ETSAP ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM

International Energy Agency

Implementing Agreement for a

Programme of Energy Technology Systems Analysis

Joint Studies for New and Mitigated Energy Systems

Summary and Table of Contents of the Final Report of Annex XI (2008-2010)

October 2011

Editors:

Kathleen Vaillancourt
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Summary

The Energy Technology Systems Analysis Program (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), first established in 1976. It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy/economy/environment/engineering (4E) analytical capability. Its backbone consists of individual national teams in nearly 70 countries, and a common, comparable and combinable methodology, mainly based on the MARKAL - TIMES family of technical-economic models, permitting the compilation of long term energy scenarios and in-depth national, multi-country, and global energy and environmental analyses. More on IEA-ETSAP activities, tools and users can be found at www.iea-etsap.org.

This report of the Annex XI "Joint Studies for New and Mitigated Energy Systems" summarizes over 350 references published between 2008 and 2010, including 86 peer-review articles, 7 Ph.D. theses, 9 books or book chapters, 120 research papers and reports, as well as numerous presentations.

The peer-review articles were published in a large variety of prestigious journals such as Energy Policy, Energy Procedia, Energy Economics, Applied Energy, Energy, Climate Policy, Environmental Modeling and Assessment, Environmental Modelling & Software, Renewable and Sustainable Energy Reviews, Computational Management Science, International Journal of greenhouse gas control, International journal of sustainable development and planning, International Journal of Sustainable Energy, International Journal of Hydrogen Energy, Fusion Engineering and Design, Fresenius Environmental Bulletin, Green Energy and Technology, European Journal of Scientific Research, Journal of Naval Science and Engineering, Technological Forecasting & Social Change, Biotechnology for Biofuels.

Most presentations were discussed at the IEA-ETSAP workshops, whose proceedings are posted at http://www.iea-etsap.org/web/Workshop.asp. By statute, ETSAP meets twice a year to exchange experiences, discuss ways to improve the tools and manage the common activities. Local experts are invited to these meetings so that they are exposed to the paradigm and can interact with the ETSAP participants from their country. These meetings are also held in non-Annex I countries and they often lead to collaborative model building projects with local and third party funds.

In this report, the studies and projects are organized by geographical coverage of the different models always following the same structure: a first part for the description of models and methodologies and a second part for the presentations of their various applications. Section 1 introduces the **Global Models**, including 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). Section 2 deals with **Regional Models**, mainly the Pan-European TIMES model, as well as MARKAL-TIMES Models for Europe, Asia and North America. Section 3 is dedicated to a large number of applications from **National Models** of 32 countries. Section 4 contains applications of **Sub-National Models** for Western China, Reunion Island (France), Lombardy (Italy), Pavia (Italy), Southwest region (Sweden) and Kathmandu Valley (Nepal). Finally, Section 5 presents **Local Models** 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).

Section 1 - Global Models

The IEA Energy Technology Perspective (ETP) model.

This global 15-region model permits the analysis of fuel and technology choices throughout the energy system. For this analysis, the IEA Secretariat co-operated with a number of modelling groups with national and/ or regional MARKAL and TIMES models for individual countries and regions have been used to assess the potential for CO_2 emissions reductions in China, OECD Europe and the United States. Using a techno-economic approach that assesses costs and benefits, ETP 2010 examines least-cost pathways for meeting energy policy goals while also proposing measures to overcome technical and policy barriers.

The most vital message of ETP 2010 is that an energy technology revolution is within reach. Achieving it will stretch the capacities of all energy-sector stakeholders and entail substantial upfront costs, but over the long term these will be more than offset by the benefits. Governments, investors and consumers around the world need to take bold, decisive action to initiate and advance change in their respective spheres of influence – and increase their commitment to working together.

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 developping countries in the design of a comprehensive worldwide climate policy to limit the global long-term temperature increase to $2^{o}C$, 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, we propose a dual approach, 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_{th} 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 ^{o}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^2 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.

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^{o}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_2 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 derived TIAM-FR Model

Some improvements investigated in TIAM-FR include modification of demand drivers, 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_2 mitigation targets during the period 2005-2050. This paper compares global efforts of CO_2 mitigation with regional climate policies expressed through targets pledged to UNFCCC and, finally discusses the impact of the development of CO_2 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 being implemented in two step, in order to study separately the two part of the water-energy nexus.

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_2 emissions from deforestation and N_2O 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 H2 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.

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_2 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_2 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.

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 15 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.

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.

Section 2 - 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_2 in the atmosphere at a level of 450 ppm in order to keep global temperature increase below 2^oC 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_2 storage in the Utsira aquifer in the North Sea. The FENCO ERA-NET project "Analysis of potentials and costs of storage of CO_2 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_2 into the Utsira formation as part of national or regional CO_2 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.

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.

- 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 Englang 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 preformed.

Section 3,4 & 5 – National, Sub-National, Local Models

There is a large number of references related to different applications of national models. By listing the most significant key words related to these studies, the table below gives a brief idea of the topics covered in 32 countries, as well as the number of references for each country in the last column.

