# “Overview of Models in Use for Mitigation/Adaptation Policy”

**Task Leader**: Prof. Bernhard Felderer,

*Institute of Advanced Studies (IHS),*

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This report has been read, commented and approved by all members of the PROMITHEAS-4 Scientific Committee.

It was also disseminated for comments, through BSEC – PERMIS and BSEC – BC, to all relevant governmental and business authorities and partners before its finalization.

Partners from the beneficiary countries* of the consortium were encouraged to contact direct national authorities, agencies, institutions and market stakeholder for comments before the finalization of this report (Annex 1).

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# Table of Abbreviations

| | |
|---|---|
| ADAM | Title of the "Adaptation and Mitigation Strategies: Supporting European Climate Policy" project |
| BAU | Business As Usual |
| CCS | Carbon Capture and Storage |
| CEEESA | Centre for Energy, Environmental and Economic Systems Analysis |
| CES | Constant Elasticity of Substitution |
| EARDF | European Agricultural Rural Development Fund |
| EC | European Commission |
| EFOM | Energy Flow Optimization Model |
| ENPEP | Energy and Power Evaluation program |
| ERDF | European Regional Development Fund |
| ESF | European Social Fund |
| ETSAP | Energy Technology and Systems Analysis Program |
| FAIR | Framework to Assess International Regimes for differentiation of commitments |
| GAMS | General Algebraic Modeling System |
| GDP | Gross Domestic Product |
| GHG | GreenHouse Gas |
| IAEA | International Atomic Energy Agency |
| IAM | Integrated Assessment Model |
| IHS | Institut für Höhere Studien (Institute for Advanced Studies) |
| IIASA | International Institute for Applied Systems Analysis |
| IEA | International Energy Agency |
| IMAGE | Integrated Model to Assess the Global Environment |
| IPCC | Intergovernmental Panel on Climate Change |
| LEAP | Long-range Energy Alternatives Planning |
| M/A | Mitigation/Adaptation |
| MARKAL | Market Allocation (Model) |
| MERCI | Model for Evaluating Regional Climate change Impacts |
| MESSAGE | Model for Energy Supply Strategy Alternatives and their General Environmental (Impact) |
| MNP | Milieu en Natuur Planbureau (Netherlands Environmental Assessment Agency) |
| NAPA | National Adaptation Programs for Action |
| OECD | Organisation for Economic Co-operation and Development |
| R&D | Research and Development |
| RES | Reference Energy Scenario |
| RES | Renewable Energy Sources |
| RIVM | Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Health and Environment) |
| SEI | Stockholm Environment Institute |
| TED | Technology and Environmental Database |
| TIMES | The Integrated MARKAL-EFOM System |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WEM | World Energy Model |

# Introduction

This report provides an overview of models that should be considered to be used for developing and quantifying adaptation and mitigation scenarios for the countries of the Black Sea Region. These models are evaluated according to the specific aspects to be regarded for the emerging economies of the countries in question, according to the advantages or disadvantages when using them for scientific and public purposes, as well as according to their terms and costs of use.

The challenges of developing a stable and sustainable energy system are manifold. Research in the industrial countries was conducted on a very broad range, however, it still has to be clarified if and how these research results can be applied to the situation in emerging economies. This is the focus of the PROMITHEAS-4 project: to develop and evaluate mitigation and adaptation policy portfolios, together with a characterization of research needs and gaps in this area. Countries of the Black Sea Region are the predominantly targeted emerging economies of this project: Albania, Armenia, Azerbaijan, Bulgaria, Moldova, Romania, Russian Federation, Serbia, Turkey and Ukraine. Estonia and Kazakhstan are also included in the beneficiary countries of this project. Their economic characteristics, however, are comparable to the ones of the Black Sea Region. The assessment of the main characteristics of emerging economies in this region will be crucial for the suitability of energy models for the use in generating M/A policy portfolios in these countries. As Urban F. *et al* (2007) have elaborated, there is reason to question the use of energy models developed in/for industrialised countries in developing countries. They find that the characteristics of the energy systems and economies of developing countries differ from those in industrialised countries in the following aspects, which apply to developing countries' energy systems:

- The electricity supply of the economy is not functioning optimally;
- The electrification rates are much lower relative to industrialized countries;
- Predominant use of traditional bio-fuels;
- The tariffs are often below long-term marginal cost of production and many bills will never be paid;
- A widespread informal economy;
- Developing countries may not follow the same trajectory towards industrialisation as today's industrialized countries did;
- The urban-rural divide causing high distribution differences within countries and regions;
- Abuse or inadequate use of subsidies;

(Urban F. *et al*. 2007, p. 3474 ff).

Data from "Procedures, sources, and data for Mitigation / Adaptation for policy portfolios" report could be used to clarify the following question: What exactly are the specific requirements for emerging economies? There is little literature dealing with this specific issue.

The situation in the Black Sea Region is of course a different one to that of developing countries. However, it is important to bear in mind that energy models in use for industrialised countries may yield insufficient or misleading outcomes for emerging economies. Therefore, a short description of the economic situation in the Black Sea Region is important for the comparison of different energy modelling tools. After defining the characteristics the models should incorporate, we will analyse them from this perspective.

A concise description of the current economic situation in the Black Sea Region can be found in a policy report prepared by the Commission on the Black Sea (Gavras, 2010). After 1999 the region experienced a period of high growth rates, growing government credibility, improvement of the legal system, low government deficits, and rapid movement towards a well functioning market-oriented economic system.

However, the financial crisis of 2008 brought this upward trend to a halt. Especially the large decrease in investment inflows into the region caused serious problems, although the situation differs among the countries. Obtaining funds became difficult, since investment into the region's countries is perceived to carry higher risks and risk aversion is reaching high levels during the current financial crisis. Through lower credit ratings (there are other factors determining a country's risk as well, but this is the most prominent one) the cost of financing budget deficits and undertaking investments rises. Furthermore, the economies have little possibilities to conduct effective stimulus programmes (Gavras p. 7ff, p. 13ff).

After having provided a very brief sketch of the economic framework within which any model employed by the PROMITHEAS-4 project will operate, we have to look at what kinds of models are eligible for use. The final set of models included in this study consist of the following models: MARKAL/TIMES, ENPEP-BALANCE, MESSAGE, LEAP, IMAGE and MERCI.

