the Renewable Energy Technology Deployment (RETD) IA, the Energy Storage IA, CERT and the IEA Secretariat for ETP.
- The participants in ETSAP are mainly research institutions appointed by national governments and usually undertake policy analysis on behalf of the government. The interaction among them within the framework of ETSAP contributes to discussing, analyzing and solving similar problems that appear in the development of national energy policy.
- National research capabilities are greatly improved through the interaction among researchers from different countries and the training activities of ETSAP

## 9. MAJOR ACHIEVEMENTS: RESEARCH PROJECTS AND MODELLING MILESTONES USING THE ETSAP TOOLS

In the period 2009-2014 ETSAP funded a number of research projects with the participation of the contracting parties. Some of these projects are presented briefly here and more details can be obtained on ETSAP's website (<http://www.iea-etsap.org>).

1) **Development of ETSAP-TIAM:** ETSAP funds the development of the TIMES Integrated Assessment Model (ETSAP-TIAM)<sup>4</sup>, which is a Global Integrated Assessment model, available to all ETSAP members, based on the TIMES model generator. The model is continuously updated through the common funding of contracting parties, and is used as a basis for the development of “spin-off” models.

2) **Energy Technology Data Sheets**<sup>5</sup>: Bottom up technology rich models like MARKAL/TIMES require detailed data about the existing and future energy technologies both on the demand and on the supply side. In order to provide these data ETSAP initiated the “Energy Technology Data Sheets” ETechDS project and produced 68 technology briefs that are published on the website. Some of

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<sup>4</sup> [http://www.iea-etsap.org/web/etsap\\_tiam/](http://www.iea-etsap.org/web/etsap_tiam/)

<sup>5</sup> [http://www.iea-etsap.org/Energy\\_Technologies/Energy\\_Supply.asp](http://www.iea-etsap.org/Energy_Technologies/Energy_Supply.asp)

these briefs related to renewable energy technologies have been developed in collaboration with IRENA. A number of Implementing Agreements have contributed to the development of the ETechDS.

3) **VEDA-TIMES Demo Models** have been developed in order to provide training material for new users. Starting from an energy balance a model is built incrementally employing a standard approach to describing the underlying Reference Energy System (RES) and careful naming conventions. The model starts with a simple supply curve feeding a single demand and grows step by step to build out the RES adding new commodities, technologies and regions; introducing new parameters and more advanced TIMES modelling features along the way. There are twelve steps with some variants in this set of basic and intermediate demo models.

4) **Transport Modal choice in a TIMES model:** Transport is one of the sectors with the highest energy consumption. The objective of this research project was to incorporate modal choice within passenger transport in TIMES models, which to date has been exogenously modelled, so that no competition could exist between alternative modes.

5) **TIMES-MERGE MACRO linking:** Linking energy system models with macro-economic models is one of the main topics of research of ETSAP partners. Two different developments with the TIMES-MACRO & MERGE links were examined: (a) the hard link of TIMES-MACRO for one region and MERGE for all other world regions and the soft link of global TIAM-MACRO.

6) **Incorporating Generation Expansion Planning under Wide-Scale RES Energy Penetration** in the TIMES model, targeted in incorporating in the TIMES model a more accurate approach of electricity generation expansion scenarios, incorporating storage, reserve plants and transmission system expansion in the cost of RES technologies. This led to an updated version of the TIMES model generator code.

7) **Integrating policy instruments into the TIMES Model:** The methodological groundwork is presented in detail for the integration of different types of policy instruments into the energy system model TIMES. This includes the theoretical background on the modelling of policy instruments in energy system models, the explicit modelling of support systems for renewable electricity in TIMES, the representation of emission trading schemes in national energy system models, and the Modelling of regulatory instruments and financial incentive measures in the buildings sector. The detailed description of how to include these options into a TIMES model is an extremely useful guide for all teams who are involved in supporting energy policy.

8) **Linking TIMES models with computational general equilibrium (CGE) models:** There are currently a number of ETSAP contracting parties and others developing methodologies to improve the linking of energy systems models to economic models in order to i) provide feedback to the economic drivers and ii) to determine the economic impacts of different energy scenarios. While this work is largely taking place within individual countries in isolation, this project brought together the different groups active in this area in order to exchange views on methodology, experiences with linking, to compare results and to provide guidance on best practice for other countries who may wish to work on this topic.

Overall, ETSAP tools have been used in modelling activities at different levels of geographical disaggregation. They include Global Models, like the IEA Energy Technology Perspective (ETP) model, the original TIMES Integrated Assessment Model (TIAM), several derived TIAM models from different modelling teams, the Global TIMES Model of the European Fusion Development Agreement (EFDA), the TIMES G5 model and the Global Multi-regional MARKAL Model (GMM). Regional Models like the Pan-European TIMES model, as well as MARKAL-TIMES Models for Europe, Asia and North America. A large number of applications from National Models have been developed in 32 countries. Applications of Sub-National Models have been developed for Western China, Reunion Island (France), Lombardy (Italy), Pavia (Italy), Southwest region (Sweden) and Kathmandu Valley (Nepal). Finally, Local Models were developed for rural areas and cities in Austria and Germany, as well as other local studies in rural areas such as Val d'Agri in Italy, other bigger cities such as Madrid (Spain), Beijing, Guangdong and Shanghai (China) and New York City (United States).

#### *The IEA Energy Technology Perspective (ETP) model.*

The ETP analysis is based on a bottom-up TIMES model that uses cost optimisation to identify least-cost mixes of energy technologies and fuels to meet energy demand, given constraints such as the availability of natural resources. Covering 28 world regions, the model permits the analysis of fuel and technology choices throughout the energy system. It has been developed over several years and used in many analyses of the global energy sector. The ETP-TIMES model is supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors.

#### *The original TIMES Integrated Assessment Model (TIAM)*

TIMES (The Integrated MARKAL-EFOM System) was conceived as a descendent of the MARKAL and EFOM paradigms, to which several new features were added to extend its functionalities and its applicability to the exploration of energy systems and the analysis of energy and environmental policies. The starting version of the global model was developed by the Canadian team – Richard Loulou, Maryse Labriet, Amit Kanudia – while working at GERAD (1999-2000). The seed of TIAM was embodied in the initial version of the global models developed by US-EIA (SAGE), IEA (ETP) and EFDA. These models cover 15 regions; 2100 is the time horizon. The following new features have been added to TIMES: linearised climate equations; multi-stage stochastic programming; new formulation for the forcing equation (linear approximation of forcing), allowing greater flexibility and power to the ETSAP-TIAM; and the possibility of binding each and every component of the cost objective function. Extensive testing of TIAM was done in 2008-2009, through more than 100 runs of the model, as part of REACCESS project, but also as part of several other EC sponsored projects (TOCSIN, PLANETS) and other projects sponsored by the French Government, by ETSAP, and by the partners' own funds. These projects also contributed to make desirable changes and additions to the already extensive TIAM database. The resulting 16 region TIAM model, has become the standard TIAM version since March 2009. The TIMES model and its ETSAP-TIAM incarnations are the result of a multiyear multi-partner effort, resulting in a set of tools for the analysis of long term energy and emission issues based on techno-economics. The outcomes of many studies using the original TIAM model were already published in peer-reviewed journals, research reports and conference proceedings. Some examples are summarized in this section:

- How crucial is cooperation in mitigating world climate? In order to study the conditions for a World self-enforcing agreement on climate change, we model cooperative and non-cooperative

World climate strategies with an integrated version of the 15-region techno-economic MARKAL model in which abatement costs and climate related damages are both included.

- Uncertainty and the role of hedging strategies for climate mitigation. In this research, we argue that the stochastic programming approach is well adapted to the treatment of major uncertainties, in spite of the limitation inherent to this technique due to increased model size when many outcomes are modeled. The article presents methodological details of the modeling approach, and uses realistic instances of the ETSAP-TIAM model to illustrate the technique and to analyze the resulting hedging strategies.
- Alternative climate targets under differentiated cooperation regimes. This article analyzes the feasibility of attaining a variety of climate targets during the 21st century, under alternative cooperation regimes by groups of countries simulated via the ETSAP-TIAM technology based, integrated assessment model.
- OPEC oil strategies in a climate regime. This paper presents an analysis of the optimal oil production quotas of OPEC under a worldwide climate regime imposing a limitation on the radiative forcing. The analysis is conducted using a multi-region detailed energy-economy-environment bottom-up model (TIAM) where the demand laws for oil and its substitutes are implicitly defined as the result of a global supply-demand equilibrium in the world energy system, including the trading of energy forms and emission permits.
- Coupling bottom-up and top-down models to investigate cooperative climate policies. In order to assess the cooperation between industrialized and developing countries in the design of a comprehensive worldwide climate policy to limit the global long-term temperature increase to 2°C, we developed an iterative procedure to link the global technology-rich optimization energy model TIAM and the global general equilibrium model GEMINI-E3.
- Coupling Bottom-up and Top-down Models to Investigate Uncertainties. In this paper, a dual approach is proposed, based on the combined use of stochastic programming in TIAM and Monte Carlo analysis to deal with these uncertainties in a coupled techno-economic analysis. These emission scenarios are then subject to an economic assessment, using a Computable General Equilibrium (CGE) model, GEMINI-E3, specifically designed to assess world climate change policies both at the microeconomic and the macroeconomic levels.
- World climate strategies (SynsCOP15). This research exploits three complementary models – the techno-economic TIMES Integrated Assessment Model (TIAM), the GEMINI-E3 macroeconomic model and the GENIE climate model – in a coordinated manner. This integrated framework is used to represent and evaluate the energy, emissions, technology, economic consequences as well as the climate impacts at global and regional levels of the several policy scenarios as proposed before and after the 15<sup>th</sup> Conference of the Parties (COP15) of the UNFCCC in December 2009.
- Energy security in EU scenarios from the PLANETS (Probabilistic Long-Term Assessment of New Energy Technology Scenarios) project. The project aims to assess the impact of technology development and deployment at world and European levels to foresee the best technological hedging policy in response to future environmental and energy policies.
- Future role of renewable energy technology for climate stabilization. In an effort to address these changes and better understand their impact on the evolution of the global energy system, the Renewable Energy Technology Deployment (RETD) Implementing Agreement of the IEA has defined its own scenario, in collaboration with the ETSAP Implementing Agreement. This report presents the results of that work. The RETD ACES Scenario was modeled using the ETSAP-TIAM3 model.

- The Role of Renewable Energies in Global Scenarios. This paper aims to test the ETSAP-TIAM global energy system model and to try out how far it can go towards a global 100% renewable energy system with the existing model database. Existing analysis with TIAM shows different ways of reaching the 2 °C target and also how uncertainty on different factors influences the optimal solution.
- Non-fossil energy technologies in 2050 and beyond. In facing energy security challenges the EU has in recent years adopted a fairly ambitious energy and climate change policy. These targets will require drastic changes in the energy systems of all countries in both the short and the long term. The scenarios for the EU27 countries plus Norway, Switzerland and Iceland (EU27+3) were examined using the global energy system model TIAM-World.
- GHG mitigation targets and potentials in large emerging economies. The outcome of the UN climate change negotiations at the COP15 in December 2009 was the Copenhagen Accord, which countries voluntarily can acknowledge alongside supplying their voluntary actions combating climate change. On this background, this paper intends to analyse the pledges made by large emerging economies regarding their GHG-emission reductions in 2020 in light of their estimated potentials and costs for the same, both looking at existing national and international literature and presenting new results from the global ETSAP-TIMES Integrated Assessment Model (TIAM).
- Reinforcing the EU dialogue with developing countries on climate change mitigation. The FP6 TOCSIN project has investigated the strategic dimensions of RD&D cooperation and the challenge of creating incentives to encourage the participation of developing countries in post-2012 GHG emissions reduction strategies and technological cooperation. We investigated the possibility and consequences of a 3.5 W/m<sup>2</sup> radiative forcing scenario.
- Meeting global GHG emissions reduction targets: EMF24 scenarios. This presentation introduces sample of results of global GHG emissions reduction targets from the TIAM model in the EMF24 analysis framework: Technology Strategies for Achieving Climate Policy Objectives.
- A Robust Optimization Approach to Design a Robust European Energy Supply. The purpose of this article is to formulate a simplified version of the above issue that mainly addresses long-term uncertainties. The formulation is done via a version of the TIAM-WORLD Integrated Model, modified to implement the approach of robust optimization. We apply the approach to improve the security of supply to the European Energy system.
- Climate mitigation under an uncertain technology future. This paper explores the impacts of long-term technology and climate uncertainties on the optimal evolution of the World energy system. Stochastic programming with the TIAM-World model is used for a parametric analysis of hedging strategies, varying the probabilities associated to each of two contrasted technology outlooks.
- A global renewable energy system. This paper aims to test the ETSAP-TIAM global energy system model and to try out how far it can go towards a global 100% renewable energy system with the existing model database. This will show where limits in global resources are met and where limits in the data fed to the model until now are met.
- Exploring the uncertainty around potential shale gas development. This paper aims to quantitatively explore the uncertainty around the global potential of shale gas development and its possible impacts, using a multi-regional energy system model, TIAM (TIMES Integrated Assessment Model).
- Feasibility to implement EU Energy and Climate Package targets. The aim of the paper is to analyse the feasibility of EU to implement 20/20/20 targets under the various international GHG trading regimes. GHG trading regimes were addressed by developing 10 energy scenarios until

2020 for EU by applying several energy modelling tools ranging from top down partial equilibrium to detailed technology based bottom up models.

- Exploration of regional burden-sharing regimes for the allocation of greenhouse gas emission reduction obligations needed to reach a 2°C long-term global climate change control target by performing an integrated energy-economy-climate assessment with the bottom-up TIAM-ECN model.
- Analysis of energy and greenhouse gas emission pathways for Latin America under different baseline scenarios and climate policy scenarios performed in the CLIMACAP project, which includes among other models TIAM-ECN and TIAM-WORLD

Other TIAM models were developed from the original ETSAP-TIAM model by different research groups; examples of studies using these different versions of TIAM are also presented.

#### *The original TIMES Integrated Assessment Model (TIAM)*

In the VTT version an additional region for Finland has also been tentatively implemented, and another new region for the other Nordic countries is under preparation. VTT has completed some enhancements to the TIAM model, in particular related to the modelling of GHG emissions and their climate change impacts. Studies with the TIAM-VTT model are:

- Global scenarios for effective climate change mitigation. The achievement possibilities of the EU 2°C climate target have been assessed with the ETSAP TIAM global energy systems model. Cost-effective global and regional mitigation scenarios of carbon dioxide, methane, nitrous oxide and F-gases were calculated with alternative assumptions on emissions trading.
- The role of CCS and renewables in global climate scenarios. The need for global and regional clean energy technology investments by 2050 are evaluated in climate policy scenarios with the bottom-up global ETSAP TIAM energy system model. The impacts of the assumed regional CO<sub>2</sub> storage potentials as well as bioenergy and wind power potentials on investments are also investigated by sensitivity analysis.
- Energy security in EU demand and supply scenarios. This work focuses on energy security in EU demand and supply scenarios of renewables and the dependence on Russian energy.
- Effort-sharing and coalitions in global climate scenarios. The post-2012 climate policy framework needs a global commitment to deep GHG emission cuts. This paper analyses reaching ambitious emission targets up to 2050 and how the economic burden from mitigation efforts could be equitably shared between countries. Being simple and transparent, the EVOC tool of Ecofys GmbH was used for calculating emission allocations, while and ETSAP-TIAM, a sophisticated but complex global energy system model of the TIMES family was used for creating the scenarios.
- The impact of residential, commercial, and transport energy demand uncertainties in Asia. In this paper, a sensitivity analysis has been carried out to study the impact of higher rates of energy demand growths in the non-OECD Asia on global mitigation costs. The long term energy and emission scenarios for China, India and South-East Asia have been contributed as a part of Asian Modeling Exercise (AME). The scenarios presented have been modeled by using a global TIMES-VTT energy system model.

