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IEA OECD ETSAP news

ANNEX X: GLOBAL ENERGY SYSTEMS AND COMMON ANALYSES

1. Main Features of TIMES, the Integrated MARKAL-EFOM System

MARKAL was originally developed by two teams with representatives from 16 countries, one working in the U.S. at Brookhaven National Laboratory and one in Germany at the Energy Research Center in Jülich. Designed over 30 years ago to meet the differing requirements of 16 countries, the underlying flexibility embodied in MARKAL has led to its being used by more than 200 institutions in over 60 countries. But over time, as with any complex software system, a fresh rethinking that builds on the experience using the tool, retains the strengths, redresses weaknesses, and prepares for the future is inevitable. To this end in 1999 ETSAP began the process of merging the merits of MARKAL with some of the capabilities of EFOM (the Energy Flow Optimization Model, a sister model to MARKAL that was used previously in Europe) to realize TIMES (The Integrated MARKAL-EFOM System). TIMES benefits from the experience gained applying MARKAL to real world problems, and meets the expanding need for a detailed technology-oriented economic model that can be scaled from the municipal level up to a multiregional global model. The resulting model embraces the same underlying philosophy, thus remaining a partial / general technical-economic equilibrium model, implemented as a least-cost optimization linear / non linear program, but readies the tool for the daunting analytic challenges 21st Century (see Figure 1).

1.1 Improvements over MARKAL

TIMES builds on the core strengths of MARKAL expanding upon them in a number of important ways.

- TIMES was designed from the beginning as a multi-region model. A regional index for all model components allows examination of trade issues and mapping to geographic information systems. This can be used to evaluate the effects of carbon emissions trading, carbon "leakage" from one country to another, and the implementation of the Clean Development Mechanism. The same feature makes it possible to evaluate infrastructure needs for electrical grid and gas transportation facilities.
- Vintaging of technologies allows for the evolving characteristics of technologies to be compactly represented, including the ability to depict the changing nature of attributes over time (e.g., decay of efficiency as a function of age).
- Time slices to any level of detail down to the hour of the day, not simply season and day/night. With this feature, for example, TIMES may be used to model the effects of time-of-use electrical rates on load curves.
- Independence of model year data from source year data, permitting data to be entered as obtained but analyzed for other years.
- Variable time period lengths that facilitates the evaluation of policies in the short term, together with five-year, ten-year, or even 20-year increments for evaluations in the intermediate and long term.
- Inter-temporal user-defined equations to permit examination of retrofitting and life extensions options straightforward, setting of cumulative limits, banking of credits, and other multi-period constraints.
- A distinction between service life and economic life of technologies.
- An uncertainty index to allow for

This double issue of the ETSAP Newsletter provides overviews of the features of the TIMES model generator and VEDA analysts' support system leading up to their debut, as well as summaries of recent improvements in the capabilities of the model, including:

- Formulation of the TIMES Climate Change Module;
- Multi-stage Stochastics - Analysis of Climate Change Policies Under Uncertainty with TIAM;
- Myopic TIMES Prototype Version, and
- Investment and Other Cost Bounds.

After establishing this foundation, several analyses using the new platform are presented, including:

- ETSAP Activities in EMF 22;
- The NEEDS Project: Ongoing Activities on Modelling Pan European Energy Scenarios, and
- The Italian Energy Sector: A Regional and Multi-Grid TIMES Model.

This issue underscores the increasingly dynamic and important contribution of the ETSAP community in providing state-of-the-art analytical tools and studies, leading to a greater understanding of the possibilities for meeting the critical energy and environmental challenges of this century.