A wide spectrum of models has been developed over the past thirty (30) years, which by far cannot be covered within this project. We therefore selected the most renowned models that, in advance, were considered to be best suited for the PROMITHEAS-4 project. Moreover, the set of models is such that at least one simulation, economic equilibrium or optimisation[1] model is included. PRIMES, for example, which is also a renowned simulation model, is not included because it is similar to ENPEP-BALANCE. Similarly, EnergyPLAN is also a simulation model, which was not included, since otherwise the simulation models would be overrepresented. Important for the inclusion of a model within our study was its suitability for emerging economies, such as evolved by Bhattacharyya and Timilsina (2010), as well as by Urban *et al.* (2007). E.g. PRIMES and EnergyPLAN are not mentioned within these studies. Another considered criterion was the availability of model applications on a national level and moreover, in countries of the Black Sea region (e.g. PRIMES is predominantly used at European level and databases are not available for many countries; the World Energy Model (WEM), although mentioned by Urban *et al.* (2007), is mainly employed at a global scale and therefore not included herein).

Summarising, there is a vast number of models that could be included within this overview. However, we decided to choose the most representative ones for each modelling category (simulation,

[1] These categories will be explained in more detail in the next two sections.

optimisation and economic equilibrium), as well as those with the highest probability to be suited for emerging economies within the Black Sea region.

As the selected model will be used to design integrated M/A scenario portfolios, comprising environmental, technological, economic and policy problems, we have to focus on integrated assessment models that are able to deliver this purpose. Thus, before we can begin with a modelling overview, we have to look at the requirements these models have to fulfil, i.e. what we understand as integrated scenarios.

## Integrated Scenarios

As it is elaborated on in the final report of the ADAM (*Adaptation and Mitigation Strategies: Supporting European Climate Policy*) project, adaptation and mitigation, even though some consider them as alternative strategies to deal with climate change, should not be regarded as mutually exclusive (Hulme *et al.*, p. 8). Thus, any policy portfolio designed for the PROMITHEAS-4 project should involve mitigation as well as adaptation strategies, not only trying to limit the global temperature increase to 2°C (which would involve already a high level of mitigation activities, see Hulme *et al.,* p. 8), but also include measures to deal with the effects of this temperature increase or a larger one of up to 4°C.

Generally, a scenario should be seen as **time paths of key variables**, which are exogenously specified and then used as inputs driving other parts of an assessment (Parson and Fisher-Vanden, 1997, p. 595). Viewed in the context of energy-economy-environmental modelling, then, scenarios are story-lines about how an energy system might evolve over time[2]. However, an M/A scenario will not only have to consider the development of the energy system and the emission patterns it induces (mitigation), but also take into account the regional aspects of adaptive measures.

Therefore, while *mitigation*, seen as identification of the appropriate set of energy efficient and renewable energy technologies, has been intensively studied and has a common knowledge base, e.g. a unified technological database, defined expectations for technological progress, etc., *adaptation* includes responses to the predicted impact of climate change and is highly dependent on local conditions and on national priorities. Thus, any modelling effort has to be supported by a model that is flexible enough to consider regional, local, and national aspects of adapting to climate change.

As has emerged from the recent discussion on climate change policies (both at European and global level), adaptation represents a new priority for policy makers, which also has to be taken into account when constructing policy portfolios. This requires not only a change in attitude, but also a change in the scale of priorities for both policy makers and scientists. In a complex financial framework such as that present for the European Union, a change in the scale of priorities, to be effective, must correspond to a shift of budgetary allocations. This step has high-level political implications and therefore needs to be dealt with in a wider framework which critically evaluates all current EU policies and priorities (e.g. cohesion, competitiveness, growth, infrastructure, etc.) (Lavalle, 2009, p. 4).

In order to take on this matter, the European Commission has issued a White Paper, "Adapting to climate change: Towards a European framework for action" (EC White Paper in the following) in 2009 as its latest formal proposal. This White Paper is based on a phased approach, the first of which will last for the period 2009-2012, preparing a comprehensive EU adaptation strategy, which is then to be

[2] UNFCCC "Module 5.1 – Mitigation Methods and Tools in the Energy Sector" 2006:55

implemented in phase 2 starting from 2013 (see EC White Paper, p. 7). Phase 1 is based on four (4) main pillars (EC White Paper, p. 7):

1) building a solid knowledge base on the impact and consequences of climate change for the EU;
2) integrating adaptation into EU key policy areas;
3) employing a combination of policy instruments to ensure effective delivery of adaptation and;
4) stepping up international cooperation on adaptation.

In order for this phase 1 to work, national, regional and local authorities have to cooperate closely. The EU provides funding for financing adaptation measures, amongst other through the following sources:

- The Common Agricultural Policy and Rural Development (EARDF);
- The Structural Fund (ERDF);
- The European Solidarity Fund (ESF);
- Civil Protection Mechanism.

To encourage developing countries and emerging economies to prepare for the expected impacts of climate change, the United Nations Framework Convention on Climate Change (UNFCCC) proposes to develop National Adaptation Programs for Action (NAPA)[3], including information, among other things, on climate change induced natural hazards like floods, droughts, heat waves, heavy rainfall, hurricanes, and tornadoes.

Even though the NAPAs are rather designed for less developed countries, which stand in contrast to the emerging economies of the Black Sea region, it seems clear that any adaptation strategy is subject to a larger framework at the EU and global level, which is being developed at this very moment.

All of these facts point to the conclusion that only a selected number of Integrated Assessment Models for Adaptation/Mitigation (IAMs) are eligible for use by the PROMITHEAS-4 project. However, one has to say that most models primarily focus on mitigation issues, and that adaptation, if present in the models, can only be implicitly depicted in the majority of cases. Therefore, adaptation issues probably will have to be dealt with also outside of a formal modelling environment, defining the adaptation part of an M/A policy portfolio predominantly based on regional economic and environmental specifics.

After an introduction into the class of IAMs, a selection of those that come into question for the PROMITHEAS-4 project will be evaluated.

[3] http://unfccc.int/national_reports/napa/items/2719.php

## Integrated Assessment Models for Adaptation/Mitigation

Before one can talk of an assessment model, it is crucial to define this term. If one follows the literature, assessment is described as

> "social processes that bridge the domains of knowledge and decision-making, assembling and synthesizinig expert scientific or technical knowledge to advise policy or decision-making".
>
> (Parson, Fisher-Vanden, 1997, p. 590, see also Parson, 1995, and Weyant *et al.*, 1996)

One way to achieve such an assessment is by employing a formal modelling environment that represents the complex relationships underlying the to-be-assessed problem field, as opposed to e.g. deliberation by interdisciplinary expert panels (see Parson, Fisher-Vanden, 1997, p. 591). The Promitheas-4 project has chosen to rely mainly on a formal modelling environment to construct M/A policy portfolios for the beneficiary countries.

Integrated assessment models, now, can deliver this purpose by combining socio-economic dimensions of climate change with systemic aspects of technological alternatives in order to address policy options and environmental impacts of climate change. In general, IAMs attempt to employ one or several of three methods associated with each other, in a combined or stand-alone form, to project emissions and with them climate change (Parson, Fisher-Vanden, 1997, p. 595): *emission scenarios* (externally specified), an accurate *bottom-up representation of technologies* for the production of energy and other goods, and *economic modelling in an aggregate form* (e.g. taking account of economic equilibrium conditions). Common to all these approaches are predictions of the future in a speculative form, who only "differ in the detail and explicitness of different components of the projections" (Parson, Fisher-Vanden, 1997, p. 595).