#### *The derived TIAM-FR Model*

Some improvements investigated in TIAM-FR include modification of demand (rivers, modification in carbon storage potential (deep ocean and coalbed methane recovery), implementation of new technologies (fossil power plants with CCS, coal-biomass co-

firing power plants with and without CCS, CHP), modification of costs (bioplants with CCS, geothermal new technologies). Studies with the TIAM-VTT model are:

- Global versus regional climate policies and technological limits. The aim of these studies is to discuss the long-term analysis of post-Kyoto commitments issued from Copenhagen/Cancun Agreements, with the modelling tool ETSAP-TIAM-FR. More precisely, we investigate different coordination schemes for regions pledging in CO<sub>2</sub> mitigation targets during the period 2005-2050. This paper compares global efforts of CO<sub>2</sub> mitigation with regional climate policies expressed through targets pledged to UNFCCC and, finally discusses the impact of the development of CO<sub>2</sub> storage technologies in the energy mix in 2050.
- Implementing water allocation in the TIAM-FR energy model. In the context of a growing world population, leading to increasing demands and competition for water and energy, it is vital to develop long-term strategic policies that consider the interconnections between the water and energy sectors. The main aim of this study is to show how issues concerning water consumption and water withdrawal can be incorporated into energy system models, thereby facilitating discussions about possible futures concerning both aspects. Water commodities and technologies in the energy model TIAM-FR have been implemented in two steps, in order to study separately the two parts of the water-energy nexus.
- Global and regional potential for bioelectricity with carbon capture and storage. The aim of this study is to assess the global and regional potential of BECCS (biomass energy with carbon capture and storage technology) up to 2050 in power generation. This analysis is conducted using the multiregional TIAM-FR optimization model.
- Fukushima's impact on the European power sector. This study evaluates the impact of nuclear power reduction in Europe on the electricity mix under carbon emission reduction scenarios while considering the availability of carbon capture and storage technological options (CCS). The potential cost of carbon reduction is also addressed using the bottom-up optimization model TIAM-FR.

#### *The derived TIAM-ECN Model*

Here is a list of major developments related to TIAM-ECN between 2009-2010: extensive changes have been made to the structure of a number of sectors (e.g. oil, coal and gas production, renewable resources as well as the residential and commercial end-use sectors), modeling of emissions has been improved by adding CO<sub>2</sub> emissions from deforestation and N<sub>2</sub>O emissions from agriculture within the explicitly modeled flows, modeling of technology diffusion has been improved both on the level of resource use as well as on the end-use level, review of the technology data for storage type specific, regional storage potentials, review of the data on the power sector, review of the regional potentials for wind and solar energy, review of the transport sector structure and the data for the H<sub>2</sub> production and transport technologies. There is an ongoing activity aiming at updating and improving structurally the modeling of bioenergy resources and potentials. Studies with the TIAM-ECN model are:

- The impact of uncertainty in long-term climate mitigation scenarios. There are large uncertainties concerning the large scale implementation of the CCS technology, one being the regional availability of storage sites for the captured carbon. We approach the issue from an energy system perspective and use an energy system model TIAMEC to study a set of scenarios covering a range of climate targets and technology futures, from two angles; 1) a sensitivity analysis consisting of a number of scenarios that assume perfect foresight for the decision making and 2) using a stochastic programming set-up, which allows the model to consider all included potential future states simultaneously.

- How to decarbonize the transport sector? This article investigates possible evolution pathways for the transport sector during the 21st century, globally and in Europe, under a climate change control scenario. We perform our study with the global bottom-up energy systems model TIAM-ECN, a version of the TIAM model that is broadly used for the purpose of developing energy technology and climate policy scenarios, which we adapted for analyzing in particular the transport sector.
- Potential for renewable energy jobs in the Middle East. Based on employment factors derived from a recent review of publications investigating opportunities for work associated with the diffusion of renewable energy technology, we here present an analysis of the potential for renewable energy jobs in the Middle East. We use energy system optimisation results from the regionally disaggregated TIAM-ECN model as input to our study. This integrated assessment model is utilised to inspect the energy technology requirements for meeting a stringent global climate policy that achieves a stabilisation of greenhouse gas concentrations in the atmosphere with a maximum additional radiative of 2.9W/m<sup>2</sup>.
- The project 'Low climate IMpact scenarios and the Implications of required Tight emission control Strategies' (LIMITS) an assessment of the emissions reductions strategies at the level of the world and the major global economies, and to assess their implementation in terms of Defining the feasibility of low carbon scenarios, Assessing the investment requirements to implement these transformation pathways, quantifying the changes in the energy infrastructure and land use which major and evaluating the linkages of climate policies with other pressing social and environmental issues such as energy security, air pollution and economic development.
- The CLIMACAP-LAMP study delivers improved modelling capacity and policy formulation to enable the development and implementation of low carbon development strategies in Latin America. To allow a detailed analysis of several Latin American countries the standard regional resolution of TIAM has been increased to 20 regions with the main Latin American countries being represented as separate modelling regions. TIAM-ECN has also been used to perform an analysis on GHG emission reductions resulting from energy efficiency improvements under climate policy. Here three carbon tax scenarios are assessed against a business as usual scenario. A general finding is, that energy efficiency improvements deploy even in the absence of climate policy measures. If climate policy is introduced via carbon taxes ranging from 40 to 100 \$ per tonne of CO<sub>2</sub>e in 2030, and kept at these levels afterwards, energy efficiency measures are responsible for 15 to 25% of the total global greenhouse gas emission reductions related to energy and non-energy use until 2050.

#### *The derived TIAM-UCL Model*

The core aim of the Energy Systems research theme in the UKERC II project is developing a global optimisation model to analyse accelerated decarbonisation of the global E3 (energy-environment-economy) system, with a comprehensive investigation of costs and benefits of the different decarbonisation options. This adds to work carried out in UKERC I placing the detailed analysis of the UK in a global context, which was not possible with the UK MARKAL model, the main tool developed under UKERC I. The TIAM-UCL model development has two phases. The major tasks (the first phase) is breaking out UK from the 15 region model and model calibration (calibrating UK and Western Europe regions). Once the 16R TIAM-UCL has been successfully calibrated, the model has been enhanced (the second phase) through technical improvements such as adding new drivers, new resources, climate change policies (cap-and-trade, carbon tax), supply resource cost curves etc. Studies with the TIAM-UCL model are:

- The role of demand reduction in global climate change mitigation. This paper investigates the role of demand reduction in meeting global CO<sub>2</sub> reduction targets using the elastic demand version of the TIAM-UCL global model under different long-term low carbon energy scenarios during 2005-2100.
- Carbon tax vs. cap-and-Trade: Implications on developing countries emissions. This paper investigates the roles of carbon tax and cap-and trade policies to mitigate global CO<sub>2</sub> emissions; these policies are analysed using the 16 Region TIAM-UCL global model.
- Demand, burden sharing and resources. This presentation introduces an analysis of burden sharing agreements for the UK under global decarbonisation trajectories.
- Decarbonising road transport with hydrogen and electricity. This paper develops long-term scenarios by implementing global technology learning endogenously in the TIAM-UCL global energy system model to analyse the role of hydrogen and electricity to decarbonise the transport sector. The analysis uses a multi-cluster global technology learning approach where key components are shared across different vehicle technologies.
- The role of energy-service demand reduction in global climate change mitigation. While efficiency and technology options have been extensively studied within the context of climate change mitigation, this paper addresses the possible role of price-related energy-service demand reduction. For this analysis, the elastic demand version of the TIAM-UCL global energy system model is used in combination with decomposition analysis.

#### *The derived TIAM-IER Model*

Studies with the TIAM-IER model are:

- Interdependencies between market power, resource availability and demand options. This presentation deals with interdependencies between market power, resource availability and demand options. A sensitivity analysis is performed with the soft coupling of TIAM and LOPEX.
- Natural gas supply for Europe. Using the same approach, this presentation concentrates on the natural gas supply for Europe. The main question is : what is the maximum profit of the natural gas exporting countries to Europe ?

#### *The Global TIMES Model of the European Fusion Development Agreement (EFDA)*

The EFDA Times Model (ETM) is a multi-regional, global and long-term energy model of economic equilibrium, responsive to energy technology innovations, domestic and international trade energy policies, climate change mitigation and environment objectives. It has been developed within the European Fusion Development Agreement (EFDA) framework starting in 2004 and forms part of the TIMES family of energy models. In ETM the world is divided into 17 regions linked by energy and emissions permit trading variables. Time horizon will be 2100. Studies with the EFDA model are:

- Revised assessments of the economics of fusion power. A new energy economics model is employed to analyse the potential market performance of fusion power in a range of future energy scenarios and this shows that there can be a significant role for fusion in a future energy market. Possible implications for fusion's role in a future energy market are then explored, using a sophisticated energy scenario tool, known as the EFDA/TIMES model.
- The future role of fusion power under endogenous technological learning. This dissertation addresses the impact of different endogenous learning approaches on the role of fusion power. To broaden the scope of endogenous learning descriptions, new approaches have been developed and implemented in the TIMES model generator.

- An analysis on the future costs of fusion power stations. There have been a wide range of studies of costs, varying primarily in the assumed materials and technology as well as assumptions about the fusion performance in scientific terms. This range is implemented in the EFDA Times Model (ETM) with the early generation plants assumed to be available in 2050, evolving to an advanced, mature plant over the following 30 years.
- Modelling CCS, nuclear fusion, and large-scale district heating. These presentations focus on modelling the infrastructure development for heat recovery from CCS and fusion in EFDA-TIMES and TIAM. CCS can be a driver for the development and expansion of large-scale district heating systems, which are currently widespread in Europe, Korea and China, and with large potentials in North America.
- The role of nuclear energy in long-term climate scenarios. Our objective is to analyze the role of nuclear energy in long-term climate scenarios using the World-TIMES (The Integrated MARKAL-EFOM System) bottom-up model.
- Global transportation scenarios in a multiregional energy model. The aim of this study is to assess the potential impact of the transportation sector on the role of fusion power in the energy system of the 21st century. For the present study a new transportation module has been linked to the EFDA-TIMES framework in order to arrive at a consistent projection of future transportation demands.

#### *The TIMES G5 model*

TIMES-G5 is a five-region, bottom-up, and process-analytic energy system model, developed at the Institute of Energy Economics and Rational Use of Energy (IER), University of Stuttgart in Germany, for the analysis and projection of long-term energy futures on a national, regional, and global basis. The TIMES-G5 model disaggregates the globe into 25 European nations (EU25), the rest of the OECD countries (R\_OECD), the rest of the non-OECD countries (R\_NOECD), India, and China, as five separate regions. The model includes the modelling horizon from 1990 to 2100, containing 19 periods having unequal time spans of 5, 8, and 10 years, and six smallest time segments (i.e., day-night basis for three seasons). Studies with the TIMES G5 model are:

- Uncertainty in the learning rates of energy technologies. This study examines the uncertainty in learning rates (LRs) of some energy technologies under endogenous global learning implementation and presents a floor-cost modeling procedure to systematically regulate the uncertainty in LRs of energy technologies. This work is executed using a multi-regional and long-horizon energy system model based on “TIMES” framework.
- Endogenous implementation of technology gap. Together, three methodologies have been developed in this study. The first methodology is global learning without a technology gap. The other two methodologies are about global learning with technology gaps, in the form of the knowledge deficit and time lag concepts. The methodologies are examined inside a multi-regional energy system model (TIMES) to understand the behavior of technologies, subject to uncertainty of learning rates.
- Energy and emissions forecast of China over a long-time horizon. This paper seeks to address those gaps on sectoral energy demands and emissions on long term by following a two-stage approach. It develops key energy indicators on useful energy demand, transport mobility and end use fuel demand for various sectors. The main drivers of these indicators are socio-economic parameters. The indicators are used to project energy service demands and emissions forward for China in TIMES G5 model at least cost approach.
- Prospects of India’s energy and emissions for a long time frame. This study developed key indicators for useful- energy demand for end-use sectors such as industry, commerce, and

residence. Key indicators for transport sector and non-energy use sectors were developed on transport mobility demand and end-use fuel demand. This work was conducted in a linear programmed (LP) TIMES G5 model on TIMES modeling framework for model horizon of 1990–2100.

#### *The Global Multi-regional MARKAL Model (GMM)*

GMM belongs to the MARKAL (MARKet ALlocation) family of models. GMM was further enhanced starting from the original version. Model improvements dealt with an extension of the number of world regions, the representation of alternative fuel chains (hydrogen and biofuels) and the personal transport sector, as well as the representation of endogenous technological learning (ETL). Studies with the GMM model are:

- An energy-economic scenario analysis of alternative fuels for personal transport. This paper deals with the long-term prospects of alternative fuels in global personal transport. It aims at assessing key drivers and key bottlenecks for their deployment, focusing particularly on the role of biofuels and hydrogen in meeting climate policy objectives. The analysis is pursued using the Global Multi-regional MARKAL model (GMM), linked to the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC).
- Supporting hydrogen based transportation. In this article we analyze the potential influence of selected factors for successful market penetration of hydrogen fuel cell vehicles in hydrogen based private transportation economy. Using a world scale, full energy system, bottom-up, optimization model (Global MARKAL Model—GMM), we address the possibility of supporting the fuel cell vehicle technology to become competitive in the markets.
- Conditions for the successful deployment of electric vehicles. In the study, we analyse scenarios of car technology deployment and the global energy system using the Global Multi-regional MARKAL (GMM) cost optimisation model. We consider some of the conditions under which new drivetrain technologies, particularly battery electric vehicles (BEVs), may be more cost competitive under different hypothetical states of the world.
- Emissions of anthropogenic hydrogen to the atmosphere during the potential transition to an increasingly H<sub>2</sub>-intensive economy. In this study, current and future anthropogenic hydrogen (H<sub>2</sub>) emissions to the atmosphere from technological processes are assessed. The Global Multi-regional MARKAL model (GMM) is a technology-oriented, bottom-up, least-cost optimization model that uses perfect foresight. Vehicle fleet scenarios were assessed to account for the inherent variability of H<sub>2</sub> exhaust emissions according to vehicle technology and world region over time.

#### *Regional Models*

##### *The Pan-European TIMES model*

This model results from the outcome of a number of projects over the last years. First, TIMES was used in the framework of the NEEDS (New Energy Externalities Developments for Sustainability) project (2004-2008) which was funded by the 6th Framework Programme, to create a model for EU-27, Iceland, Norway and Switzerland. In this model the energy systems of each one of the thirty countries are modelled separately in detail. This framework is completed by integrating LCA and External Cost into an Energy Model. Then, this model has been used as a starting point for building the RES2020 Pan-European TIMES (PET) model, and the models in the REACCESS project and REALISEGRID projects. All these models are characterised by a multi-period structure (base-year: 2000, last milestone year: 2050).

The RES2020 application of the model focused on the analysis of the renewable energy targets in EU27. This led to a more detailed representation of renewable energy sources and four alternative scenarios for achieving the targets for renewables and GHG emissions in 2020: a more detailed analysis of the availability factors for wind turbines, new decentralised electricity production technologies and further enhancements in the representation of biomass and biofuels, for instance on the differentiation of crop types and waste and residues sources to be used for the production of biofuels.

In the REACCESS project the PET model was recalibrated in detail to reproduce the 2005 statistics as a base year. In the framework of this project the PET model run together with the TIAM model (16 regions world model) and the REACCESS Corridor Model (RECOR) that link the two, in order to study the effects on the energy system of EU competing with the Rest of the World for scarce and uncertain supplies of energy sources. The PET model has 30 regions, the TIAM model 15 regions (16 minus EU+), so that the resulting integrated model has 45 regions, a heretofore unheard-of size for any technology-based energy model.

The REALISEGRID FP7 project, aims at developing a set of criteria, metrics, methods and tools to assess how the transmission infrastructure should be optimally developed to support the achievement of a reliable, competitive and sustainable electricity supply in the EU. In the framework of this project, four scenarios have been implemented with a TIMES model which includes EU27, Iceland, Switzerland, Norway and the Western Balkan region (EU27++). The geographical scope of the model has been extended to the Western Balkan adding to the model six new regions (Albania, Bosnia and Herzegovina, Croatia, FYR of Macedonia, Montenegro and Serbia). The representation of the endogenous electricity and gas trade across European countries was improved in the framework of this project, by including more precise information on the efficiency and costs of grid and trade infrastructure and on other points.