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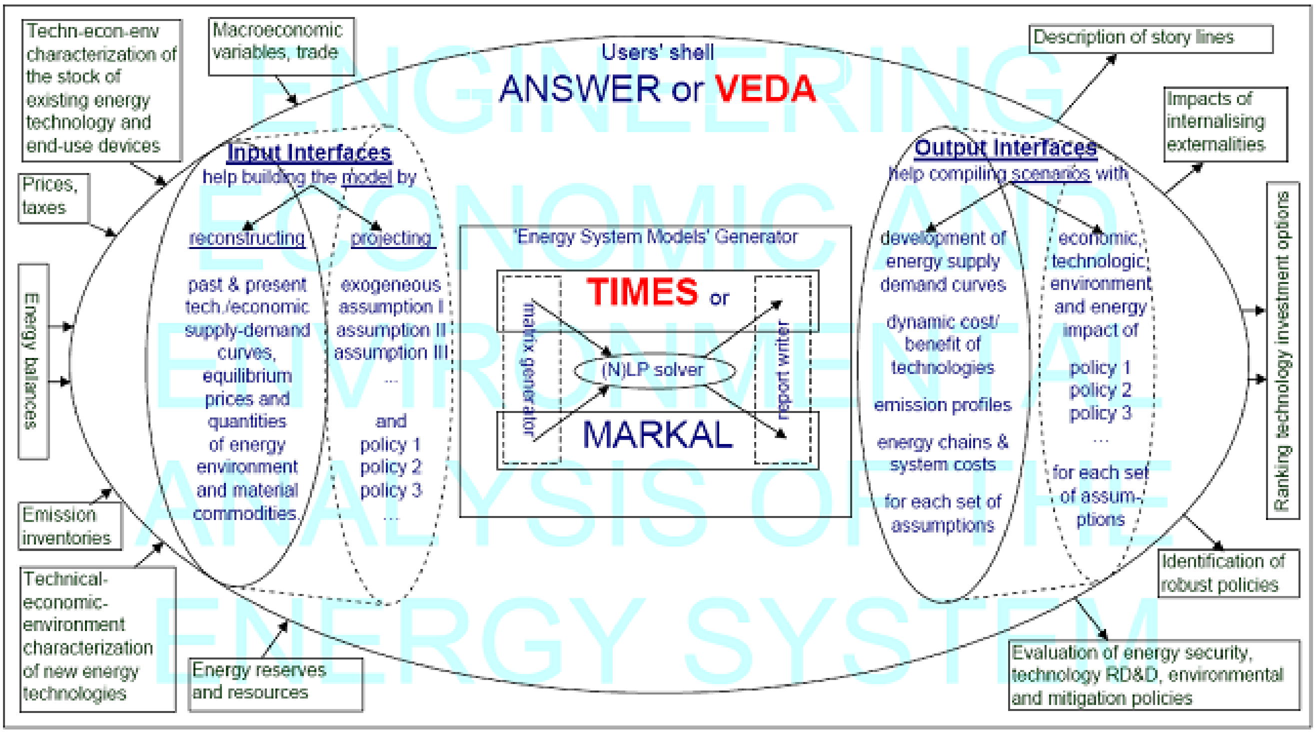

Figure 1: ETSAP tools and typical applications
[Acronyms: MARKAL = MARKet Allocation; TIMES = The Integrated MARKAL - EFOM System; LP = Linear Programming; NLP = Non Linear Programming; VEDA = VErsatile Data Analyst; RD&D = Research, Development & Deployment]

stochastic to enable examination of uncertainty in model assumptions.

- The representation of a climate impacts module to realize a full integrated assessment model when doing global modeling.

Like MARKAL, TIMES adopts a generic concept to describe the components (commodities and processes) of an RES and its interconnections.

- Commodities are defined as the energy carriers, energy demands, materials, money, and emissions that flow through the RES network.
- Processes are the means of transforming commodities from one form to another. A process is described by its capacity and activity, with the units of each explicitly defined by the user.

But unlike MARKAL, TIMES employs a standard flexible representation of all processes (with slight variants for storage and inter-regional exchange technologies) that allows the relationship between individual flows to be depicted in a natural way to describe even the most complex processes (see Figure 2). The process box allows inputs and outputs to be described in a flexible manner so that almost any (linear, for now) relationship may be depicted. This includes, but is not limited to:

- Tying input or output flows directly to either the capacity or overall activity of the process as well as each other, making it easy to associated efficiency and emissions rates with individual energy carriers;
- Establishing fixed or flexible proportions for various inputs or outputs;
- Allowing minimum and/or maximum allocation levels to be specified for all inputs or outputs to/from a process that will then be optimized by the model, and
- Allowing an input in one time-slice to control output in another.

Vintaging

In traditional systems engineering models, attributes usually have one time index, and the data generally relate to one specific future year. Without vintaging, the characteristics of any modeled technology are independent of the age structure of the stock of installations. That implies that the input data may not be changed for many of the attributes, which results in the need in to replicate technologies simply owing to allow efficiencies to improve over time. In addition, the technical characteristics of an installation often change with aging. For example, the availability of power plants may increase at first as initial problems are overcome and later decline due to more outages as parts wear out. Some changes over time may be independent of the technology itself, such as a rise in “fixed” operating and maintenance expense due to higher wages.