Given the speculative nature of these models, they serve as a means to estimate costs and benefits of policy options, always related to a possible future development of the social, economical and environmental system, all of them being dependent on each other to a certain extent. Hence, they can be used to (Dickinson, 2007, p.7):

- Assess climate change control policies (Weyant *et al.*, 1996);
- Create interdisciplinary frameworks;
- Address climate change problems including determining influential forces that make sectors sensitive to climate change;
- Quantify environmental and non-environmental problems resulting from climate change by ranking climate change control benefits and detriments in developed and emerging economies, as well as developing countries (IPCC, 2001).

IAMs can be divided into three (3) types of models: *simulation*, *economic equilibrium* and *optimisation models* (see e.g. Urban F. *et al.*, p.3479). However, Bhattacharyya and Timilsina (2010) use a different type of categorisation, especially designed for energy system models (see Bhattacharyya, p. 501):

- bottom-up, optimisation-based models (such as e.g. MARKAL);
- bottom-up, accounting models (such as e.g. LEAP);
- top-down, econometric models;
- hybrid models (such as e.g. MERCI);
- electricity system models.

Which categorisation is used will depend on the characteristics one wants to include in the differentiation of the models. For the purposes of this report, the categorisation from Urban F. et al. (2007), which essentially is an adaptation of a model classification system proposed by Van Beeck (1999,2003) and not much different to the one of Bhattacharyya and Timilsina (2010), has been chosen as the most suitable. The different aspects to and specifics of the different model classes are described in brief in Table 1 below.

**Table 1:** Integrated Assessment Models Comparison Chart

| **MODEL** | **Simulation IAMs** | **Economic Equilibrium IAMs** | **Optimisation IAMs** |
|---|---|---|---|
| Use | To simulate and approximate the environmental results of a selected policy option | To assess overall economic development and ecological impacts simultaneously | To identify optimal policies e.g. of climate change control options |
| Scale | Individual portfolio of policy options or chosen scenarios | Global or national level | Usually global |
| Description | Through the use of scenarios based on user-defined assumptions, a portfolio of policy options is produced | Finds a new economic equilibrium based on exogenously specified scenarios, endogenously finding optimal control variables | Determines the policy path that maximizes utility, or minimizes costs, while imitating the effects of mitigation on the global/local economy |
| Examples | LEAP, IMAGE, ENPEP | MERCI | MARKAL/TIMES, MESSAGE |

Source: Dickinson, 2007, p.8, Urban F. et al, p. 3479, Authors.

Integrated Assessment models were first designed beginning from the 1990's, when the focus of policy makers and the scientific community shifted towards energy-environment interactions and climate change related issues (Bhattacharyya and Timilsina, 2010, p. 498). To depict these environmental issues, some extensions to energy system models were close at hand (Bhattacharyya and Timilsina, 2019, p. 498):

- accounting models, i.e. models based on energy balances (see Bhattacharyy and Timilsina, 2010, p. 496), were able to incorporate environmental effects in relation to energy production, conversion and use by including an appropriate set of environmental coefficients;
- network-based models, i.e. models extending the energy balance framework to a network description of the energy system capturing all activities involved in the entire supply chain (see Bhattacharyy and Timilsina 2010, p. 496), could similarly estimate environmental burdens employing environmental pollution coefficients and evaluating the economic impacts by considering costs of mitigation;
- energy models with macro linkage could analyse the allocation issues taking account of the overall economic implications.

Bhattacharyya and Timilsina (2010) come to the conclusion that what they call models of bottom-up accounting type (or simulation IAMs, in the classification of this report) are best suited for the representation of energy systems for developing countries, mostly because of their flexibility, limited skill requirements (Bhattacharyya and Timilsina, 2010, p. 501), and because they can account for several specifics of developing countries.

Under the conditions delineated above, potential integrated scenario-based assessment models that include mitigation and adaptation were considered as a result of an extensive literature search, parts of which are presented in the next sessions and after communications with key Partners during the kick-off meeting, 3rd-4th March 2011, Athens.

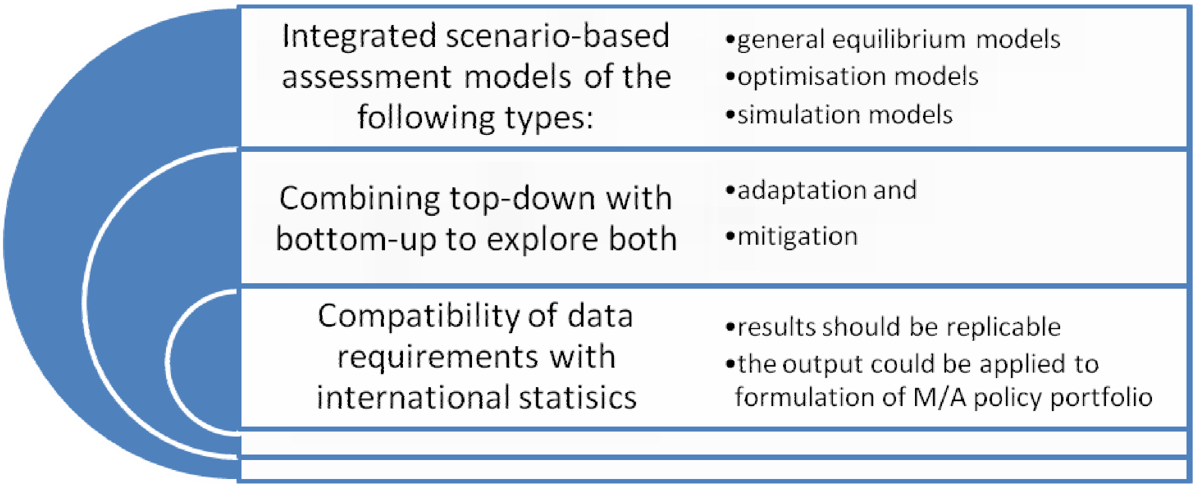


**Figure 1: Criteria for Models to be Included in this Overview**

Source: Authors.

The models subsequently described in this overview are presented in Table 2 below. The following overview is based on (a) model documentations, (b) existing research reports, (c) articles in scientific journals and (d) model websites.