Studies using the Pan-European TIMES model are:

- Technologies, fuels and sector analysis in climate and energy policy scenarios for Europe. Stabilising the concentration of CO<sub>2</sub> in the atmosphere at a level of 450 ppm in order to keep global temperature increase below 2°C requires an ambitious climate policy. This study analyses the role of different technologies in the EU-27 with regard to efficiency improvements, fuel switching and energy saving measures under such a climate policy target.
- Future European gas supply. A steady increase of natural gas demand can be observed in Europe over the last decades. With the help of a cost-minimization model of the European gas supply system, the gas flows and the infrastructure capacity development up to the year 2030 are analyzed.
- Evaluation of the RES Directives implementation in EU27 for 2020 (RES2020 Project). The project aims at analysing the present situation in the RES implementation, defining future options for policies and measures, calculating concrete targets for the RES contribution that can be achieved by the implementation of these options and finally examining the implications of the achievement of these targets to the European Economy. A number of future options for policies and measures were defined and studied with the use of the TIMES energy systems analysis model, in order to analyze the quantitative effects on the RES development.

- EU 20-20 policy implications on the EU energy system. Presentations focusing on the evaluation of the EU Energy and Climate Package as proposed by the Commission in January 2008 by studying the impacts on the EU energy system.
- Energy corridors and security of supply in Europe (REACCESS Project). An example of policy assessment within the REACCESS project is the analysis of the interplay between the global goal of mitigating climate changes and the European goal of reducing dependence and vulnerability of the energy system.
- Transmission infrastructure development to support sustainable electricity supply. The REALISEGRID FP7 project aims at developing a set of criteria, metrics, methods and tools to assess how the transmission infrastructure should be optimally developed to support the achievement of a reliable, competitive and sustainable electricity supply in the EU.
- Contribution of alternative fuels and power trains for climate targets in the EU27. Within this study, a technology oriented, linear optimization model of the EU energy system is applied in order to analyze the cost optimal contribution of the transport sector to the achievement of GHG reduction targets until 2050. A special focus lies on the analysis of the penetration of alternative fuels and vehicle technologies under ambitious GHG reduction targets.
- Perspectives of CCS power plants in Europe: Under different climate policy regimes. The target of this work is to analyse capture economics of CCS power plants and their contribution to GHG reduction in the European energy system under climate policy conditions.
- Perspectives of CCS power plants in Europe: Under uncertain power plant parameters. The perspectives of power plants with CCS in Europe are analysed with the Pan-European TIMES model (TIMES PanEU) incorporating technical and economic uncertainties of CCS technologies by the use of the Parametric Programming routine.
- Technology analysis of emission reduction potentials in the industrial sector in the EU-27. This study analyses the emission reduction potentials of the industrial sector at different carbon prices.
- Effect of a White Certificate Trading Scheme in the EU-27. The improvement of energy efficiency and thereby a reduction of energy consumption is one of the key goals of the energy and climate policy strategy of the European Union as stated in their EU 20/20/20 targets. One way of achieving this reduction target could be the implementation of a European wide white certificate trading scheme. This study examines the effect of a restriction on the total consumption of either final or primary energy on the European energy system.
- Analysis of potentials and costs of CO<sub>2</sub> storage in the Utsira aquifer in the North Sea. The FENCO ERA-NET project "Analysis of potentials and costs of storage of CO<sub>2</sub> in the Utsira aquifer in the North Sea" has studied the national and regional cost-effectiveness of CCS in five countries of North West Europe. The focus was on the feasibility of storing CO<sub>2</sub> into the Utsira formation as part of national or regional CO<sub>2</sub> mitigation strategies. The project have used the Pan European TIMES (PET) model and national MARKAL/TIMES models for the United Kingdom, the Netherlands, Germany, Denmark and Norway.
- Renewable heat: A policy and techno-economic assessment of EU2020 targets. We created cost curves for the implementation of renewable energy technologies in Flanders, for electricity production as well as for heat production. This presentation focuses on the status of renewable heat in the NREAP's, the Flemish renewables cost curve and different subsidy mechanisms for renewable heat.
- Multivariate techniques for the analysis of partial equilibrium energy models results. In this paper, multivariate statistical techniques are used to analyse the data output of partial

equilibrium energy models developed in the framework of the NEEDS Project, with the aim of emphasising their informational content and reducing redundancies.

- A Comparison of national CCS strategies for Northwest Europe. This article shows key results of a research project aiming to assess the potentials and costs of storing CO<sub>2</sub> in the Utsira formation for the time period 2015-2050. Countries included in the analysis are Denmark, Germany, Norway, the Netherlands and the United Kingdom. The starting point of the analysis are the national MARKAL and TIMES models developed for each country together with the 27 region Pan European TIMES model (PET).
- A comparison on the cost-effectiveness of storing CO<sub>2</sub> in the Utsira formation. This paper compares the potentially key role of CCS within cost-optimizing energy systems modelling at the national level (ensuring country-specific technical, economic and policy detail), and the regional level (ensuring transboundary electricity and CO<sub>2</sub> trade).
- Linking least-cost energy system costs models with MCA. In this respect, aim of this paper is to combine technoeconomic modeling and MCA approaches in a general analytical framework incorporating multiple aspects. The methodology we employ in this paper is based on a multicriteria decisions support tool called ECPI (Energy and Climate Policy Interactions decisions support tool). The input for the ECPI tool originates from the technoeconomic model TIMES, which provides quantitative results of these policies towards achieving the targets.

#### *The JRC-EU-TIMES model*

The JRC-EU-TIMES model is one of the models currently pursued by the European Commission through its Joint Research Centre (JRC). It has been developed over the last years based on earlier generations of pan-European TIMES models that have been developed in several EU funded projects, such as NEEDS, RES2020, REALISEGRID, and REACCESS. The JRC-EU-TIMES model features updated information on renewable energy potentials for EU member States, as well as for key low-carbon technologies both in the supply and demand sectors, based on the JRC Energy Technology Reference Indicators. In addition to the EU28 member States, Iceland, Norway and Switzerland, the model is also geared to include the Balkans. Its current version underwent a successful validation process in 2013 with the involvement of external modellers and representatives of several Commission services.

The model is designed for analysing the role of energy technologies and their innovation for meeting Europe's energy and climate change related policy objectives. It models technology market uptake and interactions with the energy infrastructure including storage options in an energy systems perspective. It is a relevant tool to support impact assessment studies in the energy policy field that require quantitative modelling at an energy system level with a high technology detail.

Studies using the JRC-EU-TIMES model include the assessment of the role of cost and efficiency in influencing the early competitiveness and the large scale deployment of key low-carbon technologies, with a specific focus on key innovative technologies, identified as important in the Strategic Energy Technology Plan of the European Commission (SET Plan) and the related integrated roadmap. The JRC-EU-TIMES model will also be used by the European Commission to identify the potential contribution of key technologies in the future energy mix, and deriving from it social, economic, environmental impacts, the impact on industrial competitiveness, growth and job creation, regional development, ultimately assessing the effectiveness of energy research and innovation in contributing to meeting relevant policy objectives of the EU.

### *MARKAL Models for Europe*

Studies using MARKAL Models for Europe are:

- Exploring the implications of an EU-wide 'Tradable White Certificate' scheme. Based on three evaluation criteria (cost-effectiveness, environmental effectiveness and distributional equity) this paper analyses the implications of implementing a European-wide 'Tradable White Certificate' (TWC) scheme targeting the household and commercial sectors. MARKAL is applied to a database that depicts the reference energy system of Western Europe (EU15+).
- Assessment of the European energy conversion sector under climate change scenarios. In this dissertation, the European energy conversion sector and with special focus, the electricity generation sector were analyzed regarding the impacts of climate change on the energy infrastructure, and possible GHG emission reduction pathways, in respect of costs, and energy system parameters, such as technology choices and capacity installation. EuroMM was developed in the course of a dissertation at the Paul Scherrer Institute, in context of the European ADAM project, where it was used to analyze climate change adaptation and mitigation scenarios for the European energy conversion sector. EuroMM disaggregates Europe (i.e., EU-27 plus Norway and Switzerland) into 18 regions.

### *MARKAL Models for Asia*

Studies using MARKAL Models for Asia are:

- Energy security in the Greater Mekong Sub-region Countries. The paper evaluates effects of energy resource development within the Greater Mekong Sub-region (GMS) on energy supply mix, energy system cost, energy security and environment during 2000–2035. A MARKAL-based integrated energy system model of the five GMS countries was developed to examine benefits of regional energy resource development for meeting the energy demand of these countries (Cambodia, Laos, Myanmar, Thailand and Vietnam).
- Effects of cross-border power trade between Laos and Thailand. This paper analyzed the effects of hydropower development in Laos and power trade between Laos and Thailand on economy wide, energy resource mix, power generation capacity mix, energy system cost, environment, as well as, energy security. A MARKAL-based model for an integrated energy system of Laos and Thailand was developed to assess the effects of energy resource development and trade to meet the national energy demands of the two countries.
- Clean energy in the South East Asian Nations countries. This paper focuses on energy system development of the three largest Association of South East Asian Nations (ASEAN) countries: Indonesia, Philippines and Vietnam. This paper examines and quantifies the role of clean and advanced energy technologies for efficient local resource exploitation and improving energy security and environmental conditions. The main focus is on the power sector.
- The ESMOPO (Europe – South-east Asian Energy Modelling and Policy Programme) project. The ESMOPO (2005-2007) is co-financed by the European Union through EC-ASEAN Energy Facility Program. The project considers three ASEAN countries: Indonesia, Philippines and Vietnam. The project aims at developing country specific energy system models in the MARKAL modelling framework in order to identify country specific appropriate energy technologies and to quantify their implications in terms of energy savings, fuel substitution, investment and pollutions avoided. The main focus is on renewable and advanced fossil technologies.
- The POEM modelling framework. The main focus of the study is on India and China. The primary objective is to develop a portfolio of policy options including both international and national policies as well as institutional frameworks for international cooperation for these two emerging economies to engage them in climate protection measures under a post-2012 regime. The methodology involves the application of integrated modelling framework, on a soft-linking

approach primarily, with common assumptions, iterative work procedure and a focus on co-benefits (local environment, health and energy security).

#### *MARKAL-TIMES Models for North America*

Studies using MARKAL-TIMES Models for North America are:

- Overview of the unconventional oil production up to 2030 using TIMES-Canada. Our main objective in this presentation is to analyze the evolution of conventional and unconventional oil production and exportations on the 2030 horizon in Canada, with their associated costs and GHG emissions. The development of the oil sector is analyzed under three socio-economic growth scenarios using the new energy model TIMES-Canada. The study is part of a more general research project realized with strong support and collaboration from the Office of Energy Research and Development (OERD) of Natural Resources Canada. TIMES-Canada covers the energy system of the 13 Canadian provinces and territories having their own reference energy system (RES), but linked together through energy, material and emission flows.
- Electrification of the Canadian road transportation sector. Using a newly developed bottom-up model of the entire Canadian energy system (TIMES-Canada) to assess potentials for electrification of the road transport sector. Analysed an energy policy scenario imposing targets for electric vehicle penetration and a climate policy scenario imposing targets for greenhouse gas emission reduction.
- Multi pollutant studies: Integrating climate and air quality planning in Maryland. This report was undertaken by the Northeast States for Coordinated Air Use Management (NESCAUM) and the Maryland Department of the Environment (MDE). To assist states in moving to an integrated multi-pollutant planning approach, NESCAUM developed a reference case scenario that accounted for Maryland's Renewable Portfolio Standards (RPS). NESCAUM then provided preliminary analysis of implementing the Regional Greenhouse Gas Initiative (RGGI) program as described in the Maryland Healthy Air Act, and the Maryland Clean Cars Act. Using outputs from NE-MARKAL, NESCAUM then conducted a preliminary health benefits assessment using the Co-Benefits Risk Assessment Model (COBRA).
- Exploring the benefits of insulation investment and home weatherization. This presentation explores the potential for energy savings and economic and environmental benefits in residential heating sector in New England using NE-MARKAL. The unconstrained case is a policy case representing the availability of a low interest loan for insulation purchases.
- Multi pollutant studies: A sensitivity analysis of transportation policy. This analysis first examines the multi pollutant implications of policy scenarios being considered in the northeast such as LDV efficiency standards, technology mandates and incentives and second performs a robust sensitivity analysis where 500 to 1000 model runs were performed.

#### *MARKAL-TIMES Models for West Mediterranean Area*

Studies using MARKAL-TIMES Models for West Mediterranean Area are:

- Integrated infrastructure for CO<sub>2</sub> transport and storage in the west Mediterranean. COMET - Integrated infrastructure for CO<sub>2</sub> transport and storage in the west Mediterranean- is a joint research Project cofinanced by the European Seventh Framework Programme (FP7), which started on January 2010. In this context, COMET focuses on assessing CO<sub>2</sub> transport and storage in a geographical area that until now has received little attention: the West Mediterranean area, specifically, the Iberian Peninsula and Morocco.
- CCS infrastructure development scenarios for the integrated Iberian Peninsula and Morocco energy system. This paper briefly illustrates a method to represent national energy systems and the geographical details of CCS infrastructures in the same technical-economic model. In the

MARKAL-TIMES modeling framework a model of Morocco, Portugal and Spain with both spatial and temporal details has been implemented. As a function of assumptions on the development to 2050 of mitigation levels, economic growth and CO2 capture-transport storage characteristics, dozens of scenarios were prepared with the TIMES-COMET model.

- Region specific challenges of a CO2 pipeline infrastructure in the West Mediterranean area. This paper presents results of potential CCS infrastructures in the West Mediterranean region including trajectories for CO2 pipelines. The preliminary results are generated with a combination of geographical (GIS) and partial equilibrium optimization modelling (MARKAL/TIMES-COMET).
- Planning CCS Development in the West Mediterranean. The EU FP7 COMET project aimed to pave the road towards CCS development in the West Mediterranean (Portugal, Spain and Morocco). This paper provides the main highlights of the work conducted within COMET. The project addressed the temporal and spatial aspects of the development of the energy sector and other industrial activities in relation with CCS.
- Prospective scenarios for the adoption of CCS technologies in the Iberian Peninsula. Using the TIMES\_IBERIA optimization model, this paper investigates the contribution of several factors (i.e. climate policy, RES and CCS cost curves, and gas prices) that might promote or constrain the adoption of CCS technologies as part of a portfolio for reducing CO2 emissions from the power generation and industrial sector, in the medium–long term (2020–2050), within the Iberian Peninsula energy system.

#### *National, Sub-National, Local Models*

There is a large number of publications related to different applications of national models. In Annex II a list of the topics covered in 32 countries using the MARKAL/TIMES modelling tools over the period 2009-2014 is presented together with a basic description of each application.