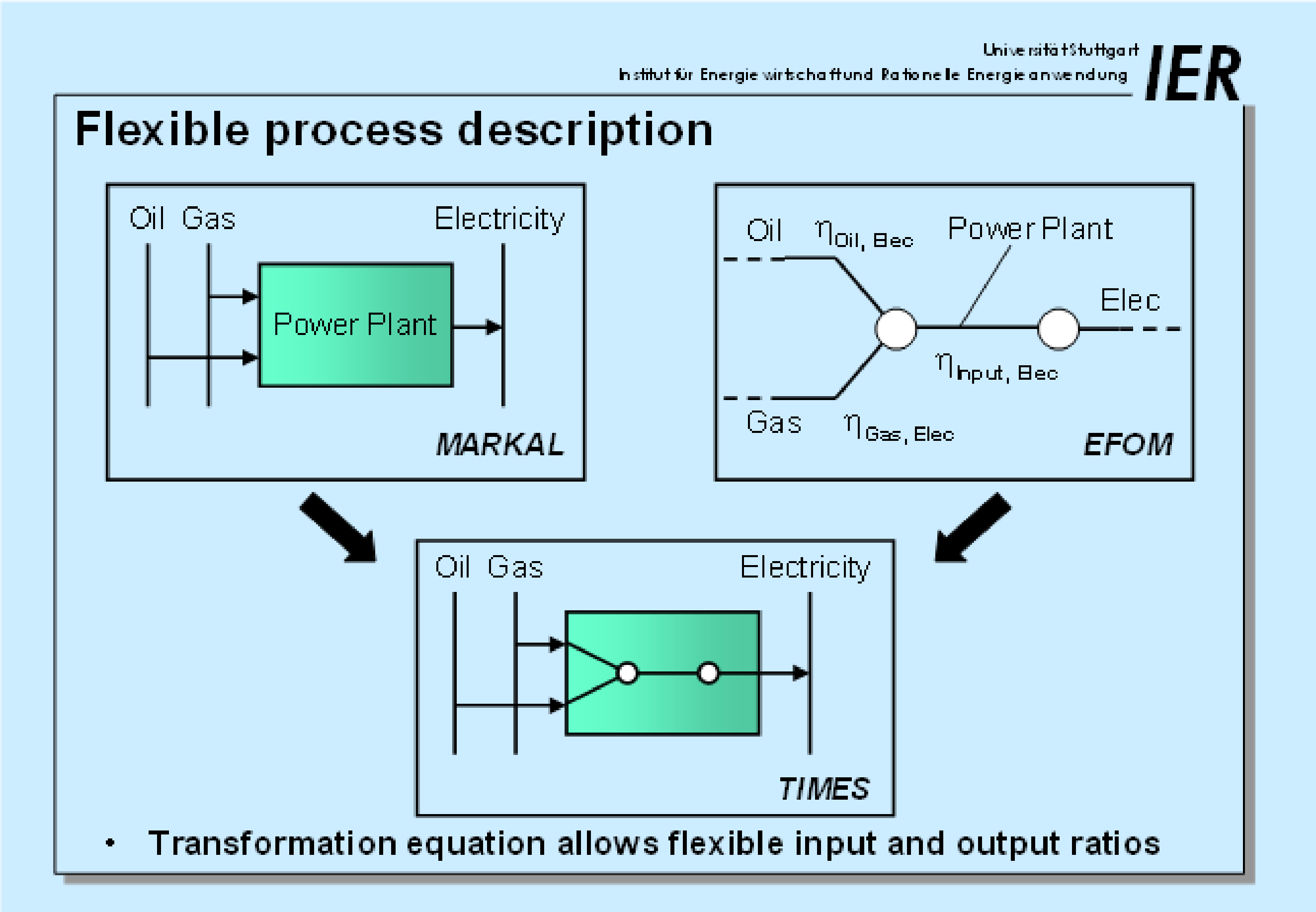

Figure 2: Flexible process description.

By vintaging installations, their technical characteristics depend upon the year of installation and the age structure of the stock (see Figure 3). The change of attribute values over the lifetime of one vintage can be specified in TIMES using a function called SHAPE.

The Objective Function

The objective function of TIMES, which is minimized by the solution to the program, includes a number of innovations (see Figure 4). The objective function is expressed as the discounted sum of annual costs minus revenues, so as to provide year-by-year reporting of net costs.

- The model accepts technology-specific discount rates as well as a general discount rate. This is used for discounting the yearly payments of investment costs over the economic life of a technology.
- The model can represent sunk costs of materials and energy carriers, that is, those embedded in a technology at its inception. Examples are the uranium core of a nuclear reactor, or the steel embedded in an automobile. Unless these are represented in the RES, their cost should be included in the investment cost.
- The investment in new technology may not occur in a single year, but can be represented as a series of annual increments.
- Fixed and variable operating and maintenance costs.
- Decommissioning or dismantling costs are accepted, with an optional time lag that, for example, may be required for radioactive material to cool down.
- The recuperation of sunk materials can be credited when a facility is decommissioned.
- Any taxes or subsidies on investment, decommissioning, and fixed annual costs are accepted by the model.
- Payments made beyond the model's horizon, for decommissioning or recuperation, are reported separately.
- Salvage costs are reported as a single lump sum at the end of the horizon.
- Resource depletion costs are computed.
- When elastic demands are used in the model, the objective function includes the loss of welfare due to the reduction or increase in demands.