**Table 2: List of Models to be surveyed**

| MODEL NAME | Organisation / Author | FURTHER INFORMATION | Availability |
|---|---|---|---|
| MARKAL / TIMES | The Energy Technology Systems Analysis Program (ETSAP), IEA | www.etsap.org | Source code free /Simulators to be purchased |
| ENPEP-BALANCE | Argonne National Laboratory. Energy and Power Evaluation Program | http://www.dis.anl.gov/projects/Enpepwin.html | Free to Download |
| MESSAGE III | IIASA, Laxenburg, Austria | Messner S., Strubegger M., (1995), User's Guide for MESSAGE III, IIASA, WP-95-069 | Commercial |
| LEAP | Stockholm Environment Institute – Boston Center | http://www.energycommunity.org/ | Free for developing countries |
| IMAGE | the Netherlands Environmental Assessment Agency | http://www.rivm.nl/bibliotheek/rapporten/500110002.pdf | Upon a cooperation agreement |
| MERCI / ATHDM E3 | IHS, Vienna, Austria | Miess M., Schmelzer S., Balabanov T. (2010), The Austrian Hybrid Dynamic Model E3: Methodology, Application and Validation, IHS internal WP | Work in progress |

Source: Authors.

## MARKAL/TIMES

The acronym "MARKAL" stands for *MARKet ALlocation*. This model was first developed by the Brookhaven National Laboratory in the late 1970's. In 1978 the Energy Technology and Systems Analysis Program (ETSAP) was established by the International Energy Agency (IEA) to pursue further development of the model. Since then, a whole family of models was created and most recently the TIMES (The Integrated MARKAL-EFOM[4] System) model was introduced as a successor of MARKAL[5].

**Main facts**

- Dynamic partial equilibrium model
- Bottom-up; exogenous energy demand
- Main focus: emissions, technology, R&D
- Applicable locally, regionally and globally
- Total surplus maximisation of consumers and producers

Source: Loulou et al. (2004); Bhattacharyya and Timilsina (2010)

### Specific Characteristics of MARKAL

The MARKAL model facilitates the analysis of different future energy system pathways over a medium to long term, by integrating energy, environmental, and economic factors. Since the development of MARKAL, many extensions were introduced. The model originally started out using a linear programming approach that focused entirely on the integrated assessment of energy systems. The developed amplifications went from the introduction of non-linear programming, combining a 'bottom-up[6]' modelling technique with a 'top-down' macro-economic view, to the application of stochastic programming, which allowed addressing future uncertainties, to model multiple regions (Seebregts *et al*. 2001).

The model works with a user defined map (Reference Energy System) of the energy system which contains information on the following features (Seebregts *et al*. 2001):

- Conversion of energy (e.g. power plants, refineries, solar plants)

[4] EFOM (Energy Flow Optimization *Model*) is another bottom-up energy model on which the TIMES model is based upon.
[5] However, MARKAL still can be used if necessary.
[6] I.e., the specific technological features of the energy sector are accounted for explicitly.

- Primary supply of energy carriers (e.g. mining, petroleum extraction);
- Consumption of energy (e.g. industrial energy use, vehicles);
- Demand[7] (exogenous, forecasts have to be produced outside the model);
- Technical characteristics;
- Technology costs.

With respect to the exogenously given end-use energy demand level, the model estimates a discrete supply curve. Therefore, all quantities and prices are in equilibrium (suppliers produce exactly the amount demanded by consumers) (Loulou *et al.* 2004). A portfolio is provided with a cost minimising set of energy resources, energy carriers, transformation technologies, etc; which satisfy the user defined constraints (e.g. energy balance, electrical system operation, emission caps, technology portfolio standards, taxes, etc.). More importantly, the model quantifies the environmental emissions resulting from this portfolio (Seebregts *et al*. 2001; Johnson 2004).

The MARKAL model has typically been employed to address issues related to carbon dioxide emission reduction, technology dynamics and R&D (Seebregts *et al*. 2001). "The specification of new technologies, which are less energy- or carbon-intensive, allows the user to explore the effects of these choices on total system costs, changes in fuel and technology mix, and the levels of greenhouse gases and other emissions." (Seebregts *et al*., 2001)

Johnson (2004) presents exemplary questions which can be investigated by the MARKAL model:

- What happens if a new technology becomes available, or if an old one becomes cheaper or more efficient?
- What are the implications of a technology forcing policy (e.g., a renewable portfolio standard)?
- How do changes in technology, environmental policy, and resource availability/costs interact?

As Bhattacharyya and Timilsina (2010) conclude, this model is among the better suited ones to be used for the specific needs in developing countries, and in our case, emerging economies, however, if compared to a bottom-up accounting type of model (as LEAP) it misses some important features of these countries (e.g. including the degree of the informal sector, energy shortages, the degree of economic transition).

## *Specific Characteristics of TIMES*

The TIMES model, as it was previously stated, is based on the MARKAL modelling paradigm. The "Documentation for the TIMES Model Part I" (Loulou *et al.* 2004, p. 52) summarises the main differences between the MARKAL and the TIMES model. The main are:

[7]Demand can be disaggregated by sector and by functions in the sector.

- User defined period lengths (e.g. small steps within the first few periods, greater durations thereafter);
- Greater user flexibility in input data specification independent of time periods (matching is done by the model);
- User-chosen time-slices of commodities;
- Processes in different Reference Energy System sectors have the same basic features, activated by data specification;
- Greater specification possibility of commodity-related criteria;
- Investment payments can be timed more accurately and it is possible to define time-dependent discount rates.

The TIMES model operates with user-provided estimates of energy related equipment in all sectors, characteristics of available technologies, together with present and future energy sources and their potentials (Loulou *et al.* 2004, p.7).

## Evaluation of MARKAL/TIMES

Urban *et al.* (2007; p.3478) find that MARKAL accounts for a medium number of developing countries characteristics, such as: electrification, traditional-bio fuels, urban-rural divide, subsidies, emission training and a wide assessment of renewable energies.

The MARKAL or TIMES models, respectively, have been used in numerous national and regional studies. The European Commission has used the TIMES model for the evaluation of the Renewable Energy Strategy for 2020 (RES2020). Further, the TIMES model (among others) was applied to optimise the Electricity, Heat and Natural Gas Markets of the EU-25. Sulkan et al. (2010) found the MARKAL model useful in modelling alternative energy futures for Turkey. Various Estonian doctoral theses[8] and studies have been conducted using MARKAL, among them "Reduction of $CO_2$ emissions in Estonia during 2000-2030" by Agabus *et al.* (2007). Also in Moldova MARKAL was applied to investigate energy efficiency measures and renewable energy sources implementation possibilities. The preliminary results of this study can be found in "MARKAL Application for Analysis of Energy Efficiency measures and Renewable Energy Sources" by Robu *et al.* (2010)

| Evaluation Criteria | Description |
|---|---|
| Methodology | Optimisation approach creating a dynamic partial equilibrium including all user provided energy sector specifics |
| Transparency, complexity, easiness of use | Technology-rich energy/economic/environmental model that requires long preparatory work |