## 10. PRESENTATION OF ETSAP PARTICIPANTS ACTIVITIES

The following table presents the different publications, presentations, reports etc that have been published in the period 2009-2014 from the ETSAP contracting parties and the users of the ETSAP modelling tools worldwide. The geographical level of disaggregation in the study

#### **Type of reference**

0 = Online information

1 = Presentations

2 = Research papers/reports (or long abstract)

3 = Peer-review articles

4 = Books or book chapters

5 = Ph.D. Thesis

Reference	Type
<b>Global - ETP</b>	
IEA - International Energy Agency Energy. (2010). Energy Technology Perspectives: Scenarios & Strategies to 2050. Paris, France, 710 p.	4
IEA (2012). Energy Technology Perspectives 2012: Pathways to a Cleaner Energy System, OECD/IEA, Paris.	4
IEA (2014). Energy Technology Perspectives 2014: Harnessing Electricity's Potential, OECD/IEA, Paris.	4
IEA/Nordic Energy Research (NER) (2013). Nordic Energy Technology Perspectives: Pathways to a Carbon Neutral Energy Future, OECD/IEA, Paris.	
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Bennaceur K. Gielen D. (2009) Energy Technology Modelling of Major Carbon Abatement Options. Energy Proce.dia 1: 4297–4306.	3
Remme U. (2010). Energy Technology Perspectives 2010. OECD/IEA. Proceedings of the ETSAP workshop, Cork (Ireland), November 24, 2010.	1
<b>Global - TIAM</b>	
<b>ETSAP - TIAM</b>	
Loulou R. Labriet M. (2008). ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. Computational Management Science, Special issue "Managing Energy and the Environment", Vol. 5, Issue 1, pp.7-40.	3
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Loulou R. Labriet M. Haurie A. Kanudia A. (2008). OPEC Oil Pricing Strategies in a Climate Regime, a Two-Level Optimization Approach in an Integrated Assessment. Submitted to Environmental Modeling and Assessment.	3
Loulou R. Labriet M. Kanudia A. (2008). OPEC Oil Strategies in a Climate Regime. Kanlo Consultants, France. McGill University, Canada. CIEMAT, Spain. KanORS Consulting, India. Proceedings of the International Energy Workshop (IEW), Paris (France), June 30 - July 2, 2008.	1
Labriet M. Drouet L. Vielle M. Haurie A. Kanudia A. Loulou R. (2010). Coupled bottom-up and top-down modelling to investigate cooperative climate policies. Research report. Cahier du GERAD G2010-30, 23 p. Submitted to Annals of Operation Research.	2
Labriet M. Loulou R. Vielle M. Drouet L. (2008). Coupling TIAM and GEMINI-E3. Kanlo Consultants, France. CIEMAT, Spain. EPFL. Ordecys, Switzerland. Proceedings of the ETSAP workshop, Nice (France), December 15-17, 2008.	1
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Babonneau F. Haurie A. Loulou R. Vielle M. (2010). Stochastic Analysis of Climate Policies: a Combined Monte-Carlo and Stochastic Programming Approach. Ordecys, Switzerland. Kanlo Consultants, France. Economics and Environmental Management Laboratory, Swiss Federal Institute of Technology at Lausanne, Switzerland. Toulouse School of Economics (LERNA). Proceedings of the International Energy Workshop (IEW), Stockholm (Sweden), June 21-23, 2010.	2
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PLANETS (2008). Report on model updating and enhancing. WP1, Deliverable 4. Project No 211859 Probabilistic Long-Term Assessment of New Energy technology Scenarios (PLANETS), 73 p. Project funded by the European Commission under the 7 <sup>th</sup> Framework Programme	2
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## ANNEX I. CONTRACTING PARTIES

The Contracting Parties which are Participants in this Implementing Agreement are the following:

<b>Country</b>	<b>IA Date of signature</b>	<b>Contracting Party</b>	<b>Participating till / from Annex:</b>
Belgium	08.09.81	The Government	Current
Canada	07.07.82	NRCan	Until Annex XII
Denmark	04.12.80	DEA	Current
European Commission	11.01.82	Commission	Current
Finland	09.01.02	TEKES	Current
France	29.01.08	ADEME/EMPT	/XI Current
Germany	13.11.80	IER	Current
Greece	01.12.80	CRES	Current
Ireland	01.05.09	SEAI	/XI Current
Italy	13.11.80	IMAA/CNR-ENEA	Current
Japan	17.09.81		
Kazakhstan	2015	The Government	Current
Korea	15.05.96	KEMCO	Current
The Netherlands	02.04.82	ECN	Current
Norway	13.11.80	IFE	Current
Russian Federation	15.09.2010	ERIRAS	XI Current
Spain	01.07.2010	The Government	VIII/ /XI Current
Sweden	18.11.80	The Government	Current
Switzerland	01.04.81	PSI	Current
United Kingdom	09.06.81	The Government	Current
United States	13.11.80	DOE	Until Annex XII
Sponsors	2014	ENEL Foundation	Current

**The following countries were invited to join ETSAP in the Executive Committee meeting in Beijing on 3<sup>rd</sup> June 2014:** Turkey, China, India, Mexico, South Africa, Brazil, Australia, Austria, Indonesia, Portugal, Croatia, Ukraine, Czech Rep., and Singapore.



## ANNEX II. NATIONAL AND LOCAL MARKAL/TIMES MODELS

### *MARKAL-TIMES National Models*

Studies using MARKAL-TIMES National models are:

#### **Bangladesh**

- The future choice of technologies and CO<sub>2</sub> emission reduction in the power sector. This paper examines the impacts of CO<sub>2</sub> emission reduction on future technology selection and energy use in Bangladesh power sector up to 2035 considering the base year 2005. It also examines the implications of CO<sub>2</sub> emission reduction targets on energy security of the country. The analysis is based on a long-term energy system model of Bangladesh using the MARKAL framework.
- Impacts of CO<sub>2</sub> emission constraints on penetration of solar PV. This paper examines the impacts of CO<sub>2</sub> emission reduction targets and carbon tax on future technologies selection especially solar PV and energy use in Bangladesh power sector during 2005-2035. It also examines the co-benefits of energy security of the country. The analyses are based on a long-term energy system optimization model of Bangladesh using the MARKAL framework.
- Impacts of CO<sub>2</sub> emission constraints on technology selection and energy resources for power generation. This paper examines the impacts of CO<sub>2</sub> emission reduction target and carbon tax on future technologies selection and energy use in Bangladesh power sector during 2005–2035. The analyses are based on a long-term energy system model of Bangladesh using the MARKAL framework.

#### **Belgium**

- The role of transport pricing to achieve the EU climate change objectives. This paper examines the effects of replacing current fuel taxes by a system of taxes that account better for all the different external costs of the different transport modes. Using the MARKAL–TIMES model for the Belgian energy sector, putting all sectors and technologies on equal footing shows that a fuel tax reform makes that it is not cost efficient to require large CO<sub>2</sub> emission reductions in the transport sector and that traditional car technologies will continue to dominate the car market in 2020–2030.
- EU-objectives on climate change and renewable energy for 2020. In this paper, we analyze the impact for Belgium of the EU-objectives for climate change and renewable energy for 2020. The specific targets for Belgium are a reduction of 15% CO<sub>2</sub>eq in 2020 compared to 2005 for the non-ETS sectors and a renewable target share of 13% in 2020. In addition, there is a target for renewable energy in the transport sector of 10% (biofuel target). The issue is studied with the Belgian TIMES model.

#### **China**

- The role of CCS to achieve near zero emissions coal. This paper introduces some areas of recent R&D on CCS in China and focuses, in particular, on the Near Zero Emission Coal (NZE) project, a China-UK CCS initiative. NZE is being undertaken in three phases. The ultimate aim of NZE, following Phase 3, is to have constructed and operated a coal-fired power plant with integral CCS in China.
- The potential role of CCS to mitigate carbon emissions. This paper presents the results of an energy systems analysis exercise using the China MARKAL model under the support of NZE

(China-UK Near Zero Emissions Coal) Initiative, to provide a perspective on the energy technologies that may be deployed in China to 2050 to meet its energy needs.

- Scenario analysis of China's future energy demand based on TIMES model system. The China TIMES model system, integrated with China energy service demand projection model (ESDPM) and TIMES model, is built to study China's future sustainable energy and environment development strategy, based on energy demand projection with scenario analysis.
- Carbon Capture and Storage in China - Main Findings from China-UK Near Zero Emissions Coal (NZEC) Initiative. The China-UK Near Zero Emissions Coal (NZEC) Initiative examined options for carbon (CO<sub>2</sub>) capture, transport and geological storage in China. It was developed under the 2005 EU-China NZEC Agreement which aims to demonstrate CCS in China and the EU.
- Implications of the international reduction pledges on long-term energy system changes and costs in China and India. This paper analyses the impact of postponing global mitigation action on abatement costs and energy systems changes in China and India. It compares energy-system changes and mitigation costs from a global and two national energy-system models under two global emission pathways with medium likelihood of meeting the 2 °C target.

### **Colombia**

- LNG investment options in the framework of regional energy integration. In this paper, the economic aspects of electricity and gas integration between Colombia and Central America are analyzed. The Colombian MARKAL model was adjusted to include demands for electricity and natural gas in Central America and the availability of resources in that region.

### **Cuba**

- Scenario analysis for the power sector analysis for Cuba. To identify cost effective investment strategies under uncertainties, a supply and power sector MARKAL model was assembled. The implications of least-cost investment strategies for new capacity builds, investment spending requirements, electricity prices, fuel expenditures, and CO<sub>2</sub> emissions for each scenario were assessed.

### **Finland**

- Impacts of EU CO<sub>2</sub> emissions trading on electricity markets and electricity consumers. In this paper, the likely impacts of the EU emission trading system on the Nordic electricity market and on the position of various market actors are assessed. The impacts of emissions trading were studied with the VTT electricity market model and with the TIMES energy system model.
- Prospects for application of CCS in Finland. In this paper, the possibilities and conditions for CCS applications in Finland are assessed. The future role of CCS in the Finnish energy system is further assessed with energy and emission scenarios created with a comprehensive model called TIMES-Nordic.

### **France**

- Modelling the different types of industries - Approach and methodology. This thesis develops a coherent methodological framework for the estimation of the evolution of the energy consumption of most intense energy industries by 2050. For a more complete analysis, the prospective approach of type MARKAL/TIMES gives a detailed description of all the energy intensive industrial sectors. Particular emphasis was placed on the pulp and paper, steel and cement industries.
- Modelling the different types of industries - Approach and methodology. A different methodology has been developed for modelling the non-energy intensive (NEI) industry.

Regarding the segmentation of the industry, we use three main criteria: (i) the existing differences in magnitude of energy intensity across manufacturing sectors; (ii) the NEI sectors share of energy costs in value of production; the quantity of energy consumed by production site.

- The response of energy intensive industries to environmental constraints. We use a prospective energy model to assess the response of industry to environmental constraint. The modeling tool is the TIMES model. We include a full description of multi-option processes involved in the production of paper, glass, cement and steel, providing typical energy consumption in each process step. We identify, for each large energy-consuming industry and for different carbon constraints, the best technologies or optimisations to reduce production cost, and we calculate the energy savings potential and the corresponding CO<sub>2</sub> emission reductions.
- The response of the aluminium industry to environmental constraints. A TIMES (MARKAL) model allows us to build the RES of the French aluminium sector in order to follow the evolution of the sector under different conditions of electricity prices and carbon taxes. The methodology applied is a “bottom up” one: the RES is described in detail with specific economic and technical parameters. In a prospective point of view, we added the possibility in the future to evolve towards more efficient technologies.
- Households under carbon constraint and the burden sharing issue. As a member of the EU, France is concerned to achieve the global 20% reduction of CO<sub>2</sub> emissions in 2020 and the French government has inscribed a 75% reduction of CO<sub>2</sub> emissions by 2050 in its energy orientation law in 2005. Describing household energy behaviour in long-term energy planning models such as TIMES is crucial to answer correctly to the question. The paper survey helps us to provide specific values of discount rates for each kind of technology and each type of households. So that we are able to model differentiated investment behaviour.
- A long term prospective analysis of the Paris/Île-de-France transportation sector. A large part of the energy consumption in urban areas is dedicated to transportation with an important role in total GHG emission. This paper presents a long-term prospective analysis of the contribution to GHG emission and energy consumption of Paris/Île-de-France personal-vehicles transportation sector based on a MARKAL/TIMES bottom-up model.
- Regional future use of biomass and biofuels. The aim of this study is to assess the potential of biomass for energy uses for France by 2050 and to provide a path for biofuel technologies deployment. To achieve this objective, we have developed a detailed MARKAL/TIMES model for biomass use as energy source in France. Using this methodology biomass has been studied as part of the European Union’s renewable strategy for 2020 in the RES2020 project.
- Carbon value dynamics: A key driver to support mitigation pledges at country scale. This paper quantifies the dynamic evolution of carbon values for French climate and energy policy. Its time dependency over successive periods and the effects of setting intermediate targets are evaluated using a long-term optimization model.
- Heat recovery with heat pumps in non-energy intensive industry. We have developed the first detailed bottom-up energy model for Non-Energy Intensive industry (NEI) to study its global energy efficiency and the potential for CO<sub>2</sub> emissions reduction at a 4-digit level of NACE classification. In this paper, the modelling of NEI is done by energy end-use owing to the unsuitability of the end-product/process approach used in the Energy Intensive industry modelling.
- Carbon value dynamics for France. This paper quantifies the dynamic evolution of carbon values for French climate and energy policy. Its time dependency over successive periods and the effects of setting intermediate targets are evaluated using a long-term optimization model. We produce consistent energy, emissions and carbon value estimates with a 5-year time step. The

TIMES\_FR model is used to compute the energy system's responses to strict CO2 mitigation policies under different conditions specified by scenarios.

### **Germany**

- Projecting energy market trends until 2030. An integrated, model-based approach is adopted to illustrate the German energy markets as part of the European energy system. This is to account for embedding the German power supply system into the European domestic market as well as to capture in an appropriate way the effects of transnational, EU-wide regulation approaches like the European Emission Trading System.
- Cost efficient utilisation of biomass in the German energy system. The aim of the presented study is to assess the different biomass options against the background of energy and environmental political targets based on a system analytical approach for the future German energy sector. The methodological approach is based on a scenario analysis within the energy system model TIMES Germany.

### **Greece**

- Energy policy scenarios of CCS implementation in the electricity sector. This work presents a roadmap with the modeling of the main technologies associated to the CCS and its implementation into the Greek energy system considering existing National and International Strategic energy plans under different scenarios. For this purpose, TIMES (The Integrated MARKAL/EFOM System) has been chosen as the principal tool for building a technoeconomic model of the Greek energy system and its possible evaluation over time (2040).

### **India**

- Assessment of demand for natural gas from the electricity sector. The sustained electricity deficit and environment policies have added to an already rising demand for gas. This paper (160) models the future demand for gas in India from the electricity sector under alternative scenarios for the period 2005–2025, using bottom-up ANSWER MARKAL model.
- An outlook to energy consumption in large scale industries. Steel, aluminium and cement are the key manufacturing industries in India which provide inputs to various other sectors such as construction, transportation, power transmission, etc. This paper makes a foray into the energy demand for these industries and explores the potential of any future reduction in their energy consumption.
- Nuclear and clean coal technology options for sustainable development. In this paper Indian power sector has been examined by using MARKAL model for introduction of clean coal and advanced nuclear technologies with implementation of energy conservation potential.
- Renewable energy for sustainable electrical energy system. The path towards sustainability is exploitation of energy conservation and aggressive use of renewable energy systems. Detailed MARKAL simulations, for power sector in India, show that full exploitation of energy conservation potential and an aggressive implementation of renewable energy technologies lead to sustainable development.
- Parametric sensitivity analysis for techno-economic parameters in power sector. This paper examines the variations in technical as well as economic parameters that can mostly affect the energy policy of India. MARKAL energy simulation model has been used to analyze the uncertainty in all techno-economic parameters. Various ranges of input parameters are adopted from previous studies.
- National energy map for India: Technology Vision 2030. The key focus of this study was to examine the role that various technological options could play under alternative scenarios of

economic growth and development, resource availabilities, and technological progress. After an extensive survey of existing models, the MARKAL (MARKet ALlocation) model was selected to examine the pathways for optimal energy supply to meet the end uses services in the five energy-consuming sectors (agriculture, commercial, residential, industrial, and transport) under various scenarios.

- Sustainable transport for developing countries. The paper proposed extensions in an integrated modeling framework used earlier for modeling low carbon scenarios. These involved adding in the ANSWER MARKAL model time costs and infrastructure costs to model the modal choices endogenously. The revised model framework was used to examine low carbon transitions along two pathways.
- Nuclear energy option for energy security and sustainable development. This paper examines the implications of penetration of nuclear energy in Indian power sector. Four scenarios, including base case scenario, have been developed using MARKAL energy modeling software for Indian power sector. The least-cost solution of energy mix has been measured.
- Parametric sensitivity analysis for techno-economic parameters in Indian power sector. This paper examines the variations in technical as well as economic parameters that can mostly affect the energy policy of India. MARKAL energy simulation model has been used to analyze the uncertainty in all techno-economic parameters.