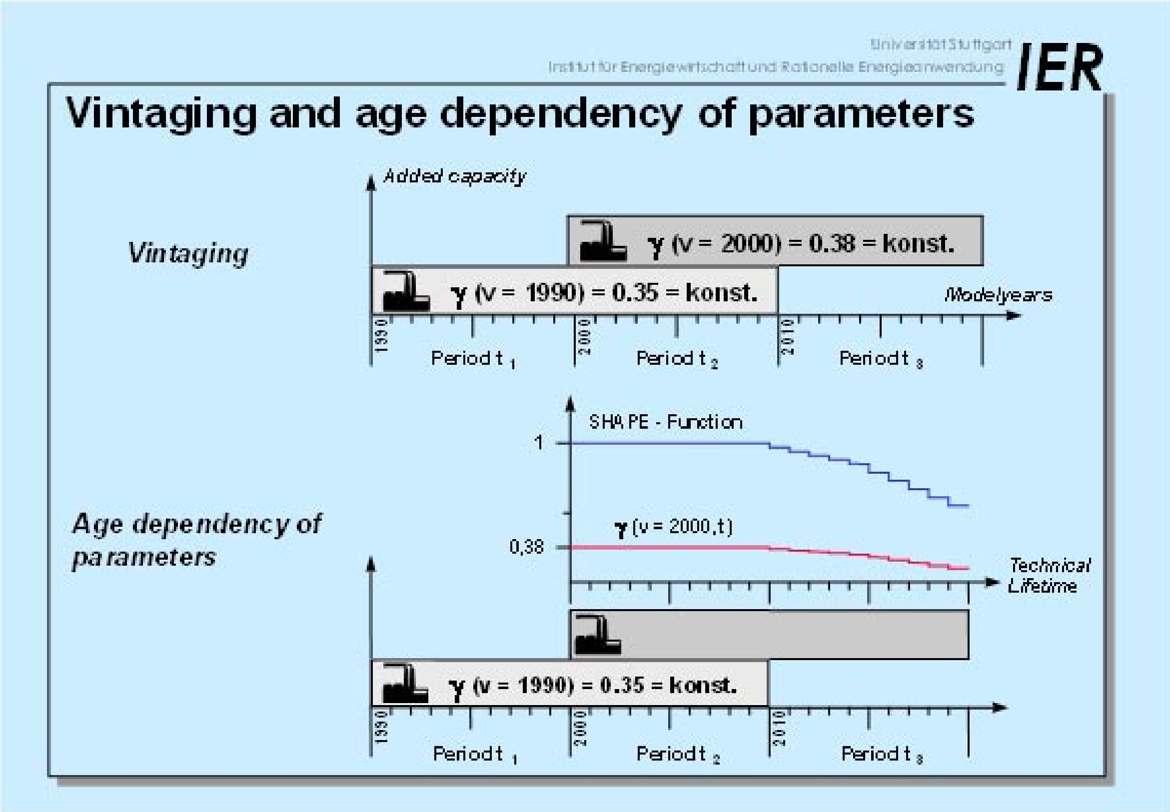

Figure 3: Vintaging and age dependency of parameters

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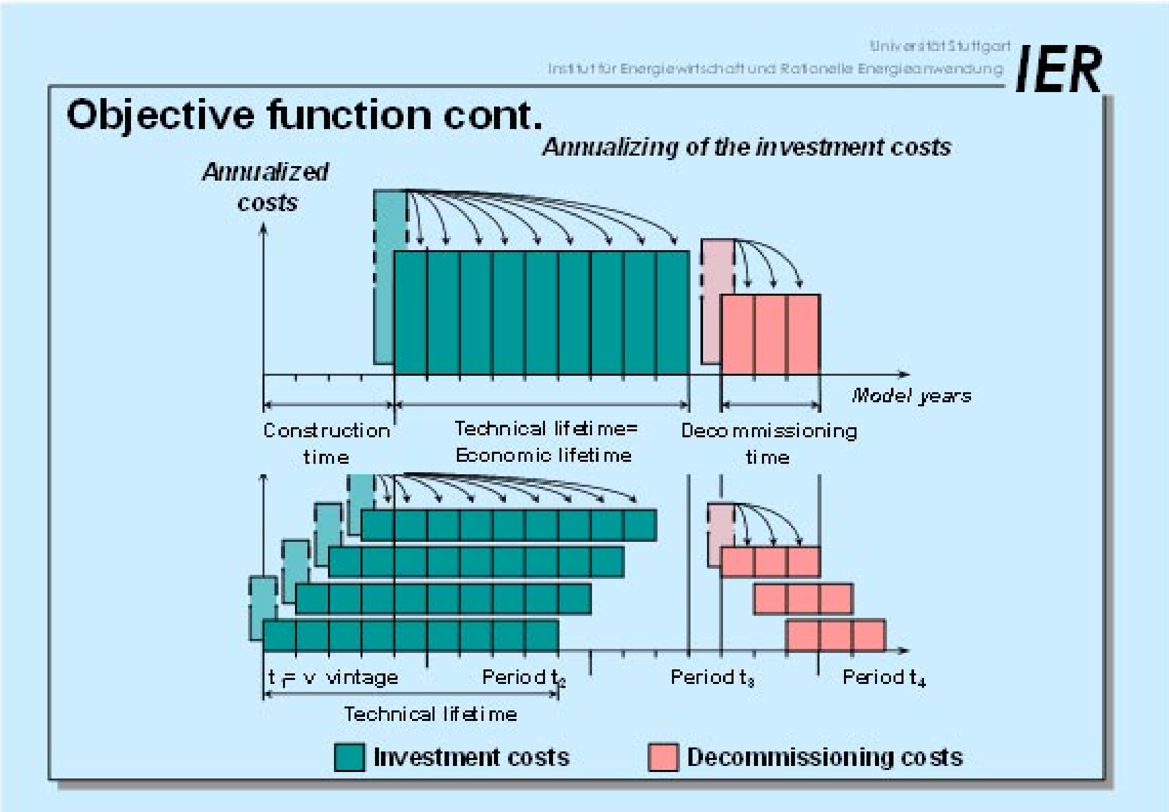

Figure 4: *The Objective function reports year-by year net costs*

1.2. Formulation of the TIMES Climate Module

The Climate Module starts from global emissions as generated by the TIMES global model, and proceeds to compute successively (see Figure 5):

- the changes in CO_2 concentrations in three reservoirs,
- the total change (over pre-industrial times) in atmospheric radiative forcing from anthropogenic causes, and
- the temperature changes (over pre-industrial times) in two reservoirs.

The Climate Equations used to perform these calculations are adapted from Nordhaus and Boyer (1999), who proposed linear recursive equations for calculating concentrations and temperature changes. These linear equations give results that are good approximations of those obtained from more complex climate models (Drouet et al., 2004; Nordhaus and Boyer, 1999). In addition, the non-linear radiative forcing equation used by these authors is the same as the one used in most models. The choice of the Nordhaus and Boyer's climate equations is motivated by the simplicity of their approach and by the fact that their climate module is well-documented and acceptably accurate. In the TIMES implementation, the forcing equation has been replaced by a linear approximation whose values closely approach the exact ones as long as the useful range is carefully selected.

Rigorously, the concentration and forcing equations used in the climate module are applicable only to the carbon cycle, and a different treatment of other greenhouse gases — methane, N_2O, ozone, aerosols, etc. could be done using specific models of their own life cycles. However, following a commonly accepted approach, it is possible to use the CO_2 equations to calculate the impact of other gases on climate. To do so, it is necessary to first convert the emissions of each GHG into a CO_2-equivalent quantity, and to add these CO_2-equivalents to form a fictitious emission of total CO_2-equivalent, which is then treated as if it were real CO_2 emissions. The coefficients used for converting emissions of other gases into CO_2-equivalents are the Global Warming Potentials (GWP) recommended by the IPCC Third Assessment Report (IPCC 2001). Therefore, in what follows, the term CO_2 used in the climate equations should really be thought of as CO_2-equivalent