[8] "Long-Term Capacity Planning and Feasibility of Nuclear Power in Estonia Under Uncertain Conditions" by Landsberg (2008) and "Large-Scale Integration of Wind Energy into the Power System Considering the Uncertainty Information" by Agabus (2009).

| | |
|---|---|
| Data requirements & software requirements | Medium to high data requirement, including estimates of: energy related equipment in all sectors, characteristics of available technologies, present and future energy sources and their potentials; GAMS (General Algebraic Modeling System) is required; Windows based |
| Costs | Cost per user for educational license: €1.200– €3.000; for the 12 beneficiaries the licensing costs could reach € 30.000 |
| Level of coverage of M/A issues | MARKAL-MACRO: provides for endogenous and price responsive demands, and estimates of GDP impact and feedbacks;<br>Allows certain behavioural characteristics of observed markets to be reproduced |
| Compliance of outputs with projects objectives | Used to simulate European Commission integrated policies on the use of renewable sources, climate change mitigation and energy efficiency improvement, the so called 20–20–20 targets, and far more stringent M/A targets in the longer term at the national and pan EU level |
| Availability of training and technical support | The most demanding and expensive part of MARKAL/TIMES is the training of 8 days €22.000-€30.000; however, broad documentation is available resulting from the wide use of the model; Costs of Technical support: €500-€1.800 for one year |
| International recognition | Most widely used bottom-up optimisation model; used in > 40 countries |

Sources: http://www.etsap.org/; Loulou *et al.*2004; UNFCCC 2006.

## ENPEP-BALANCE

The Energy and Power Evaluation Program (ENPEP) was developed in 1999 by the Centre for Energy, Environmental and Economic Systems Analysis (CEEESA[9] - Argonne National Laboratory in the USA) and the U.S. Department of Energy (DOE). It is now used in over 80 countries. BALANCE is one of ten (10)[10] integrated energy, environmental and energy analysis tools named by the UNFCCC in its 2006 report on mitigation assessment (UNFCCC 2006, p.39).

| Main facts |
| --- |
| • Non-linear, iterative equilibrium<br>• Bottom-up, exogenous energy demand<br>• Graphical user interface<br>• Applicable locally, regionally and globally<br>• Market share algorithm for the solution process of the energy system |

Sources: Argonne National Laboratory 2008; UNFCCC 2006 "

### *Specific Characteristics of ENPEP-BALANCE*

The ENPEP-BALANCE Model uses the following input parameters: energy system structure, base year energy statistics (with production levels, consumption levels and prices included), energy demand growth projections as well as technical and policy constraints. With this information, an energy network is created graphically and configured by the user. The developers stress the importance of the model applying a market share algorithm. Through this it is possible to estimate the penetration of supply alternatives (Argonne National Laboratory 2008, p.1). "The equilibrium solution develops an energy system configuration that balances the conflicting demands, objectives, and market forces without optimizing across all sectors of the economy" (Argonne National Laboratory 2008, p.2).

This equilibrium solution, i.e., the set of market clearing prices and quantities, is found by the simultaneous intersection of supply and demand curves for all energy forms, as depicted in the network structure (Argonne National Laboratory 2008, p.2). Regarding environmental issues, BALANCE calculates green house gas emissions, local air pollutants (such as $SO_X$, $NO_X$, CO, $CO_2$, and methane), water pollution and land use (UNFCCC 2006, p. 39; Argonne National Laboratory 2008, p.3).

[9] CEEESA – Center for Energy, Environmental, and Economic Systems Analysis;
[10] The nine modules are: MACRO-E, MAED, LOAD, PC-VALORAGUA, WASP, GTMax, ICARUS, IMPACTS and DAM.

The model allows for an annual analysis over a time horizon of up to 75 years (Connolly 2010:1069).

The model, being a simulation type of model, allows for better incorporation of non-price factors in the analysis. This is of particular importance if emerging or developing country features are being considered.

## *Evaluation of ENPEP-BALANCE*

The model was applied in various studies[11], among them the following involving participating economies of PROMITHEAS-4: A regional European project to evaluate various GHG mitigation options conducted studies for 10 countries including Bulgaria, Turkey and Ukraine; A World Bank Project to develop an Energy and Environmental Review for Bulgaria (The World Bank 2001); A CEEESA project together with the Romanian Institute of Power Studies and Design to develop a long-term energy strategy for Romania (Koritarov et al. 1998); And a CEEESA project to analyse carbon mitigation policies in Turkey conducted for the World Bank (Conzelmann *et al.* 2002). Furthermore, ENPEP-III (an older version of the model) is applied in Moldova.[12] It is already evident from this summary that the ENPEP-BALANCE model is mostly employed to analyse national (versus regional) energy-systems (Argonne National Laboratory 2008, p.4f; Connolly *et al.* 2010, p.1069).

| **Evaluation Criteria** | **Description** |
|---|---|
| Methodology | Non-linear, equilibrium energy system model with economic and environmental modules; determines the response of various segments of the energy system to changes in energy prices and demand levels |
| Costs | Can be downloaded for free from <www.dis.anl.gov/projects/Enpepwin.html>; However, training costs for 5 days amount to ~ € 7000; Costs for technical support amount to another € 7000 |
| Data requirements & software requirements | Medium to high: energy statistics, energy demand growth projections, technology coefficients; Windows based |
| Level of coverage of M/A issues | The emphasis is on mitigation studies; some were already conducted in PROMITHEAS-4 participating economies |
| Compliance of outputs with projects objectives | Used for green - house-gas (GHG) emissions projections and modelling the regional electricity networks; analysis of mitigation strategies |
| Availability of training and technical support | Typical training duration is 5 days for basic applications and two weeks for advanced applications; Technical support is provided via phone or email (€ 7.000 for 80 hours) |
| International recognition | Used in over 80 countries |
| Sources: UNFCCC 2006, p.23, Argonne National Laboratory 2008, p. 4f; <http://www.dis.anl.gov/projects/Enpepwin.html#balance>. | |

[11] An extensive list can be found on the developer's web page: <http://www.dis.anl.gov/projects/Enpepwin.html#balance>

[12] See "Greenhouse Gas reduction for scenarios of power sources development of the Republic of Moldova" by Robu and Comendant (2010).

## MESSAGE

The acronym "MESSAGE" stands for *Model for Energy Supply Strategy Alternatives and their General Environmental* Impact. The model was developed by the International Institute for Applied Systems Analysis (IIASA) in the 1980s and is widely used by the International Atomic Energy Agency (IAEA) and its member states (Connolly *et al.* 2010:1072). The model operates similar to the MARKAL/TIMES model and the actual version is MESSAGE IV.