#### **Indonesia**

- Secure energy supply in 2025: Indonesia's need for an energy policy strategy. Two scenarios for the energy situation in 2025 have been elaborated and are discussed. An overall energy policy strategy and regulatory framework covering non-renewable and renewable resources are crucial for securing energy demand.

#### **Ireland**

- Building the Irish model. UCC has secured research funding for a two year project entitled "Energy Modelling – Irish TIMES" to build an energy systems model for Ireland. Irish TIMES will provide a range of energy system configurations for Ireland that will deliver projected energy demand requirements optimised to least cost and subject to a range of policy constraints for the period out to 2050. The PET-IE model from RES 2020 is used as starting point for Irish TIMES (2009 -2011).
- Modelling ambitious renewable energy and CO2 reduction targets. This paper focuses on reductions in energy-related CO2 emissions in particular and explores how an optimal mix of technologies may be determined to deliver a pre-established target. The paper uses the TIMES energy systems model to address this question. It uses one country, Ireland as a specific case study but may be readily applied to other countries.
- Comparing results with a power systems model. The focus of this work is to investigate the added value of the inclusion of extra technical constraints for thermal generators and the high resolution portrayal of wind and load variability in a power system model. The PLEXOS model which can replicate at a high resolution (30 minute time steps) the chronological modeling of a power system is compared for a number of test years to results from TIMES. This analysis therefore intends to benchmark the performance of the TIMES electricity modeling against detailed results of the PLEXOS software in the Irish power system.
- Modelling the impacts of challenging 2050 European climate mitigation targets. This paper focuses on mitigation targets for one Member State, Ireland, an interesting case study due to the growth in GHG emissions and the high share of emissions from agriculture. We use the Irish TIMES energy systems modelling tool to build a number of scenarios delivering an 80%

emissions reduction target by 2050, including accounting for the limited options for agriculture GHG abatement by increasing the emissions reduction target for the energy system.

- Modelling the impacts of challenging 2020 non-ETS GHG emissions reduction targets. This paper focuses on Ireland's ambitious target for 2020 to reduce greenhouse gas (GHG) emissions by 20% below 2005 levels for sectors not covered by ETS (Non-ETS). The analysis is carried out with the Irish TIMES model. The paper uses scenario analysis to provide pathways that demonstrate how Ireland can meet the non-ETS target at least cost.
- The case of constrained oil supply for Ireland. This work models energy security scenarios for Ireland using long term macroeconomic forecasts to 2050, with oil production and price scenarios from the International Monetary Fund, within the Irish TIMES energy systems model.
- Soft-linking of a power systems model to an energy systems model. In this paper we present a soft-linking methodology that employs detailed simulation outputs from a dedicated power systems model to gain insights and understanding of the generation electricity plant portfolio results for the electricity sector from a separate energy systems model.

## Italy

- A business as usual scenario for the energy system. The aim of this article is to present a new model for the Italian energy system implemented with a common effort in the framework of an integrated project under the Sixth Framework Programme. In particular, the main features of the common methodology are briefly recalled and the modelling structure, the main data and assumptions, sector by sector, are presented.
- Assessment of externalities related to global and local air pollutants. The integration of energy system analysis methods with externalities assessments represents a powerful tool to support a systemic multi-objective investigation, aimed at achieving a better resource management as well as at reducing environmental pollution. This chapter is addressed to describe, from a methodological and an operating point of view, how strategic energy planning can benefit from external costs evaluation. In particular the effects of external costs on the least-cost optimised energy system configuration were analysed in a national case study with the NEEDS-TIMES Italy model, considering the externalities related to local and global air pollutants (NO<sub>x</sub>, SO<sub>2</sub>, VOC, particulates and GHGs).
- Analysis of possible deployment scenarios for hydrogen. The paper analyses Italian hydrogen scenarios to meet climate change, environmental and energy security issues. An Italy-Markal model was used to analyse the national energy–environment up to 2050. About 40 specific hydrogen technologies were considered, reproducing the main chains of production, transport and consumption, with a focus on transport applications.
- Cost-benefit analysis in the Italian electricity sector - Feasibility of the nuclear option. This paper wants to show an alternative scenario of evolution of the Italian Power System in 2030. We want also analyse the sensitiveness of the cost of the nuclear plant in comparison with the price of the fossil fuels, particularly natural gas, at the aim of knowing if there is an indifference line between the two. At the scope of evaluate the possible ways of development of the power system it is necessary to use a model approach: the MARKAL-TIMES multi-region representation of the Italian electric system.
- Impact of a return to the nuclear option using an electricity model. The objective of the study is to analyse the impact of a “return” to nuclear generation in CO<sub>2</sub> emissions and fossil fuel consumption for the Italian electricity system and the economic implications.
- Cost-benefit analysis in the Italian electricity sector - Feasibility of the storage option. In this study, the AIEE research group analyzes the cost-benefit of the electricity storage technologies penetration into the Italian electricity market: CAES – Compressed Air Energy Storage (both

underground and surface storage), Flywheels, Super-Capacitors (ECC), Superconducting Magnetic Energy Storage (SMES), Sodium Sulphur (NAS) Battery, Polysulfide-Bromine (PSB) Battery, Vanadium Redox Battery (VRB), H<sub>2</sub>/FuelCell.

- Calibration and scenario analysis for the national energy strategy. A TIMES model for Italy has been developed from the ETSAP-TIAM model with 42 energy service demands. The first objective was to analyse National Energy Strategy with transparency of both scenario analysis and the model, as well as with transparent interaction between modellers and policymakers. The model was used to get estimation of potential impact and costs of policy measures and technology options, with technological detail comparable with major policy documents, technology-by-technology abatement cost curves and soft-link of new model with GTAP-Italy and Italian SAM.
- *Rapporto Energia e Ambiente 2013. Verso un'Italia Low Carbon: sistema energetico, occupazione, investimenti.* ENEA, 2013. In the report the perspectives of the National Energy system have been analyzed comparing a Reference Scenario with a Roadmap Scenario built following the paths of decarbonisation identified in the roadmap of the European Union to achieve a 80% CO<sub>2</sub> reduction by 2050.

The Times-Italia model has been widely used to support policymakers in the implementation of energy and environmental policies. Most important contributions are:

- Support to the Ministry of Economic Development in the preparation of the National Energy Strategy (2013). The model has been used to: 1) analyze a set of scenarios designed to test the consistency of the objectives and policies considered and their impacts on the rest of the energy system (systemic approach). 2) provide insights on technology foresight and research priorities in the medium-long term.
- Implementation of a decision support system (DSS) for the Ministry of Economic Development (2012-2015). In this research project ENEA prepared the algorithms to feed a Social Accounting Matrix and the GAINS model with some inputs and outputs of the Times-Italia model in order to achieve a comprehensive economic and environmental analysis of each Times scenario.
- Support to the Italian Government in the evaluation of the impacts of new EU targets at 2030. For this activity, ENEA and RSE prepared a Reference Scenario and two policy Scenarios (-36% and -40% of CO<sub>2</sub> emissions) in order to analyze the effects of EU environmental policies on the energy system. The analysis has been completed feeding a Social Accounting Matrix and the Gtap model (a General Equilibrium Model) with the results of the Times-Italia model. The linkage provided an evaluation of the impacts on GDP, employment and sector competitiveness.
- Research activity on the perspectives of Liquefied Natural Gas in the national energy system (ENEA- Italian Federation of the chemical industry, 2013). The Times-Italia model has been used to analyze the role of LNG under various hypotheses of energy and environmental policies.

## Japan

- Integrated assessment for CDM activities using energy and life-cycle assessment models. This study aims at developing a method for evaluating CDM activities in the next decades, focusing on investment in supply-side energy technologies in Asian countries. By combining energy systems analysis and life-cycle assessment, potential amount of CDM credit anticipated from those activities will be discussed with their costs and benefits including co-benefits, in the light of the contribution of technology development to Japanese global environment policies. Possible energy-related CO<sub>2</sub> emission reduction is analyzed for estimating necessary CDM credits by using MARKAL model for Japan.

- Long-term scenario analysis of zero-carbon energy system. Nuclear power and renewable energy are expected to contribute significantly to this in the future in Japan. Therefore, in the present study, their roles in future zero-carbon electricity system was examined using long-term scenario analysis from 2005 to 2100 based on an integrated analysis model. The proposed optimization method is quite different to many models proposed in past studies such as MARKAL and AIM (Asia-Pacific Integrated Model), which aim to find the least cost solution.

#### **Kazakhstan**

- Electricity and heating system in Kazakhstan. This paper presents scenario studies on the possible evolutions of these sub-systems to 2030. It describes the representation of the heat and electricity chains in the MARKAL–TIMES-Kazakhstan model. The main scenario drivers are the need to improve the efficiency of electricity and heat in the residential and commercial sectors and to reduce GHG emissions from the energy system as a whole.

#### **Macedonia**

- Evaluation of climate change impacts on energy demand. This paper may contribute to fill this gap, identifying the interactions between climate change and the energy demand in Macedonia. The analyses are conducted using the MARKAL (MARKet ALlocation)-Macedonia model, with a focus on energy demand in commercial and residential sectors (mainly for heating and cooling).

#### **Malaysia**

- Review of MARKAL energy modelling. In this paper, an attempt has been made to understand and review the various emerging issues related to the MARKAL energy modeling. The need to develop comprehensive energy models and their related infrastructures as the energy scenarios in Malaysia have compelled Pusat Tenaga Malaysia (PTM) to consider the MARKAL for the long term energy planning.

#### **Moldova**

- Energy efficiency and RES analysis. The paper presents results of analyses of energy efficiency measures and renewable energy sources implementation in the Republic of Moldova using MARKAL model. Energy savings and costs are identified for implementation of renewable energy sources and Energy efficiency measures.

#### **Nepal**

- Energy planning and policy analysis. Nepal is facing a difficult energy supply crisis. One of the main research questions, therefore, in the presynopsis report was to develop a modelling framework for the energy sector of Nepal so that energy policy analysis could be conducted and based on the framework. Nepal – MARKAL energy modelling framework was developed and inputs of the useful energy demands from the end-use approach (MAED) were exogenously incorporated in.
- Transport sector electrification in a hydropower resource rich developing country. This paper analyzes the co-benefits of transport sector electrification in terms of reductions of greenhouse gas and local environmental emissions, improvement in energy security and employment generation during 2015–2050 in the case of Nepal—a developing country with large hydropower potential. A bottom up energy system model of Nepal based on the MARKAL framework was developed.
- Benefits of low carbon development in a developing country. This paper analyzes the direct and indirect benefits of reducing CO<sub>2</sub> emission during 2005 to 2100 in the case of Nepal, a low income developing country rich in hydropower resource. It discusses the effects on energy supply mix, local pollutant emissions, energy security and energy system costs of CO<sub>2</sub> emission

reduction targets in the country by using an energy system model based on the MARKAL framework.

## Norway

- Introduction of hydrogen in the Norwegian energy system. If the national targets to reduce emissions of GHG should be met, a substantial reduction of CO<sub>2</sub> emissions has to be obtained from the transport sector. This paper presents the results of the analyses of three Norwegian regions with the energy system model MARKAL during the period 2005-2050. The MARKAL models were used in connection with an infrastructure model H2INVEST.
- Coupling the model with a GIS for infrastructure analysis. The NorWays project aims at providing decision support for introduction of hydrogen in the Norwegian energy system by modelling of energy system and hydrogen infrastructure at various spatial levels. GIS-based regional hydrogen demand scenarios and fuelling station networks have been generated, considering organic growth of regional hydrogen coverage and increasing density of hydrogen users over time. The project includes modelling at national, regional and local level, utilizing energy system modelling (MARKAL), well-to-wheel-studies and infrastructure analysis.
- Impacts of climate change on the Norwegian energy system toward 2050. The overall objective of this work is to identify the effects of climate change on the Norwegian energy system towards 2050. The impact of climate change is evaluated with an energy system model, the MARKAL Norway model, to analyse the future cost optimal energy system.
- Global technology learning and CO<sub>2</sub> emissions under policy constraints. The possibility to realize an ambitious global emission reduction scenario is enhanced by coordinated action between countries in national policy implementation. The analysis of the national measures are done with a bottom-up energy systems model of the Norwegian energy system (MARKAL) with input from a global model (ETP) and a national macroeconomic model (MSG6). The national policies to stimulate technology deployment are input to the MARKAL model.
- Regional TIMES model with high time resolution. A regional TIMES model has been developed by Institute for Energy Technology (IFE) on commission of the Norwegian Water Resources and Energy Directorate (NVE). The overall aim of this modelling work has been to develop a model that could be used in connection with the hydropower/power market model Multi-area Power-market Simulator (EMPS). We have increased time resolution to cover all weeks during each year and five time slices pr week, equally 260 time slices annually. The TIMES model covers seven regions in Norway with exchange of electricity between regions and with neighbouring countries.
- The impact of future energy demand on renewable energy production. This paper presents long-term projections of the Norwegian energy demand as a two-step methodology of first using activities and intensities to calculate a demand of energy services, and secondly use this as input to the energy system model TIMES-Norway to optimize the Norwegian energy system.
- Analysis of the EU renewable energy directive. The RES directive is modelled as a constraint in the TIMES- Norway model. The target of 67.5% needs to be achieved on a national level by 2020, as well as 10% share of renewable energy for transport. The TIMES model will choose the optimal investments portfolio for each of the seven regions to satisfy the RES directive.
- Modelling the effects of climate change on the energy system. The overall objective of this work is to identify the effects of climate change on the Norwegian energy system towards 2050. The impact of climate change is evaluated with an energy system model, the MARKAL Norway model. Ten climate experiments, based on five different global models and six emission scenarios, are used to cover the range of possible future climate scenarios and of these three experiments are used for detailed analyses.

- Norwegian climate policy reforms in the presence of an international quota market. This study shows that the second-best optimal difference between tax rates on goods that generate greenhouse gas emissions and non-polluting goods is equal to the quota price plus a Ramsey tax on the quota price when emission quotas are traded between governments and the price elasticity of these goods is identical. Model simulations show that a unilateral increase in emission tax to above the international quota price generates a welfare gain for Norway.
- Introducing technology learning for energy technologies in a national CGE model through soft links to global and national energy models. This paper describes a method to model the influence by global policy scenarios, particularly spillover of technology learning, on the energy service demand of the non-energy sectors of the national economy. It is exemplified by Norway. Spillover is obtained from the technology-rich global Energy Technology Perspective model operated by the International Energy Agency. It is provided to a national hybrid model where a national bottom-up Markal model carries forward spillover into a national top down CGE1 model at a disaggregated demand category level.
- Technology learning in a small open economy. This paper reviews the characteristics of technology learning and discusses its application in energy system modelling in a global-local perspective. Its influence on the national energy system, exemplified by Norway, is investigated using a global and national Markal model.

#### **Pakistan**

- Energy, environmental and economic effects of Renewable Portfolio Standards (RPS). This paper analyses the potential of renewable energy for power generation and its energy, environmental and economic implications in Pakistan, using a bottom up type of long term energy system based on the MARKAL framework.

#### **Portugal**

- Cost of energy and environmental policy in CO<sub>2</sub> abatement—scenario analysis to 2020. This paper quantifies the contribution of Portuguese energy policies for total and marginal abatement costs (MAC) for CO<sub>2</sub> emissions for 2020. The TIMES\_PT optimisation model was used to derive MAC curves from a set of policy scenarios.
- Cost of counteracting policy instruments in place in Portugal. This paper presents such a quantitative bottom-up approach that estimates the losses or gains on cost-effectiveness of interacting policy instruments using TIMES\_PT, a bottom-up optimization technology model implemented for Portugal.
- The impact of climate change mitigation options on air pollutants emissions. The objective of the paper is to present the modeling approach and results on the evaluation of the impacts of GHG mitigation options on the SO<sub>2</sub>, NO<sub>x</sub> and PM<sub>2.5</sub> emissions by 2030. The technological bottom-up model TIMES\_PT was used to assess the impact of different GHG mitigation levels in air pollutants. TIMES\_PT models the Portuguese energy system from 2005 to 2030, and has been extended in order to include acidifying pollutants SO<sub>2</sub> and NO<sub>x</sub> (Dias, 2009) and fine particulate matter PM<sub>2.5</sub>.
- Contribution of different exogenous assumptions on the uncertainty of GHG emission scenarios. The development of GHG emission scenarios is fundamental for climate policy. The degree of scenario's uncertainty depends on the assumptions implemented in the model as exogenous parameters. This paper assesses the contribution of different exogenous parameters for the case study of the Portuguese energy system. The linear optimization technology model TIMES\_PT is used to develop seven alternative GHG scenarios for 2020.
- Forecasting of residential energy services demand for 2030. Forecasting energy services demand is a very challenging topic, either as a long-term or a short-term exercise, since it depends on

several (in) dependent factors from economic to climate drivers. This work proposes a bottom-up approach to develop energy services demand scenarios of the residential sector up to 2030 for Portugal. The results have been used as inputs of the technological economic model TIMES\_PT to obtain final energy consumption.