Country	Topic	No of ref.
National models		**/peer rev.**
Bangladesh	mitigation scenarios, electricity sector	1 / 1
Belgium	EU climate change objectives, transport pricing, renewable energy, CCS, iron and steel, no-regret measures, households	5 / 1
China	CCS, zero coal emissions	4 / 2
Colombia	LNG, regional energy integration	1 / 1
Cuba	scenario analysis, electricity sector	2 / 1
Finland	CO2 emission trading, electricity markets	1 / 1
France	energy intensive industries, mitigation scenarios, households, burden sharing, prospective analysis, transportation sector, biomass and biofuels	9 / 1
Germany	projection, energy market trends	1 / 0
India	natural gas, electricity sector, outlook, large scale industries, nuclear, clean coal technologies, renewable energy, electrical system, parametric sensitivity analysis, national energy map, sustainable transport	8 / 5
Ireland	renewable energy targets, mitigation scenarios, electricity model	5 / 0
Italy	business as usual scenario, externalities, global and local air pollutants, deployment scenarios, hydrogen, cost-benefit analysis, electricity sector, nuclear option, electricity model, storage option, scenario analysis, national energy strategy	12 / 3
Japan	CDM activities, energy and life-cycle assessment, long-term scenario analysis, zero-carbon energy system	4 / 0

Country	Topic	No of ref.
Malaysia	energy modeling	1 / 1
Moldova	energy efficiency	2 / 0
Nepal	energy planning, policy analysis	2 / 0
Norway	global technology learning, mitigation scenarios, regional modelling, transportation, hydrogen, GIS coupling, infrastructure analysis, climate change impacts, high time resolution modeling	15 / 6
Portugal	cost analysis, energy policy, mitigation scenarios, air pollutants emissions, exogenous assumptions, uncertainty, GHG scenarios, forecasting, residential energy services demand	6 / 1
Russia	GHG scenarios, carbon reduction potentials, stochastic experiments, deterministic models	5 / 0
Slovenia	national energy system	1 / 0
South Africa	technology learning, renewable energy, mitigation scenarios, long-term mitigation scenarios, renewable electricity target	4 / 1
South Korea	mitigation scenarios	1 / 1
Spain	EU renewable directive	2 / 1
Sweden	ancillary benefits, climate policy, biomass use, bioenergy sector	3 / 1
Switzerland	energy–economic scenario analysis, Social MARKAL, behavioural changes, residential and commercial sectors, staff operating modes, IT appliances, Coupling with macro models, post-2012 climate policy, sustainability, neutrality, electricity model	12 / 1
Taiwan	long-term mitigation scenarios, electricity sector, energy prices, mitigation scenarios	2 / 1
The Netherlands	electricity sector, CCS, transboundary air pollution, integrated GIS-MARKAL toolbox, CO2 storage infrastructure and feasibility, Utsira formation	6 / 5
Thailand	co-benefits, mitigation scenarios, CCS, electricity sector, energy supply and demand, future power plants, competitiveness	7 / 2
Turkey	optimum energy strategies, energy technologies selection, emissions mitigation strategies, post-Kyoto period	8 / 1
Ukraine	EU renewable energy targets, coal sector development	3 / 0
United Kingdom	GIS linking, spatial aspects, hydrogen infrastructures, stringent decarbonisation targets, uncertainties, low carbon power technologies, residential sector, coupling with macro models, hybrid modelling, long-term mitigation scenarios, sensitivities, iterative contribution, energy policy, low carbon societies, low carbon economy, climate change policy, energy scenarios, long-term UK carbon reduction targets, elastic demands, transition pathways, low carbon electricity system, resilient energy scenario, transport energy demand, coupling with global models	37 / 13
United States	multi-pollutant policies, power sector, uncertainty, American Clean Energy and Security Act, Climate Security Act, optimal strategies, technology choices, energy efficiency, benefits for CO2 reduction, energy demand, coupled technological and economic models, recent US climate policy analysis, cap-and-trade program, biomass-to-hydrogen, deep CO2 emission scenarios, technology R&D, mitigating carbon emissions, demand technology representation, unilateral US carbon policy, economic impact analyses, macroeconomic policy analysis, demand driven computational model, US energy grid	19 / 2
Vietnam	internalizing externalities, capacity expansion planning, electricity	1 / 1

Sub-National models

Country	Topic	No of ref.
Western Region (China)	energy development, west to east energy transfer	1 / 1
California	optimal transition pathways, low carbon economy	2 / 0
Colorado	renewable energy development, infrastructure project	1 / 0
Georgia	renewable electricity policy, electricity generation model, lowest cost path, electricity demand, carbon cap-and-trade, renewable electricity credits, carbon taxes	3 / 1
Pennsylvania	carbon mitigation strategies, municipal level	2 / 0
Reunion Island (France)	flexibility and reliability, electricity sector, long-term planning	6 / 0
Lombardy (Italy)	regional energy planning	1 / 0
Pavia (Italy)	energy efficiency, cogeneration from biomass, EPB directive requirements, promotion of renewable energy	2 / 0
Southwest region (Sweden)	biomass gasification, district heating systems	1 / 1
Kathmandu Valley (Nepal)	carbon emission targets, energy implications	1 / 1
Local models		
Rural and Urban Areas (Austria and Germany)	future energy infrastructure roadmap, rural energy systems, urban planning, spatial optimization, biomass, GHG emissions reduction, different model sizes	6 / 1
Val d'Agri (Italy)	environmental impact, anthropogenic activities, comprehensive energy systems analysis tool, decision making	2 / 1
Madrid (Spain)	market penetration analysis, hydrogen, road transport sector	1 / 1
Beijing, Guangdong and Shanghai (China)	natural gas consumption	1 / 1
New York City (United States)	integrated analysis tool, energy, waste, water, GHG emission	1 / 0

Table of Contents