**Main facts**

- Systems engineering optimisation tool
- Bottom-up; exogenous energy demand
- Applicable nationally and globally
- Minimises total discounted system costs, subject to energy system constraints

Sources: IIASA, Connolly et al. 2010

### Specific Characteristics of MESSAGE

The user determines all the system-inherent and physical constraints and a Reference Energy System, where all the necessary configurations of the energy network are represented. Moreover, the necessary input data includes the performance characteristics of the technologies. The model then creates various energy system scenarios, which minimise total system costs, from resource extraction to the end-use. This is done starting from the base year leading up to the end of the time horizon (max. 120 years) in five to ten year steps[13] (Connolly *et al.* 2010, p. 1072). "All thermal generation, renewable, storage/conversion, transport technologies, and costs (including $SO_2$ and $NO_x$ costs) can be simulated by MESSAGE as well as carbon sequestration (Connolly et al. 2010, p. 1072)."

Moreover, a stochastic energy system model was developed to assess key uncertainties within the energy system. This includes uncertainties concerning technological, socio-economic and climate change specifications into the modelling structure.

[13] http://www.iiasa.ac.at/Research/ECS/docs/models.html [Accessed 12/05/2011];

MESSAGE was further linked with the MACRO[14] model to allow for a specific treatment of the impact of policies on energy costs, GDP and on energy demand. Another important model development includes extension of the model to cover all six (6) Kyoto GHGs, their drivers and mitigation technologies. In their research project about further developments of the Kyoto-Protocol, Nakicenovic and Riahi applied the "macroeconomic model MACRO [...] to assess the economic impact and price-induced changes of energy demand due to carbon abatement policies (Nakicenovic, Riahi 2003, p.4)."

## Evaluation of MESSAGE

The report by Urban *et al.* (2010, p. 3478) assessing energy models for developing countries finds that many developing countries (again, similarities arise regarding IAM characteristics for emerging economies) characteristics are included. These are electrification, traditional bio-fuels, urban-rural divide, subsidies, clean development mechanism, emission trading and renewable energies.

The model was applied in the following research projects: The development of global energy transition pathways for the World Energy Council (Nakicenovic, N., Riahi, K., 2001); GHG emission scenarios for the Intergovernmental Panel on Climate Change (Nakicenovic *et al.* 2000); Energy supply options in the Baltic states (IAEA, 2007); Moreover research projects are currently being undertaken using MESSAGE in Moldova.

[14] "MACRO corresponds to the macroeconomic module of the top-down macroeconomic model MERGE" (Manne, Richels 1992).

| Evaluation Criteria | Description |
|---|---|
| Methodology | Systems engineering optimisation model; Technology-rich energy systems model with economic and environmental modules |
| Transparency, complexity, easiness of use | Time demanding development of case studies |
| Costs | Free for academic purposes |
| Data requirements & software requirements | Data: Energy/Economic/Environmental database, which corresponds to the EU statistical standards.<br>Software: A free Linear Programming (LP) solver is provided. However depending on the problem complexity, more powerful LP and Non-Linear Programming (NLP) solvers can be seamlessly used by the software; Windows based |
| Availability of the model and the Data | Economic/Energy/Environmental Data base corresponds to the EU statistical standards |
| Level of coverage of M/A issues | The model is mostly used to estimate global or regional multi-sector mitigation strategies |
| Compliance of outputs with projects objectives | With emphasis on mitigation a multitude of national studies has been completed, e.g. on options for increasing the use of renewable energy for China or energy supply options in the Baltic States, etc |
| Availability of training and technical support | The training (also conducted by IAEA) takes approximately 2 weeks; most demanding part after the initial training is the development of case studies: this can take up to half a year with IIASA team's support |
| International recognition | Several hundred users; wide use in IAEA member countries |
| Sources: Connolly *et al.* 2010:1072; <http://www.energycommunity.org/default.asp?action=71> [Accessed 12/05/2011]. | |

## LEAP

The Long-range Energy Alternatives Planning (LEAP) model was developed in 1980 in the USA. Later, the Stockholm Environment Institute (SEI) took over the maintenance and further development of the model.

**Main facts**

- Accounting model
- Bottom-up, exogenous energy demand
- Graphical user interface
- Can be used at various geographical levels (city, state, country, region or global)
- Includes a scenario manager to describe individual policy measures and to create a hierarchy of scenarios

Sources: Bhattacharyya and Timilsina 2010, Connolly et al. 2010:1071, UNFCCC 2006, p. 50f.

### *Specific Characteristics of LEAP*

LEAP offers broad modelling possibilities: The whole range of sectors, technologies and costs within energy-systems can be simulated. Questions regarding externalities for any pollutant, decommissioning costs and unmet demand costs can be answered. The time horizon for the evaluation of national energy-systems in LEAP typically lies between 20 and 50 years, but can be extended unlimitedly. The analysis is conducted on an annual basis (Connolly *et al.* 2010, p. 1071).

The model requires relatively low data inputs, e.g. there is a possibility to assess energy systems and GHG emission without further information on technology costs (UNFCCC 2006, p.50).

Different approaches are taken to model the demand and supply side. On the demand-side a spectrum from bottom-up, end-use accounting technique to top-down macroeconomic modelling is covered. The supply side offers a spectrum of physical energy and environmental accounting as well as simulation methodologies, which are used for developing a clear picture of the electricity power generation and for planning capacity expansions (Connolly *et al.* 2010, p.1071; UNFCCC 2006, p.51).

The LEAP output consists of the following details: fuel demands, technology costs, unit productions, resource extraction, GHG emissions, air-pollutants, full system social-cost-benefit analysis and non-energy sector sources and sinks. “Usually, these results are then used to compare an active policy scenario versus a policy neutral business-as-usual baseline scenario (Connolly *et al.* 2010, p.1071; UNFCCC 2006, p.50).”

Bhattacharyya and Timilsina (2010) consider this type of model to be the most suited one for addressing developing countries' characteristics. The accounting framework makes the model very flexible regarding data requirement. However, especially the underlying scenario-based structure (versus an optimisation approach) makes them recommend this model for developing countries (Bhattacharyya and Timilsina 2010, p. 508; 513). Moreover the United Nations Framework Convention on Climate Change (UNFCCC), in its Training Handbook on Mitigation Assessment, describes the calculations of the model as non-controversial because of their simple verification and high transparency (UNFCCC 2006, p. 51).

## *Evaluation of LEAP*

LEAP was also reviewed by Urban *et al.* (2007, p. 3478). They found that it includes a large number of developing countries' characteristics (therefore, also characteristics of emerging economies), such as performance of the power sector, electrification, traditional bio-fuels, urban-rural divide, subsidies, individual assumptions per country, emission trading, clean development mechanism, renewable energies and rural energy programmes.