- High-resolution modeling framework for planning electricity systems. This paper presents a modeling framework that is able to optimize the investment in new renewable generation capacity on the long-term while taking into account the hourly dynamics of electricity supply and demand. The framework was applied to continental Portugal for the time period of 2005–2050, in order to identify optimal investment plans in new renewable and fossil generation capacity with the goal of achieving significant CO<sub>2</sub> emissions reduction, under different scenarios.
- Projections of energy services demand for residential buildings. This paper presents a bottom-up methodology to project detailed energy end-uses demand in the Portuguese residential buildings until 2050, aiming to identify the parameters governing energy services demand uncertainty. The partial equilibrium TIMES model was used to assess technology options and final energy needs for the range of parameters variations for each end-use.
- Assessment of Carbon Capture and Storage Opportunities. Applying TIMES model tool, this paper examines different scenarios regarding the price levels of CO<sub>2</sub> taxes and trading under the Emissions Trading System in Europe and consider the perspectives of using carbon capture and storage (CCS) technologies to mitigate the greenhouse gas (GHG) emissions.

#### **Russia**

- Carbon emissions projections and reduction potentials. The purpose of the paper is to estimate CO<sub>2</sub> emissions trends, potentials and costs of CO<sub>2</sub> mitigations in Russia. On the current stage of the analysis we consider pathways of CO<sub>2</sub> emissions in the power and heat production sector up to 2030. We analyze official and alternative projections of socio-economic development of the Russian economy, and apply RU-TIMES model for policy scenarios comparison and emissions projection.
- Designing stochastic experiments with deterministic models. There is a good reason to turn to stochastic models, as they allow incorporate probabilistic (random) elements into optimization process. Let's consider an example based on TIMES model for Russian energy system (power and heat sector). Instead of assigning certain values to unknown parameters for deterministic runs, specification of distributions of the parameters is required.

#### **Singapore**

- Impacts of Photovoltaics and Electromobility. This paper discusses the possibility to produce substantial amounts of electricity by solar photovoltaics (PV). In addition, the integration of electromobility in Singapore is analysed. The paper will describe the TIMES (The Integrated MARKAL EFOM System) model for Singapore which is developed within the project TUM CREATE (Technische Universität München Campus for Research Excellence and Technological Enterprise).

#### **Slovenia**

- Modelling the national energy system within the European framework. These tools are utilized in the framework of the Integrated Project NEEDS of the VI Framework Programme to develop the energy system models of 30 EU countries. In this paper are presented the main results obtained at country level for the Slovenia energy system in the Business As Usual – BAU scenario that provides the optimised development of the energy system in agreement with the main

national energy and environmental policies. In the following the main results produced by the NEEDS\_SI TIMES model for the BAU scenario are presented.

### **South Africa**

- Technology learning for renewable energy: Implications for long-term mitigation scenarios. Technology learning can make a significant difference to renewable energy as a mitigation option in South Africa's electricity sector. This article considers scenarios implemented in a MARKAL energy model used for mitigation analysis. It outlines the empirical evidence that unit costs of renewable energy technologies decline, considers the theoretical background and how this can be implemented in modeling.
- Long-Term Mitigation Scenarios (LTMS). The purpose of the is to outline different scenarios of mitigation action by South Africa, to inform long-term national policy and to provide a solid basis for our position in multi-lateral climate negotiations on a post-2012 climate regime. This Technical Summary therefore provides the basis, in abridged form, for the scenarios – stories of possible futures.
- Costing a 2020 target of 15% renewable electricity. The problem was to assess the national cost of South Africa achieving a target of 15% of electricity generated from renewable sources by 2020. We used a bottom-up, partial equilibrium MARKAL model of the South African energy system (originally developed for South Africa's Long-Term Mitigation Scenarios) to model the electricity system, which allowed us to model supply options, as well the impact of demand-side options.
- South Africa's greenhouse gas emissions under business-as-usual. This article describes the methodology for projecting business-as-usual GHG trajectory developed in technical work for South Africa's Long-Term Mitigation Scenarios (LTMSs), in particular the 'Growth without Constraints' (GWCs) scenario. The key drivers for the GWC scenario include GDP (both growth rate and composition), population, discount rate and technological change. The LTMS GWC scenario is compared to other projections, nationally and internationally.

### **South Korea**

- Impact assessment of CO2 mitigation options. The goal of this study is the identification of the viable technology and legal options for CO2 mitigation, and the impact assessment of the options for the Korean power generation sector. The MARKAL modeling package of IEA/ETSAP was used as an appropriate tool to make the database of Korean energy system in the model and assess the effects of the options.
- Analysis of the energy and environmental effects of green car deployment. By 2020, Korea has set itself the challenging target of reducing nationwide greenhouse gas emissions by 30%. Therefore, this study proposes a new methodology for overcoming problems associated with the use of MARKAL models, by interfacing with a forecasting model based on the discrete-choice model. The new methodology was applied to green car technology to verify its usefulness and to study the ripple effects of green car technology on greenhouse gas reduction.

### **Spain**

- Implementation of the EU renewable directive. Based on the European project RES2020, the analysis evaluates the energy strategies to be implemented in Spain in order to satisfy the EU Renewable Directive. The modelling framework relies on the technico-economic model TIMES-Spain, part of the Pan-European TIMES model used in the project.

- Analysis of the environmental impacts and compliance of the emission-related Directives in the cement production and electricity generation sectors in Spain using the LCA method and TIMES-Spain energy model

### **Sweden**

- Ancillary benefits of Climate Policy. The paper addresses a number of health-related improvements (ancillary benefits) that could accompany the reduction in CO<sub>2</sub> under different climate policy designs in Sweden. The reliance on a technology-rich energy system optimization model of the Swedish energy system (TIMES-Sweden) has permitted us to address the economic significance of these environmental side-effects as well as to provide a detailed assessment of the respective technology and fuel choices that underlie any net changes in the estimated ancillary benefits. TIMES-Sweden is a techno-economic and original developed as a part of the Pan-European TIMES model.
- Regional use of biomass and development of the bioenergy sector. In this paper we firstly present how highly spatial and temporal estimations of biomass potentials can be integrated into a sub-national TIMES model. Secondly, we in the paper evaluate the possible extension of the bioenergy sector in Sweden and France based on the increased range of feedstocks available for bioenergy production and development of conversion technologies. The proposed model is evaluated for France and Sweden as both countries employ large amounts of forestry biomass in the energy sector.
- Achieving cost-effective oil use reduction in passenger cars in Sweden. In this work, the energy and technology costs associated with reducing oil consumption in passenger cars in Sweden are calculated for a number of possible future transport fuel pathways and for different energy prices and climate policies. An optimisation model is applied in a simulatory multiple-run approach for this purpose. The model encompasses the transportation sector, as well as the stationary energy system.
- Ancillary benefits of climate policy in a small open economy. The purpose of this paper is to estimate the domestic ancillary pollution benefits of climate policy in Sweden, and investigate how these are affected by different climate policy designs. The analysis relies on simulations within the energy system optimisation model TIMES-Sweden, and focuses on four non-GHG pollutants.
- Cost-effective biogas utilisation. This study investigates requirements for policy support to overcome techno-economic barriers of biogas utilisation and effects of different biogas distribution strategies. Two potential sectors for biogas use are covered: the transport sector and the district heating sector. A quantitative, optimising, energy system modelling approach is applied and the region of Västra Götaland, Sweden, is studied.
- Sub-national TIMES model for analyzing future regional use of biomass and biofuels. The objective of this study is to improve evaluations of the future use of biomass sources in Sweden and France by representing the high spatial variations of the supply and cost of biomass sources in energy system models. A TIMES energy system model was used to evaluate bioenergy production potential under the assumption that it should not be at the expense of domestic food and forestry supply.

### **Switzerland**

- Intermediate steps towards the 2000W society: An energy-economic scenario analysis. Could the target of the 2000W society, i.e. a primary energy per capita (PEC) consumption of 2000 W, be realized until 2050? Various combinations of PEC and CO<sub>2</sub> targets are tested, and the additional costs to be paid by the society are estimated. The assessment is carried out with the

Swiss MARKAL model, a bottom-up energy-system model projecting future technology investments for Switzerland.

- Social MARKAL: Integrating behavioural changes in the residential and commercial sectors. A new MARKAL framework, the Socio-MARKAL, was recently proposed by the authors. This study takes into consideration, technological improvements on the demand side by consumers as well as behavioural changes minimizing CO<sub>2</sub> emissions and encouraging rational use of energy. Based on the statistical analysis of this survey, we have determined coefficients to feed the database of the Socio-MARKAL model.
- First modeling attempts in the Nyon residential and commercial sectors. Based on this new SOMARKAL formulation, we will simulate the possible contribution of awareness campaigns in triggering energy consumption behavioural changes and possibilities of technology switch, in the residential area of the city of Nyon (Switzerland), for the period 2005-2025. The main focus is on lighting technologies. Three fictitious scenarios were produced, referring to three possible penetration rates of low consumption lighting technologies.
- Observing and analyzing operating modes of staff using IT appliances. This particular study aimed at analyzing the electricity consumption of ICT equipment used by staff members of the Geneva School of business administration. First, the methodological approach used for information collection was presented. Second, a model designed to derive the subsequent electricity consumption has been presented. This information is intended to be fed into the Socio MARKAL model.
- Assessment of GHG mitigation policies after 2012 with focus on the residential sector. The objective of the paper is to assess some of the instruments envisaged for the the revision of the Swiss CO<sub>2</sub> Law. To attain our objective we devise a coupled model, combining a global economic model (GEMINI-E3) with a Swiss residential energy use model (MARKAL-CHRES).
- Sustainability, neutrality and beyond in the framework of Swiss post-2012 climate policy. In this paper we use a coupled top-down bottom-up model to assess the impacts of a number of ambitious climate policies in Switzerland. We find that stringent policies with both domestic and total emission targets are affordable for a wealthy country like Switzerland.
- Linking bottom-up models to the multi-regional MERGE model. There are two versions of the MACRO stand-alone model developed by A. Manne; the first one corresponds to the macroeconomic module of MERGE while the second one corresponds to the M-M approach specially developed for the ETSAP tools. Activities will start with the national T-M or M-M models trying to decompose them and link them either with a stand-alone macroeconomic sub-model or with MERGE directly and will continue with extensions to multi-regional global models like e.g., TIAM or GMM.
- Experience from the development a new TIMES electricity model. Understanding how structural changes occur in energy supply requires approaches that are able to represent the structure of the energy system in detail and the main factors affecting structural change. We will develop a Swiss TIMES Energy system Model (STEM) and validate its input variables through stakeholder engagement.
- Cost of ad-hoc nuclear policy uncertainties in the evolution of the Swiss electricity system. We have analysed possible electricity supply options for responding to these two developments under different conditions using the Swiss TIMES electricity sector model—a least-cost optimization framework.
- SOCIO-MARKAL: Integrating energy consumption behavioral changes. The present study aims at assessing the joint impact of awareness campaigns and technology choice, on end-use energy consumption behavior. Actions to achieve energy savings through the use of more energy-

efficient end-use technology are included. A new MARKAL framework – i.e., SOCIO-MARKAL – is proposed.

## **Taiwan**

- Long-term CO<sub>2</sub> emissions reduction target and scenarios of power sector. This study analyses a series of CO<sub>2</sub> emissions abatement scenarios of the power sector in Taiwan. The MARKAL-MACRO energy model was adopted to evaluate economic impacts and optimal energy deployment for CO<sub>2</sub> emissions reduction scenarios. This study includes analyses of life extension of nuclear power plant, the construction of new nuclear power units, commercialized timing of fossil fuel power plants with CCS technology and two alternative flexible trajectories of CO<sub>2</sub> emissions constraints.
- Sensitivity study of energy prices for CO<sub>2</sub> abatement scenarios. The purpose of this paper is to discuss under the CO<sub>2</sub> emissions reduction targets, how the energy prices development affect the technology development and domestic economics. Different trajectories of energy prices are set and economic impacts are analyzed in CO<sub>2</sub> abatement scenarios.
- Taiwan's GHG mitigation potentials and costs: An evaluation with the MARKAL model. This paper presents the results on the simulations of different technology development scenarios under the same emission reduction goal, utilizing the MARKAL model to evaluate emissions reduction on Taiwan's electricity, industry, buildings, and transportation sectors.
- Policy progress in mitigation of climate change in Taiwan. Taiwan government has made a commitment of a step wise reduction of nation-wide greenhouse gas (GHG) emissions, which returns the nation-wide GHG emission to 2008 levels by 2020, then reduces to 2000 levels by 2025, and finally cuts 50% of 2000 levels by 2050. The purpose of this paper is to present an updated review of the outcomes of GHG emission reduction in Taiwan.
- An assessment of Taiwan's energy policy using multi-dimensional energy security indicators. This study applies multi-dimensional energy security indicators to review the performance of Taiwan's energy security related measures and to analyze the impacts of the current energy policy on Taiwan's energy security.

## **The Netherlands**

- Planning for an electricity sector with CCS. Before energy companies will invest in power plants with CCS, appropriate climate policy should be in place, a need for new power plants must exist, CCS technology should be cost-effective, and CO<sub>2</sub> transport infrastructure and CO<sub>2</sub> sinks must be available. We carried out a quantitative scenario study for the electricity and cogeneration sector in the Netherlands using the energy bottom-up model generated with MARKAL.
- The impacts of CO<sub>2</sub> capture on transboundary air pollution. The focus of this research is to develop a first assessment of the impacts of the implementation of CO<sub>2</sub> capture technologies in the Dutch power sector on the transboundary air pollution (SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, PM<sub>10</sub> and PM<sub>2.5</sub>) levels in 2020.
- Designing a cost-effective CO<sub>2</sub> storage infrastructure using an integrated GIS-MARKAL toolbox. A toolbox that integrates ArcGIS, a geographical information system with elaborate spatial and routing functions, and MARKAL, an energy bottom-up model based on linear optimization has been developed. Application of this toolbox led to blueprints of a CO<sub>2</sub> infrastructure in the Netherlands. The research methodology applied in our study can be summarised into several steps, including extension of MARKAL-NL-UU model to incorporate spatial data from ArcGIS.
- Feasibility of storing CO<sub>2</sub> in the Utsira formation. This study provides insight into the feasibility of a CO<sub>2</sub> trunkline from the Netherlands to the Utsira formation in the Norwegian part of the North Sea, which is a large geological storage reservoir for CO<sub>2</sub>. Least-cost modelling with a

MARKAL model in combination with ArcGIS was used to assess the cost-effectiveness of the trunkline as part of a Dutch GHG emission reduction strategy.