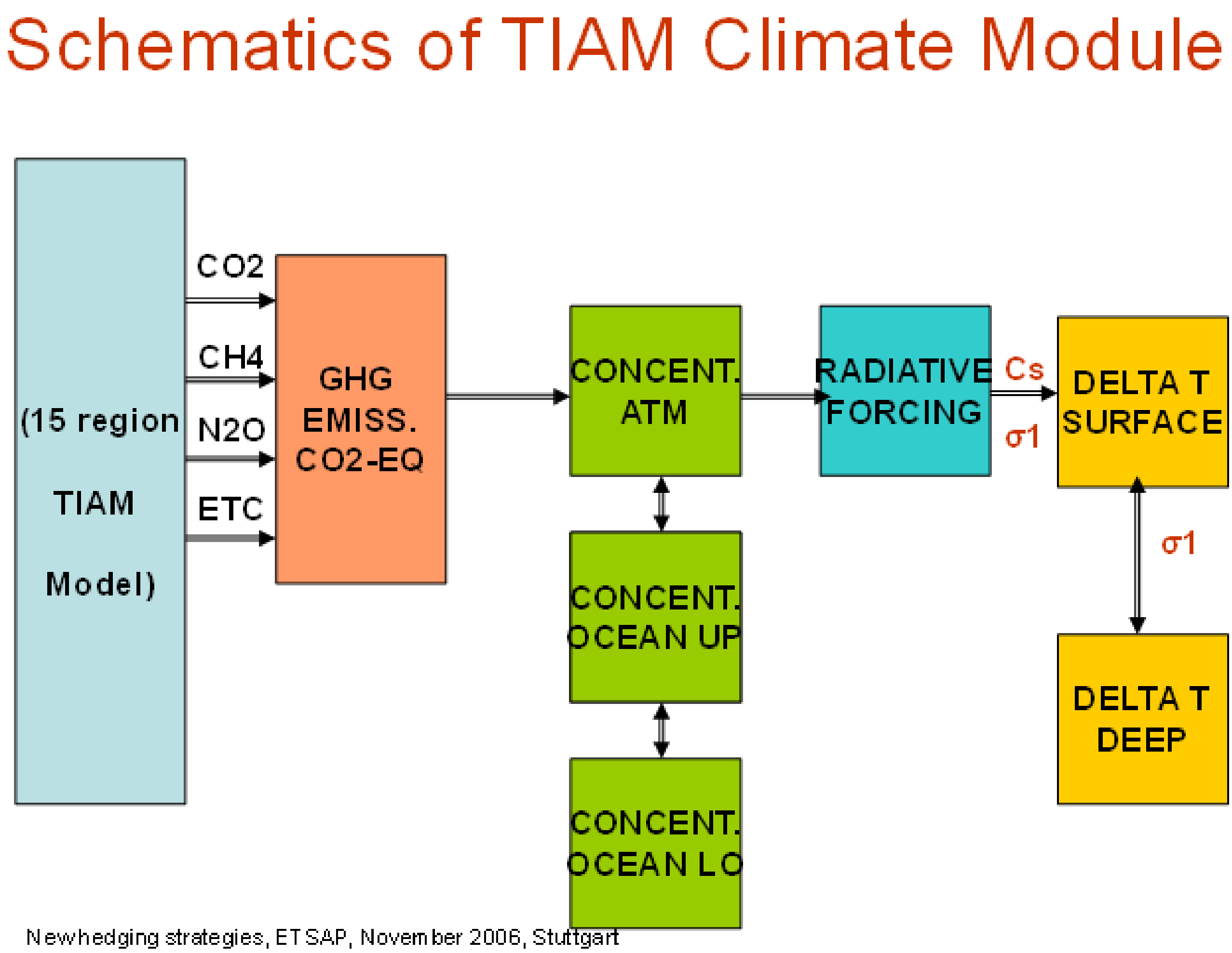

Figure 5: Diagram of the climate module of TIMES

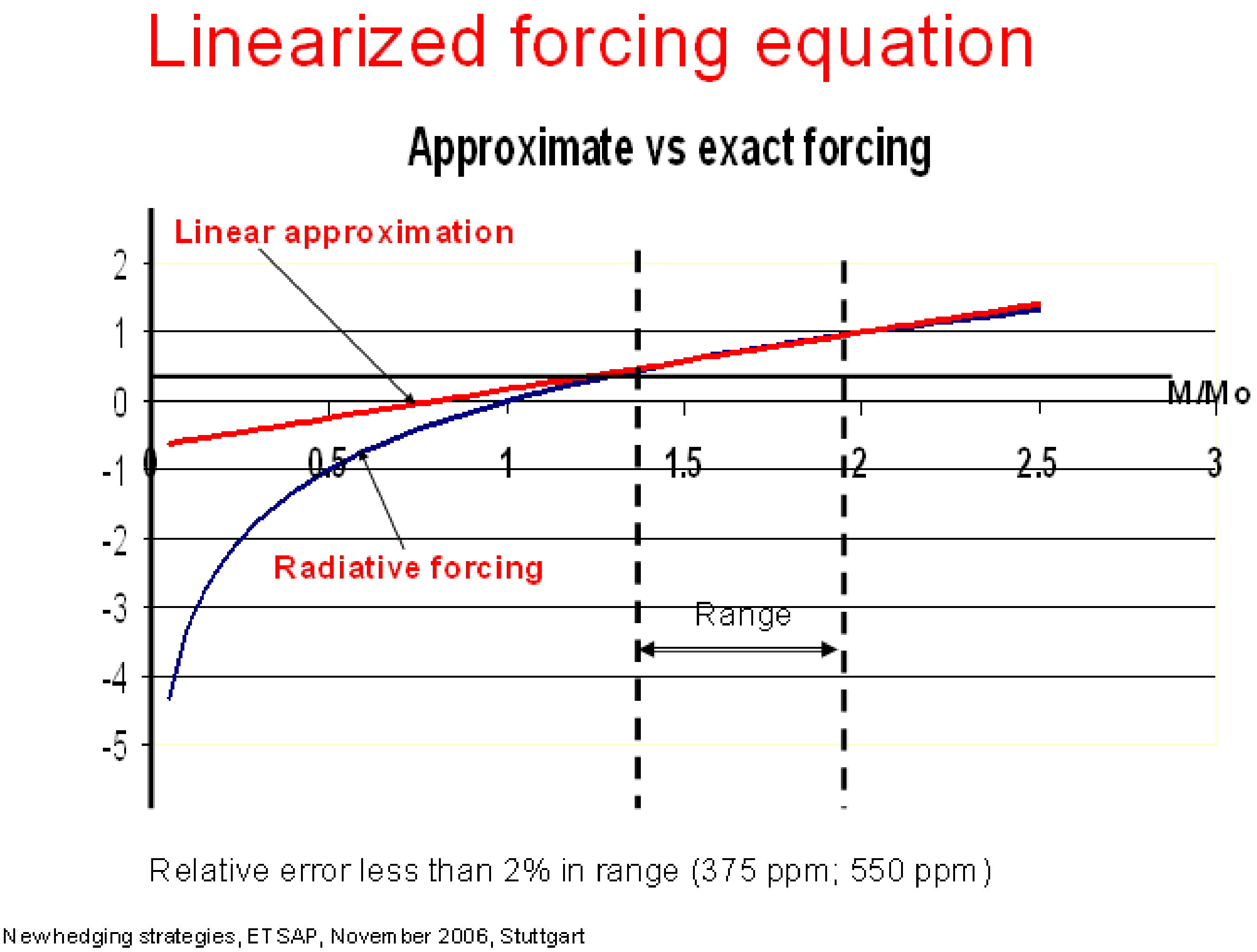

Figure 6: Linear approximation in TIMES of the exact forcing equation

1.3. Multi-stage Stochastics for Uncertainty Analyses

Richard Loulou, Amit Kanudia (GERAD, Montreal, Canada), Antti Lehtila (VTT, Finland)

Many TIMES parameters may be subjected to uncertainty in terms of their input values and employed in a stochastic analysis. To help explain the merits and use of stochastics examples from an Analysis of Climate Policies under Uncertainty with TIAM are used.

The objective of this work is to assess the feasibility, cost, and means of maintaining the global temperature increase to a 2 to 3 degree Centigrade range over the long term, taking into account high economic and climate uncertainty. The uncertainties considered are:

- climate sensitivity [Cs] and a lag parameter , sigma [lc] 1; this uncertainty is treated explicitly via stochastic programming;
- Other uncertainties explored in the previous version of this work [Cape Town 2006] include economic growth and associated GHG emissions treated via stochastic programming, and
- Technology development, including nuclear power and carbon sequestration treated through sensitivity analysis.

Stochastic optimization involves the definition of an event tree, such as that shown in Figure 7.

The expected consumer surplus is then maximized subject to the conditions that all TIMES constraints must be satisfied for each branch (outcome) of the event tree, and that there must be a single set of decisions prior to the resolution of uncertainty (i.e., while the decision maker does not yet know the outcome). The optimal solution then results in a hedging strategy.

The stochastic parameters selected for this study are given in Table 1.

Hedging is relevant if decisions prior to 2040 are different for the hedging strategy than under the base case (see Figures 8-9). If not, adopting a policy of “wait and see” is the proper course of action. The main interest of a hedging strategy is to provide a single strategy in the short term which is robust