The applications of the LEAP model are numerous (Community for Energy, Environment and Development - URL). Recently, an assessment of CCS (Carbon capture and storage) potential was conducted in Greece, to analyse the emission mitigation strategies for 2050 (Bellona Foundation 2011). Moldova used LEAP for preparing the "Second National Communication of the Republic of Moldova to UNFCCC"[15]. In Estonia, two studies were prepared recently on the basis of LEAP: "Energy Planning Models Analysis and Their Adaptability for Estonian Energy Sector" by Dementjeva and "Analysis of current Estonian energy situation and adaptability of LEAP model for Estonian energy sector" by Dementjeva and Siirde. Another notable study was prepared by the SEI, analysing how Europe can show leadership in keeping global climate change under the limit of 2°C higher warming.

| **Evaluation Criteria** | **Description** |
|---|---|

[15] This can be downloaded at: <http://unfccc.int/essential_background/library/items/3599.php?rec=j&priref=7159&suchen=n >

| | |
|---|---|
| Methodology | Accounting type; Optimisation model was released on May 7th |
| Transparency, complexity, easiness of use | Notable for its flexibility, transparency and user-friendliness |
| Costs | Free to qualified users, but there is a cost for OECD (Organisation for Economic Co-operation and Development) based users; Paid license for EU27/free for developing countries; Whether costs arise for emerging economies has yet to be clarified.<br>Total cost arising for the project € 8.800 |
| Data requirement & software requirement | Data: Provides national "starter" data sets; Includes a built-in Technology and Environmental Database (TED) for a variety of technologies<br>Software: Windows |
| Level of coverage of M/A issues | For adaptation macroeconomic indicators (price, GDP, etc.) |
| Compliance of outputs with projects objectives | Final and useful energy demand analyses; Stock-turnover for transport; Scenarios of energy and non-energy sector emissions and sinks |
| Availability of training and technical support | Online training is available but not sufficient;<br>One week of trainer-led training is recommended;<br>Technical support provided against fee; |
| International recognition | Currently LEAP has over 5000 users in 169 countries |
| Source: Connolly D. et al. 2010, UNFCCC "Module 5.1 – Mitigation Methods and Tools in the Energy Sector" 2006:50ff. | |

## IMAGE

The Integrated Model to Assess the Global Environment (IMAGE) was developed in the late 1980s[16] by the National Institute for Public Health and the Environment (RIVM) in the Netherlands and is currently maintained by the Netherlands Environmental Assessment Agency (MNP). The latest version, incorporating many enhancements and extensions, created in close co-operation with different institutions in this area, is IMAGE 2.4.

| Main facts |
| --- |
| • Simulation model<br>• Top-down bottom-up hybrid model<br>• Complex modelling framework including submodels<br>• Applicable on a global level<br>• Incorporates feedback mechanisms within the biophysical system |

Sources: Bouwman *et al.* 2006, p.5, Urban *et al.* 2007, p. 3479.

### *Specific Characteristics of IMAGE*

The IMAGE 2.4 model is one of the most complex modelling frameworks developed until now. Different independent models can be combined for various purposes: For example, the TIMER hybrid model investigates the energy supply and energy demand side of the economies and the FAIR model analyses policy options (PBL – Netherlands Environmental Assessment Agency - URL). Human activities in areas such as industry, housing, transport, agriculture or forestry have various implications on human and natural systems. In IMAGE these interactions are specified and explored thoroughly. The "key-drivers" of the model are defined as change, population and macro economy (Bouwman *et al.* 2006, p. 8).

The specific features of the IMAGE 2.4 framework can be divided into three (3) interacting categories (Bouwman *et al.* 2006, p.13):

- Socio-economic system: This category includes demographics, energy supply and demand, agricultural demand and trade, as well as the broad category "world economy".
- Earth system: This category contains an explicit land use and land cover model, including the carbon, nitrogen and water cycle, as well as the atmosphere and ocean systems[17].

[16] It was called Integrated Model to Assess the Greenhouse Effect.

[17] An additional model, GLOBIO 3, can be used to address biodiversity issues.

- Impacts: This category offers options for evaluating climate policies, using the policy decision-support model FAIR[18]. Hence, climate impacts, land degradation issues, water stress, biodiversity, as well as water & air pollution can be addressed.

## *Evaluation of IMAGE*

Urban F. et al. (2007), in their assessment of developing countries' features that are accounted for energy models, described the IMAGE model as incorporating a medium number of developing countries' characteristics, namely electrification, traditional bio fuels, urban-rural divide, clean development mechanism, emission trading and a wide assessment of renewable energies (Urban *et al.* 2007; p.3478).

Research conducted on the basis of the IMAGE model includes: IPCC Special Report on Emissions Scenarios (SERS; IPCC Special Report on Emissions Scenarios, 2000), EUruralis study focusing on future prospects for agriculture and the rural areas of the EU-25 countries[19], and various Greenhouse Gas Reduction studies[20].

| **Evaluation Criteria** | **Description** |
|---|---|
| Methodology | Hybrid simulation model |
| Transparency, complexity, easiness of use | Comprehensive Integrated Assessment Model (IAM) consisting of variety of sub-modules |
| Costs | The model is useable only in close cooperation with the IMAGE developers, costs are therefore not specified; |
| Data requirements & software requirements | IMAGE cannot be provided as a "ready to use package" to others: Much of the performance of IMAGE actually comes from design of scenario assumptions and its translation into actual model input. Therefore a lot of expert knowledge is necessary. |
| Level of coverage of M/A issues | Provides insights into the full range of adaptation and mitigation options, including the costs, benefits and risks of different climate futures, policies and socio-economic development pathways, etc. |
| Compliance of outputs with projects objectives | Applied in assessing climate mitigation strategies |
| Availability of training and technical support | The developers are open for serious collaborations with other institutes, to share model results, to work together on projects or model development. |
| International recognition | Multitude of studies analysing scenarios of global and regional environmental change. |
| Sources: Bouwman *et al.* 2006; http://themasites.pbl.nl/en/themasites/image/overview/index.html. | |

[18] "FAIR is widely used to assess the environmental and abatement cost implications of international regimes for the differentiation of future emission reductions of greenhouse gases. The model links long-term climate targets and global reduction objectives with regional emission allowances and abatement costs, accounting for the Kyoto Mechanisms." Bouwman *et al*. 2006, p.16

[19] Initiated in 2004; http://www.eururalis.eu/

[20] E.g.:http://www.pbl.nl/en/publications/2000/Global-and-Regional-Greenhouse-Gas-Emissions-Scenarios [accessed 14/05/2011]; Studies mentioned in: Bouwman *et al.* 2006, An extensive list can be found here: http://themasites.pbl.nl/en/themasites/image/publications/articles/index.html [accessed 14/05/2011]

## MERCI

The *Model for Evaluating Regional Climate change Impacts* (MERCI) was developed by the Institute for Advanced Studies (IHS) Vienna in 2009, and is still being refined and advanced during its use in diverse projects. Since then it has been used in applied research for different Austrian ministries. MERCI is a multisectoral dynamic hybrid top-down bottom-up model, currently implemented at a national level.