- Combining hybrid cars and synthetic fuels with electricity generation and carbon capture and storage. We examined the co-evolution of the transportation, and electricity and heat generation sectors in the Netherlands until 2040 using a MARKAL bottom-up cost optimisation model. All scenario variants investigated indicate a switch away from crude oil-based diesel and petrol for transportation.
- The influence of international climate policies on the deployment of CO<sub>2</sub> capture and storage at the national level. The deployment of large scale CO<sub>2</sub> Capture and Storage (CCS) may depend largely on the emissions price resulting from a greenhouse gas emission trading system. However, it is unknown whether such a trading system leads to a sufficient high CO<sub>2</sub> price and stable investment environment for CCS deployment. To gain more knowledge, we soft-linked WorldScan, an applied general equilibrium model for global policy analysis, with MARKAL-NL-UU, a techno-economic energy bottom-up model of the Dutch power generation sector and CO<sub>2</sub> intensive industry.
- Impact of international climate policies on CO<sub>2</sub> capture and storage deployment. A greenhouse gas emission trading system is considered an important policy measure for the deployment of CCS at large scale. However, more insights are needed whether such a trading system leads to a sufficient high CO<sub>2</sub> price and stable investment environment for CCS deployment. To gain more insights, we combined WorldScan, an applied general equilibrium model for global policy analysis, and MARKAL-NL-UU, a techno-economic energy bottom-up model of the Dutch power generation sector and CO<sub>2</sub> intensive industry.

### **Thailand**

- Co-benefits of CO<sub>2</sub> reduction in a developing country. In this paper, we examine the co-benefits of reducing CO<sub>2</sub> emissions in Thailand during 2005–2050 in terms of local pollutant emissions as well as the role of renewable-, biomass- and nuclear-energy. The analyses are based on a long term energy system model of Thailand using the MARKAL framework.
- CO<sub>2</sub> mitigation with CCS in the power sector. Due to the cheap fuel costs, fossil fuels dominate in energy supply. However, utilization of more fossil fuels results in increasing CO<sub>2</sub> emissions. The introduction of CCS for the future thermal power plant in Thailand is modeled in the multi-period linear programming MARKAL (MARKet ALlocation) model.
- Optimization of energy supply and demand in the power sector. In the same context, the objective of this study is to optimize the long-term energy supply and demand in Thailand with the potential of renewable energy on the low carbon fuels and technologies in the power sector.
- Comparison of the future power plants competitiveness. The paper describes the application of MARKAL (MARKet Allocation) for comparing economic parameters of the future power plant Thailand. The method is applied to determine competitive specific investment costs of power plants which are planned to be built in the future. The Thai MARKAL energy systems model has been used to investigate long-term planning in the electricity generation options.

### **Turkey**

- Determining optimum energy strategies. The TURKISH MARKAL model is available to analyze alternative scenarios in order to see their possible effects on our energy system. General structure of MARKAL model and the database architecture is overviewed by the group with an interdisciplinary approach.
- Establishing energy technologies selection and emissions mitigation strategies. This study has aimed at developing clear perception and mitigation options for energy-related emissions and

the economic costs of the different measures that can be taken in all Turkish energy sectors and at handling Turkish side of the problem as well as integrating to the world solution efforts.

- A Preliminary study for post-Kyoto period. With several input parameters of technology related, economic and environmental coefficients MARKAL calculates the alternatives for minimum possible cost. This article reports the results of the Turkish energy model that has been developed by using MARKAL Model Generator.

## **Ukraine**

- Achieving EU targets on renewable energy. According to a Government Decree, IEF was assigned to create information-analytic system for strategic planning of energy sector and projection of the energy balance, where TIMES-Ukraine model was supposed to be taken for the basis. The work on TIMES-Ukraine model started at IEF in 2006 in the framework of special research projects of Ukrainian National Academy of Sciences. In 2009 after joining SYNERGY project and with contribution from IRG and CRES experts the initial TIMES-Ukraine model was finished, however, the model update is performed quarterly.

## **United Kingdom**

- Future formulation and modelling of long-term bioenergy scenarios. This paper explores the prospects and policy implications for bioenergy to contribute to a long-term sustainable UK energy system. The UK MARKAL technology-focused energy systems dynamic cost optimisation model is enhanced with detailed representation of bio-energy chains and end-uses. This provides an important advance in linking bioenergy expert-knowledge with a whole system modelling approach, in order to better understand the potential role of bioenergy in an evolving energy system. A working paper also presents the detailed dataset used for the bioenergy chains of the BIOSYS-MARKAL model used for the TSEC-BIOSYS project modelling exercise.
- Accelerated development of bioenergy in the future energy mix. This work explores the potential contribution of bioenergy technologies to 60% and 80% carbon reductions in the UK energy system by 2050, by outlining the potential for accelerated technological development of bioenergy chains.
- Soft-linking MARKAL to a GIS to investigate spatial aspects of new hydrogen infrastructures. This paper describes an innovative modelling approach focusing on linking spatial (GIS) modelling of hydrogen supply, demands and infrastructures, anchored within a economy-wide energy systems model (MARKAL). The UK government is legislating a groundbreaking climate change mitigation target for a 60% CO<sub>2</sub> reduction by 2050, and has identified H<sub>2</sub> infrastructures and technologies as potentially playing a major role, notably in the transport sector.
- Impacts of long term decarbonisation targets on the energy system (60% by 2050). Range of technical, social and market challenges, combined with alternate market investment strategies mean that large scale deployment of key classes of low carbon electricity technologies is fraught with uncertainty. The UK MARKAL energy systems model has been used to investigate these long-term uncertainties in key electricity generation options. Another paper focuses on modelling of the residential sector in a system wide energy–economy models (UK MARKAL) and key UK sectoral housing stock models. In an energy system with 60% economy-wide CO<sub>2</sub> reductions, the residential sector plays a commensurate role.
- Analysis with the UK MARKAL & MARKAL-Macro (M-M) energy systems model. A major component of the development work was the integration of MARKAL with a neoclassical growth model (MARKAL-Macro), to facilitate direct calculation of macro-economic impacts from changes in the energy sector as well as endogenous behavioural change in energy service demands. The UK M–M model was developed for underpinning analysis of the UK's groundbreaking mandatory long-term –60% CO<sub>2</sub> emissions reduction target.

- The iterative contribution and relevance of modelling to energy policy. This paper discusses the iterative provision of modelling insights on long-term decarbonisation scenarios for UK energy policymakers. A multi-year model construction process of the UK MARKAL- Macro-hybrid energy-economic model, and four subsequent major policy analyses illustrates the scope of this interaction. This paper analyses the large number of long-term UK CO<sub>2</sub> reduction scenarios through a clustering approach on target stringency and barriers to implementation.
- Long-term scenarios for Low-Carbon Society (LCS). An international modelling comparison was undertaken by nine national teams, with a strong developing-country focus. Core model runs were a Base case, a Carbon price case (rising to 100/tCO<sub>2</sub> by 2050) and a Carbon-plus case to investigate an LCS scenario with a 50% reduction in global CO<sub>2</sub> emissions by 2050. In this context, an integrated set of LCS scenarios for the UK were analysed using the UK MARKAL Macro (M-M) model (285). A \$100/tCO<sub>2</sub> carbon price scenario was compared with long-term LCS scenarios with a domestic 80% CO<sub>2</sub> reduction target.
- Impacts of long term decarbonisation targets on the energy system (80% by 2050). The UK CO<sub>2</sub> reduction target has been strengthened to an 80% reduction (relative to 1990 levels); it has become legally binding through the Climate Change Bill. In this our first report, we begin by explaining why the UK should aim for an 80% reduction by 2050 and how that is attainable, and we then recommend the first three budgets that will define the path to 2022. Several studies have followed, for instance:
  - ⇒ A study that quantifies a range of policies, energy pathways, and sectoral trade-offs when combining mid- and long-term UK renewables and CO<sub>2</sub> reduction policies.
  - ⇒ A paper that investigates this dichotomy between the UK policy priority in reducing energy-related CO<sub>2</sub> emissions, and concerns over the feasibility, costs and achievability in meeting this unprecedented change in energy production and use.
  - ⇒ A paper that describes ongoing energy-economic modelling that seeks to better characterize uncertainties in long term UK decarbonisation transition pathways, specifically recognizing the iterative characterisation of UK decision making and the inherent nature of uncertainties in key UK and global assumptions that may only be resolved through time.
  - ⇒ A paper that present a new two-stage stochastic variant, which provides additional near-term insights for policy makers under future uncertainties. In this paper, the use of cumulative CO<sub>2</sub> targets, equivalent to 80% and 90% reductions by 2050 allow comparison between current UK policy and the modelled results.
- Pathways to a low carbon economy. This report is the first in the UKERC Energy 2050 project series. It focuses on a range of low carbon scenarios underpinned by energy systems analysis using the newly developed and updated UK MARKAL elastic demand (MED) model.
- Developing transition pathways for a low carbon electricity system in the UK. This paper describes the approach to developing transition pathways for a low carbon electricity system in the UK, being pursued in a major new inter-disciplinary research project. It also describes its application to several outline transition pathways to a low carbon energy system in the UK.
- Modelling a resilient energy scenario in the Elastic Demand (MED) version. This report explores ways of enhancing the “resilience” of the UK energy system to withstand external shocks and examines how such measures interact with those designed to reduce CO<sub>2</sub> emissions. Under the UK Energy Research Centre (UKERC) Energy 2050 project, four core scenario analyses have been undertaken to explore the pathways to a low carbon and resilient energy system. Within the analytical framework of the UK MARKAL elastic demand (MED) model, the resilient energy system has been characterised through diversity in energy supply and reducing the final energy

demand. A set of user-defined constraints have been chosen to model the resilient scenario in MED.

- Modelling transport energy demand in the Elastic Demand (MED) version. This paper addresses that gap by presenting a scenario exercise using an integrated suite of sectoral and whole systems models to explore potential energy pathways in the UK transport sector. Techno-economic driven scenarios are contrasted with one in which social change is strongly influenced by concerns about energy use, the environment and well-being.
- Analysis with the MARKAL-UK and TIAM-UCL energy systems model. UK energy policy makers must reconcile the persuasive impact of external international drivers with the national level implementation of CO<sub>2</sub> reduction legislation (-80% by 2050). This paper presents continuing work on combined modelling using partial equilibrium technology rich optimisation models; via UK MARKAL and via a new global model with a dedicated UK region (TIAM-UCL).
- Business-as-Unusual: Existing policies in energy model baselines. This paper argues that the range of existing energy and emissions policies are an integral part of any long-term baseline, and hence already represent a “with-policy” baseline, termed here a Business-as-Unusual (BAuU). To assess the long-term role of existing policies in energy modelling, currently identified UK policies are explicitly stripped out of the UK MARKAL Elastic Demand (MED) optimisation energy system model, to generate a BAuU (with-policy) and a REF (without policy) baseline.
- What are the costs of Scotland’s climate and renewable policies? This paper analyses the energy, economic and environmental implications of carbon and renewable electricity targets in Scotland and the UK using a newly developed two-region UK MARKAL energy system model, where Scotland (SCT) and rest of the UK (RUK) are the two regions.
- Modelling transport energy demand: A socio-technical approach. This paper addresses that gap by presenting a scenario exercise using an integrated suite of sectoral and whole systems models to explore potential energy pathways in the UK transport sector.
- Methodologies for representing the road transport sector in energy system models. In this paper, we review how different energy system models have represented both vehicles and fuel infrastructure in the past and we provide guidelines for their representation in the future. In particular, we identify three key modelling decisions: the degree of car market segmentation, the imposition of market share constraints and the use of lumpy investments to represent infrastructure. We examine each of these decisions in a case study using the UK MARKAL model.
- The future of the UK gas network. We examine potential future uses of the gas network in the UK energy system using an improved version of UK MARKAL that introduces a number of decarbonisation options for the gas network including bio-methane, hydrogen injection to the natural gas and conversion of the network to deliver hydrogen.
- The role of gas infrastructure in promoting UK energy security. This paper considers whether commercially driven investment in gas infrastructure is sufficient to provide security of gas supply or whether strategic investment encouraged by government is desirable. The paper focuses on the UK in the wider EU context. A modelling analysis of the impact of disruptions, lasting from days to months, at the UK’s largest piece of gas infrastructure is at the heart of the paper.
- Accelerating the development of marine energy. The paper describes a scenario for the accelerated development of marine energy technology, and the incorporation of this scenario into wider scenarios of UK energy system decarbonisation from now to 2050. Different combinations of these technology acceleration scenarios were then assembled together at the system level, and scenarios of UK energy system development from now to 2050 were generated using an energy systems model, the UK Markal MED model.

- Implications of sustainability constraints on UK bioenergy development. This paper uses UK MARKAL to examine the implications of adopting a precautionary approach to bioenergy development in the UK. The paper then examines the implications of these scenarios using the energy systems model MARKAL, finding that a precautionary approach adds to the cost of decarbonisation, but does not significantly alter the optimal technology mix.
- Spatial development of hydrogen economy. This paper presents a framework where a spatially explicit hydrogen module is embedded in the UK MARKAL Energy System model to explore energy system trade-offs for the production, delivery and use of hydrogen at the sub-national level.
- Possible hydrogen transitions in the UK. This paper presents a hybrid approach to assessing hydrogen transitions in the UK, by linking qualitative scenarios with quantitative energy systems modelling using the UK MARKAL model. Three possible transition pathways are explored, each exploring different uncertainties and possible decision points, with modelling used to inform and test key elements of each scenario.
- Conversion of the UK gas system to transport hydrogen. We review the technical feasibility of this option using semistructured interviews underpinned by a literature review and we assess the potential economic benefits using the UK MARKAL energy systems model.
- Critical mid-term uncertainties in long-term decarbonisation pathways. Over the next decade, large energy investments are required in the UK to meet growing energy service demands and legally binding emission targets under a pioneering policy agenda. We investigate the effect of two critical mid-term uncertainties on optimal near-term investment decisions using a two-stage stochastic energy system model.
- What are the key drivers of MAC curves? A partial-equilibrium modelling approach for the UK. This paper addresses the influence of several key parameters on MAC curves for the United Kingdom and the year 2030. A technology-rich energy system model, UK MARKAL, is used to derive the MAC curves.
- Costs and potentials of reducing CO<sub>2</sub> emissions in the UK domestic stock. This paper addresses the issue of abatement costs and potentials in the housing stock from a systems perspective in order to capture interactions and interdependencies with the wider energy system. Marginal abatement cost (MAC) curves for the UK residential sector are derived based on the energy systems model UK MARKAL in combination with decomposition analysis.
- Intertemporal issues and marginal abatement costs in the UK transport sector. An energy system model, UK MARKAL, is combined with decomposition analysis and sensitivity analysis to derive mitigation costs and emissions reduction potentials in the UK transport sector. The paper tests the robustness of a marginal abatement cost curve for the year 2030 for two parameters: path dependency and discount rate.
- The development and application of a temporal MARKAL energy system model using flexible time slicing. This paper reports on a methodology for temporal disaggregation in the widely applied energy service driven, technology rich, cost optimizing, linear programming MARKAL energy system model. A flexible time slicing feature is developed to enhance representation of diurnal and seasonal electricity demand curves through disaggregation of resource availability and energy service demands.

## **United States**

- Analysis of multi-pollutant policies for the power sector under uncertainty. We analyze how three uncertainties - electricity demand growth, natural gas prices, and power sector GHG regulations could affect electric power sector investment decisions and costs in the U.S. over the next four decades. A two-stage stochastic version of the energy-economy model MARKAL

simulates the market. We also calculate the value of policy coordination (VPC), the cost saved by avoiding surprise changes in policy. The basis of the below analyses is the USEPA National MARKAL database (version EPANMD07).