The main strength of MERCI lies in its ability to simultaneously depict overall economic circumstances, as well as such concerning the energy sector at a detailed technological level.

Currently MERCI can be used on a national level, or for an entire region with a homogenous economic structure, due to its multisectoral composition and the precondition of regional equality in prices and the state of technology.

**Main facts**

- Dynamic general equilibrium model
- Top-down bottom-up hybrid model; endogenous demand
- Main focus: economic policies, energy mixes
- Applicable nationally and regionally
- Multisectoral small open economy, detailed depiction of technologies in the energy sector

Source: Authors

### *Specific Characteristics of MERCI*

MERCI makes use of the hybrid, top-down, bottom-up modelling approach suggested by Böhringer and Rutherford (2008). The top-down part of the model consists of (currently 13) cost minimizing production sectors, an infinitely lived representative agent, who maximizes total lifetime utility, i.e. a composite of consumption and leisure, a government agent in charge of various political instruments such as taxes, subsidies and quotas, and an artificial agent representing foreign trade. All production and utility functions are in the form of Constant Elasticity of Substitution (CES) functions. The theoretical underlying is the classical structure of the small open economy Ramsey model.

Within the bottom-up part of the model, the electricity sector is split up in currently eight (8) different technologies, all producing the same consumption good, electricity. These technologies require different input structures of labour, capital and other intermediate input goods for production, which determine their different production costs. Energy demand is taken from the top-down equilibrium, and, subject to resource and capacity constraints of each technology (e.g. locations for hydro power plants, plant capacities of processing raw energy, etc.), the most cost efficient technology mix is found within the bottom-up solution process.

The top-down and the bottom-up parts of the model are solved simultaneously, generating a set of activity levels (i.e. output quantities) of production sectors and technologies, and prices of all goods and factors, such that demand meets supply in all markets.

MERCI is designed to assess different possible future developments in a complex economic and ecological sense, and to evaluate them with respect to the criteria important to the user. Based on an equilibrium data set in the base year, and a calibrated long term reference path (Business As Usual, BAU), a shock is imposed on the economy, and a new equilibrium path is computed. These shocks, or scenarios, typically include unforeseen changes in the economic structure, or political instruments, in order to design economy and environment. The range is broad, and can be adapted according to nearly any focus of interest.

Currently imposed scenarios are amongst others changes or introductions of taxes on fossil fuels, subsidies or quotas for renewable energy sources, or a price raise in raw energy commodities.

The results (sectoral output, consumer prices, wage rates, energy mix, etc.) of the newly computed equilibrium path are compared with the BAU reference scenario. Due to the general equilibrium structure of the model, results are always in the context of the overall economy, in the form of a new equilibrium, so that important economic interdependencies are never left out. In this way the scenario effects can be analysed from different angles, with respect to several kinds of evaluation criteria.

## *Evaluation of MERCI*

| **Evaluation Criteria** | **Description** |
|---|---|
| Transparency, complexity, easiness of use | The model is formulated as a mixed complementarity problem (MCP) within the programming surrounding GAMS. Currently there is no graphical user interface, so detailed GAMS knowledge and mathematical skills are required for use. |
| Cost | Training costs for MERCI would be free for this project. |
| Data requirements & software requirements | The model is available at a development stage and needs comprehensive national level Input/Output tables and technological data |
| Level of coverage of M/A issues | The top-down part is analyzing the adaptation options of the overall economy, while the bottom-up part depicts the technological processes on the energy level. |
| Compliance of outputs with projects objectives | Could provide us national trends in the interdependency between macroeconomic issues and mitigation and adaptation strategies. |
| Availability of training and technical support | Model development is still in progress; training personnel and technical support are currently only partly available. |
| International recognition | MERCI was used in two studies for Austrian ministries at a national level. |

Source: Authors.

# Conclusion

In short, the following advantages and disadvantages of the six models surveyed in this deliverable are summarised:

- MARKAL/TIMES is widely used in the research community and comes with extensive documentation. However, it requires high computer skills and other models may be better suited for use in emerging countries.
- ENPEP-BALANCE offers a graphical interface and was already employed in various studies, including countries within the Black Sea Region. However, neither the study by Urban *et al.* (2007) nor the study by Bhattacharyya and Timilsina (2010) analyse ENPEP-BALANCE for its developing countries' features. Therefore no conclusions can be drawn regarding this issue.
- One of the drawbacks of MESSAGE is the lengthy preparation of scenarios. However, Urban *et al.* (2007) find MESSAGE to be the most suited model, together with LEAP, among the ones analysed that addresses developing countries' specifics.
- Urban et al. (2007) and Bhattacharyya & Timilsina (2010) find that LEAP is the most suited model available to address issues related to developing countries. Also the low costs and the broad user-base are notable advantages. Still, until recently, LEAP did not incorporate an optimisation tool. The actual version provides this feature. However, this optimization module is still a work in progress, as has been noted by the developers, and should be handled with reservation. However, it has already become quite clear that LEAP is the most suited model for the mitigation/adaptation analysis to be conducted in the PROMITHEAS-4 project.
- IMAGE 2.4's main disadvantage regarding the focus of the PROMITHEAS-4 project is that it is not possible to provide it as a 'ready-to-use' software. However, it is capable of incorporating a medium number of developing countries' characteristics into the scenario analysis.
- MERCI is a complex modelling tool, whith high-level theoretical background, flexibility of use and hybrid structure allow for a comprehensive cost-benefit analysis when it comes to environmental and energy questions within the economy. However, it has only been set up for Austria. Consequently, the process of transferring the database has not been standardized yet. This may bring some unexpected problems with it. Furthermore, MERCI has no graphical user interface that can be easily explained to trainees, and, being a highly complex modelling tool, would thus probably prolong the training process. Another point is that a computable general equilibrium model, often imposing rigorous assumptions on the economy, might not be best suited for use in emerging economies.

The next deliverable (D 2.2) will evaluate the models presented, also taking into account the conclusion from this report that the LEAP model is the most suited one for the analysis, using the following criteria, which were decided upon in the ad-hoc working group's protocol – *"Chain of activities for concluding with policy portfolios"* – 4th of March, 2011, Athens:

a. The choice will be restricted to models used at European level;
b. The wideness of the model in covering mitigation/adaptation issues (The model that is closer in covering these issues will be taken into consideration);
c. Transparency, complexity and easiness in using the model;

d. Availability of inputs (available in statistics books, national accounts);
e. Flexibility of the model in building scenarios (e.g.: a simulation model does not impose bias in modelling outputs);
f. Compliance of outputs with our contractual obligations (socio-economic, technological penetration);
g. Cost of acquiring the model;
h. International recognition of the model (used by governments);
i. Training and technical support.

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