- Optimal strategies for achieving the objectives of the American clean energy and security act. A paper investigated cost-effective strategies to achieve the bills objectives for the Natural Resources Defense Council (NRDC) as part of its Cap 2.0 initiative. This paper presents detailed results from that effort using the US National MARKAL model (USNM-50) to identify least-cost technology and policy pathways for attaining these emissions reduction goals.
- US Technology Choices, Costs and Opportunities under the Climate Security Act. This presentation shows US technology choices, costs and opportunities under the Lieberman-Warner Climate Security Act, using the US National MARKAL model (USNM-50), a Comprehensive Energy System Planning Model.
- Energy efficiency and the benefits for CO<sub>2</sub> reduction. The EPA currently has two MARKAL databases representing the U.S. energy system available for public use: a 9 region representation based on the U.S. census divisions, the EPAUS9r, and an aggregate national representation, the EPANMD. Using the EPA MARKAL Model, this presentation deals with energy efficiency and the benefits for CO<sub>2</sub> reduction in the United States
- Energy demand analytics using coupled technological and economic models. This presentation looks at the impacts of a range of policy scenarios on end-use energy demand using a coupling of MARKAL, an energy system model with extensive supply and end-use technological detail, with Inforum LIFT, a large-scale model of the U.S. economy with inter-industry, government, and consumer behavioral dynamics. The work was done as part of the Energy Modeling Forum (EMF) 25, 'Efficiency and Shape of Future Energy Demand'
- Highlights of recent US climate policy analysis at Brookhaven National Lab. A series of scenario based analysis sponsored by the Office of Policy and International Affairs using the BNL's 10-region US MARKAL model focused on current climate energy bills, for example:
  - ⇒ The cap-and-trade program of the Climate Security Act. This presentation introduces an analysis of Climate Security Act (S. 2191) that establishes a cap on GHG emissions through a emission allowance program.
  - ⇒ Role of biomass-to-hydrogen in deep CO<sub>2</sub> emission reduction scenarios. The goal of this analysis is to explore the role that hydrogen technologies could play in meeting deep carbon emission reduction goals using the BNL's 10-region US MARKAL model. We focused on CO<sub>2</sub> caps from Waxman-Markey bill.
  - ⇒ The role of technology R&D in mitigating carbon emissions. This analysis utilizes parametric analysis to examine the potential for energy technology R&D to mitigate carbon emissions in the power generation sector. We are using a new 10-region U.S. MARKAL model of the U.S. energy system.
- Rethinking demand technology representation. The objective of our presentation is to initiate a discussion regarding different approaches to demand technology representation. To this end, we will review the residential and commercial sectors in the EPANMD and present alternative, simplified approaches for consideration.
- Implications of unilateral United States carbon policy. The administration of President Barack Obama has announced targets for US GHG emission reductions, of 80% lower than the present. In addition, a renewable portfolio standard (RPS) of 25% of generation and a low carbon fuel standard (LCFS) of at least 20% relative GHG reduction, both by 2030, have been announced. MARKAL was used to model the implications of these policy actions.

- Applications to economic impact analyses. EPA's Office of Air Quality Planning and Standards (OAQPS) and Office of Research and Development (ORD) are exploring the application of MARKAL to EPA's regulatory economic impact assessments. This presentation (322) will include an overview of a selection of these efforts and their future direction being conducted in the Air Benefits and Cost Group of the Health and Environmental Impacts Division of OAQPS.
- Macroeconomic policy analysis. This paper describes the conceptual framework of REMI-E3 using the application of the REMI PI+ macroeconomic model conjoined with the MARKAL/TIMES energy system model.
- Demand driven computational model of the US energy grid. A MARKET ALLOCATION (MARKAL) model is constructed using a bottom-up demand model from preexisting New York City Best Practice Model house hold data to simulate travel demand and energy consumption at a micro level. This approach creates a fine resolution dynamic demand market to drive a supply chain model which co-optimizes supply resources and load-reducing demand resources to maximize reliability and minimize costs in real-time.
- Multi-regional evaluation of the U.S. electricity sector under technology and policy uncertainties. We examine a number of different scenarios and explore their possible impacts on the future of energy system. We focus on future projections for electricity generation mix, electricity costs, emissions and emissions abatement costs under different scenarios. We have examined the key regulations through analyzing various assumptions using the MARKET ALLOCATION (MARKAL) model and the Environmental Protection Agency's Nine Region MARKAL Database (EPAUS9r).
- Alternative policy impacts on US GHG emissions and energy security. This study addresses the possible impacts of energy and climate policies, namely corporate average fleet efficiency (CAFE) standard, renewable fuel standard (RFS) and clean energy standard (CES), and an economy wide equivalent carbon tax on GHG emissions in the US to the year 2045. For this study, we use a hybrid energy modeling approach, MARKAL-Macro, that combines the characteristics of two divergent approaches, in order to investigate and quantify the cost of climate policies for the US and an equivalent carbon tax. In this study we use the national single region the US EPA MARKAL model.
- Analysis of US renewable fuels policies. In this research we have modified the standard US MARKAL model to include a land resource base, corn stover and miscanthus feedstocks, and new cost information for biochemical and thermochemical conversion technologies. We then used this revised MARKAL model to estimate the impacts of four different policy and technology choice scenarios.
- Integration of agricultural and energy system models for biofuel assessment. This paper presents a coupled modeling framework to capture the dynamic linkages between agricultural and energy markets that have been enhanced through the expansion of biofuel production, as well as the environmental impacts resulting from this expansion. The framework incorporates the interactions between agricultural and energy markets at the macro-level, and an assessment of production practices and environmental impacts at the micro (field)-level. For macro-level analysis, we use two existing modeling frameworks: the CARD U.S. agricultural markets model and the MARKAL energy systems model.
- Implications of energy policy on a product system's dynamic life-cycle environmental impact. We propose an integrated approach combining an energy-economic model with a life-cycle assessment to analyze the impacts of energy policies on the dynamic changes in the various environmental impacts of a product system. We employ the Market Allocation (MARKAL) framework to foresee the changes in several economic- and technological-parameters over specific periods for different energy policies.

### **United States - Georgia**

- State-scale evaluation of renewable electricity policy. We present a least-cost linear-optimization model of electricity generation using MARKAL that can be applied at the level of an individual state. The state-level model provides local and regional decision-makers with a basis for understanding the potential impacts of policy changes, and provides a basis for planning and policy analysis. We apply the model to address state-scale impacts of a renewable electricity standard (RES) and a carbon tax in one southeastern state, Georgia.
- The role of renewable electricity credits and carbon taxes. We have developed a state-scale version of the MARKAL energy optimization model, commonly used to model energy policy at the US national scale and internationally. We apply the model to address state-scale impacts of a renewable electricity standard (RES) and a carbon tax in one southeastern state, Georgia.

### **United States - Pennsylvania**

- Effectiveness of carbon mitigation strategies at the municipal level. In this paper, we describe our efforts to develop and apply MARKAL-family of models at two municipalities in Western Pennsylvania, and examine the responsiveness of the two energy and material systems to different policy instruments enacted at the state level and implemented at the municipal level. The legal framework at the state level, specifically, PA Act 129 and Act 213, provided the ex ante basis for modeling different scenarios, and the model outcomes provided clues on the effectiveness of existing measures to mitigate GHG emissions.

### **United States - California**

- Modeling Optimal Transition Pathways to a Low Carbon Economy. Our project goal is to develop an integrated system model that will identify optimized scenarios for meeting 2050 climate policy goals and evaluate the resource and economic impacts to the state of California. We focus on assessing low-carbon transportation energy futures for California.
- Deep greenhouse gas reduction scenarios for California. This paper describes an effort to fill this important gap, introducing CA-TIMES, a bottom-up, technologically-rich, integrated energy engineering and environmental economic systems model that has been developed to guide the long-term policy planning process. We find that meeting California's 80% emission reduction goal can be achieved through a combination of mitigation strategies.
- Renewable and low carbon hydrogen for California. This paper describes the development and use of a hydrogen infrastructure optimization model using the TIMES modeling framework, H2TIMES, to analyze hydrogen development in California to 2050. H2TIMES is a quasi-spatial model that develops the infrastructure to supply hydrogen fuel in order to meet demand in eight separate California regions in a least cost manner subject to various resource, technology and policy constraints.

### **United States - Colorado**

- Renewable energy development infrastructure project. A state-specific MARKAL model is developed to assess the state's renewable energy development potential for the Renewable Energy Development Infrastructure (REDI) project. The study concentrates on the electric power system of Colorado and presents the development of an energy system incorporating Renewable Energy Standards, Demand-Side Management and Energy Efficiency (DSM/EE) measures.

### **Vietnam**

- Internalizing externalities into capacity expansion planning: The case of electricity. This paper examines the impacts of including external costs such as environmental and health damages

from power production on power generation expansion planning in Vietnam. Using the MARKAL model and covering a 20-year period to 2025, the study shows that there are substantial changes in the generation structure in favor of renewable energy technologies and other low emitting technologies.

### ***MARKAL-TIMES Sub-National Models***

**Studies using MARKAL-TIMES Sub-National models are:**

#### **Western Region (China)**

- Energy development and west to east energy transfer. This paper describes Western China Sustainable Energy Development Model (WSED) to evaluate various energy development scenarios for western China. The model includes a Western China MARKAL model, a Computable General Equilibrium Model for Western China (WCGE), and an Energy Service Demand Projection Model (ESDP).

#### **Reunion Island (France)**

- Flexibility and reliability of the electricity sector in long-term planning. A series of presentations and papers focuses on the electricity sector and on problems of flexibility and reliability in power systems in order to improve results provided by long-term planning exercises. Flexibility needs are integrated as an additional criterion for new investment decisions in a MARKAL model dedicated to the French electricity sector, while reliability of supply in future power systems is dealt with a focus on the Reunion Island. A TIMES model dedicated to the electricity sector of the Reunion Island is also presented.

#### **Lombardy (Italy)**

- Regional energy planning. How does it possible to support the energy planning process taking into account environmental, technological, political and economic issues? An useful approach (not the unique) is the development of an energy model that is a mathematical simplified description of energy flows of the regional system, able to investigate different energy paths and the interrelations among all included sectors.

#### **Pavia (Italy)**

- The role of energy efficiency, renewables and cogeneration from biomass. The authors will report the results of an energy planning case study focused on the impact of the partial achievement of two of the EU commitment for the year 2020: 20% of the electricity (non-industrial use) from renewables and the reduction of 20% of residential electricity consumptions.
- The impact of tightening the EPB directive requirements vs. the promotion of renewable. The aim of this work, a case study for the Province of Pavia, Northern Italy, is to analyze and compare different energy development scenarios in order to provide a strategic assessment of measures for the local energy planners, through a bottom up approach with an optimization model (MARKAL Standard).

#### **Flores Island (Portugal)**

- The relevance of the energy resource dynamics in the mid/long-term energy planning models. This work analyzes different modeling methodologies for balancing the electricity supply sources and the electricity demand in systems with high penetration of intermittent renewable energy sources, such as wind and run-of-river hydro. These reasons and circumstances are illustrated for the Flores island (Azores) case study which has already achieved a share of 50% of renewable

energies in electricity production in 2009. This paper proposes to study the incorporation of dynamic renewable resources in the mid- and long-term modeling tools with three of the more used planning tools, LEAP, MARKAL/ TIMES and EnergyPLAN.

- The impact of demand side management strategies in the penetration of renewable electricity. This work analyzes the impact of demand side management strategies in the evolution of the electricity mix of Flores Island in the Azores archipelago which is characterized by high shares of renewable energy and therefore the introduction of more renewable energy sources makes it an interesting case study for testing innovative solutions. The electricity generation system is modeled in TIMES.
- Modeling hourly electricity dynamics for policy making in long-term scenarios. This paper presents an extension of the TIMES energy planning tool for investment decisions in electricity production that considers seasonal, daily and hourly supply and demand dynamics. The inclusion of these dynamics enables the model to produce more accurate results in what concerns the impact of introducing energy efficiency policies and the increased use of renewable energies.

#### **Southwest region (Sweden)**

- Biomass gasification in cost-optimized district heating systems. In this study, different applications of biomass gasification in connection to district heating (DH) are analysed and contrasted to conventional technology options. An application of the cost-optimizing energy system model MARKAL with a detailed description of the DH sector in a southwestern region of Sweden was developed within the study and used in the analysis.

#### **Kathmandu Valley (Nepal)**

- Energy and environmental implications of carbon emission targets. This paper analyzes the sectoral energy consumption pattern and emissions of CO<sub>2</sub> and local air pollutants in the Kathmandu Valley, Nepal. It also discusses the evolution of energy service demands, structure of energy supply system and emissions from various sectors under the base case scenario during 2005–2050. A long term energy system planning model of the Kathmandu Valley based on the MARKet ALlocation (MARKAL) framework is used for the analyses.

#### ***MARKAL-TIMES Local Models***

**Studies using MARKAL-TIMES local models are:**

#### **Urban planning in Salzburg (Austria)**

- Developing a Roadmap for the Future Energy Infrastructure in Salzburg. The main objective of the project is to develop a roadmap for the future energy infrastructure in the city of Salzburg with focus on optimising heat supply chains using mathematical energy models. The work focuses on the district heating system, while the methodology could well be extended to other fields.

#### **Rural Areas (Germany)**

- Spatial optimization of rural energy systems with focus on biomass. To offer small communities a decision support tool, a computer based optimization model for regional energy systems is developed. Using the data derived from the GIS models and the assumptions on harvesting and on energy conversion processes, the input data for the TIMES model are developed. In order to develop scenarios, assumptions on general conditions and future developments (e.g. oil and milk prices) are elaborated. The model is implemented as a case study for the municipality St. Roman in Austria and the results allow diverse analysis.

### **Rural and Urban Areas (Austria and Germany)**

- Energy models for urban planning. Three kinds of models were designed: 1) Models covering all sectors in the city. The first kind of model was applied in Greifswald and Oldenburg to define GHG emission targets. 2) A second kind of model was applied in Salzburg to define a strategy to enlarge the district heating system. 3) The last kind of model is mainly used to understand the possibility of rural areas to become self sufficient in regard of energy. The energy model is coupled with a simple land-use model which is also implemented in TIMES. Models of different sizes deals with different types of questions.
- Economic effects of GHG emissions reduction on a local level. This presentation focuses on the applications of a model for a middle-sized city. The investigation area is Greifswald in the northeast of Germany. The approach involves the development of an energy model and a simplified model of the local economy, using the TIMES framework.

### **Pesaro (Italy)**

- Municipal scale scenario. This work presents three 25-year energy scenarios developed with the TIMES model generator for Pesaro, a seaside municipality in central Italy. It evaluates the effectiveness of local-scale energy policies in three sectors: households, transport, and the public sector (PS).
- Local authorities in the context of energy and climate policy. This work analyzes the public administration's role in energy and climate policies by assessing carbon-lowering measures for properties and services managed directly by local governments in central Italy. The MARKAL-TIMES energy model was applied to long-term energy planning to assess the effect of low-carbon initiatives on public-sector energy consumption up to 2030.

### **Val d'Agri (Italy)**

- Integrated evaluation of the environmental impact of anthropogenic activities. An analytical methodology based on the integration of Life Cycle Assessment (LCA), ExternE and Comprehensive Analysis was developed to perform an in-depth investigation of energy systems. This paper presents an integrated application of these three methodologies to a local scale case study (the Val D'Agri area in Basilicata, Southern Italy), aimed to better characterise the environmental impacts of the energy system, with particular reference to extraction activities.

### **Madrid (Spain)**

- Market penetration analysis of the use of hydrogen in the road transport sector. This study therefore consists of the modelling and simulation of energy consumption, by type of vehicle and fuel or energetic vector, in the road transport sector of the Madrid Region, during the period 2010–2050, using the MARKAL model.

### **Beijing, Guangdong and Shanghai (China)**

- The future of natural gas consumption. In order to identify some of the important factors that might drive natural gas consumption in key demand areas in China, we focus (355) on three regions: Beijing, Guangdong, and Shanghai. Using the economic optimization model MARKAL, we initially assume that the drivers are government mandates of emissions standards, reform of the Chinese financial structure, the price and available supply of natural gas, and the rate of penetration of advanced power generating and end-use.
- Energy strategy of Chinese capital region under the new national policy of reducing carbon dioxide emissions. Chinese government committed to reducing carbon dioxide emissions per unit of GDP by 40% to and one of the biggest cites. The paper analysis the characteristics of

energy supply and energy consumption in Beijing, and setups the economic-energy-environment-oriented reference energy system (RES), selects MARKAL as the optimal model and constructs districted multi-period linear programming matrix.

#### **New York City (United States)**

- A tool for integrated energy, waste, water and GHG emission analysis. In this paper we describe our initial results of the construction of integrated urban energy-water-solid waste systems analysis frameworks (Urban MARKAL) for New York City and Long Island based on the MARKAL modeling platform.