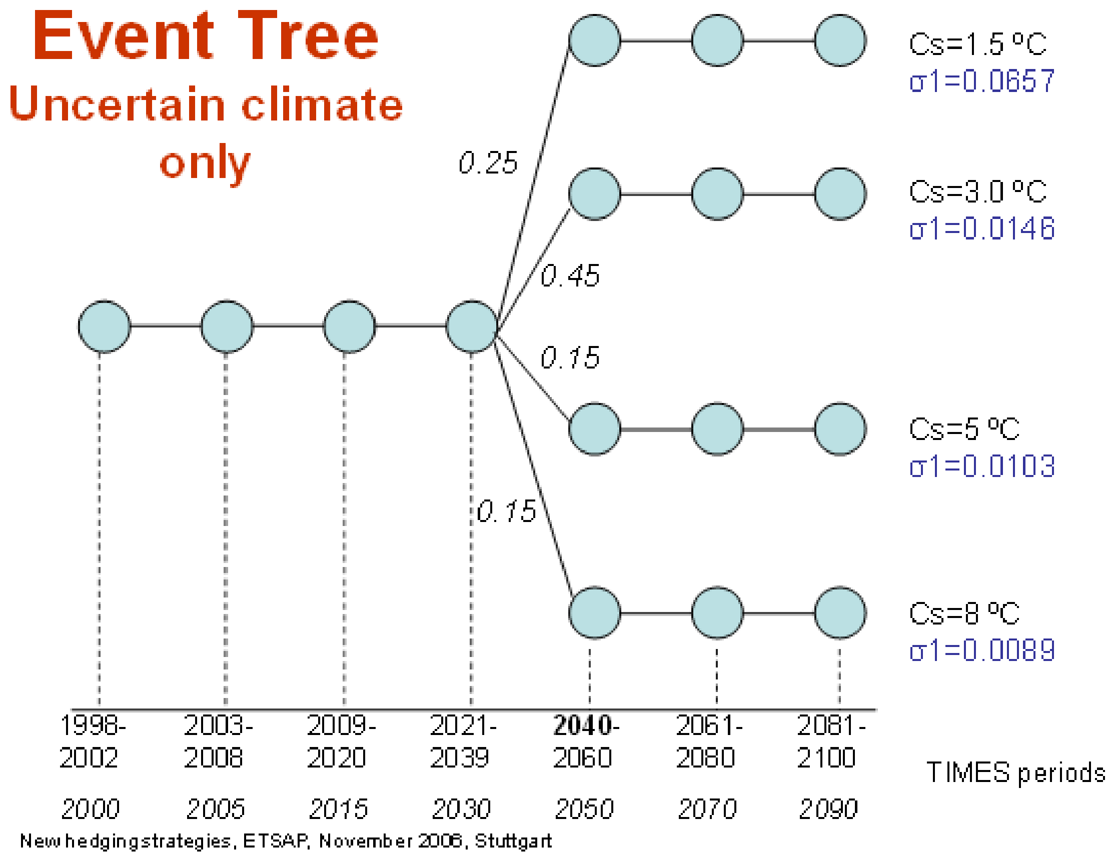

Figure 7: Event tree that represents in TIMES an uncertain climate *future*

Table 1: Declaration of stochastic parameters in TIMES

Declaration of stochastic parameters

Documentation: http://www.etsap.org/Docs/TIMES-Stochastic.pdf

2 stages: before and after information is known

4 possible states of the World (SOWs) after 2050

~scenario:SEMFCs
~TFM_INS

~include_comm

TS	BD	Stage	SOW	Prmtr	Yr	AllREG	AFR	AUS	CAN	Sets	Comm_Na
		1		SW_START		2000					
		2		SW_START		2050					
		1	1	SW_SUBS		4					
		2	1	SW_SPROB		0.25					
		2	2	SW_SPROB		0.45					
		2	3	SW_SPROB		0.15					
		2	4	SW_SPROB		0.15					
		2	1	S_CM_CONST			1.5				CS
		2	1	S_CM_CONST			0.06574				SIGMA1
		2	2	S_CM_CONST			3.0				CS
		2	2	S_CM_CONST			0.01461				SIGMA1
		2	3	S_CM_CONST			5.0				CS
		2	3	S_CM_CONST			0.01028				SIGMA1
		2	4	S_CM_CONST			8.0				CS
		2	4	S_CM_CONST			0.00886				SIGMA1

Probabilities for each branch

Values of Cs and σ_1 for each branch (stage 2)
Cs and are constant data (CM_CONST) of the climate module.

New hedging strategies, ETSAP, November 2006, Stuttgart against uncertainty, as opposed to dealing with a variety of scenarios, each of which provides a different strategy.

Greenhouse emissions (through 2090) for the base case, perfect foresight and hedging strategies for a wide range of temperature increase limitations are shown below. The results are striking in that the hedging strategies and perfect forecast strategies diverge relatively early over the time horizon considered, and that hedging strategies yield somewhat comparable results to perfect forecasts over the longer term for similar temperature increases. A comparison of primary energy use through 2040 is shown in the second figure below, results over the longer term for the primary energy mix.

The principal conclusions from this study to date are:

- Stochastic programming produces a hedging strategy against climate uncertainty that is not well approximated by any PF strategy;
- Hedging is important for Cs uncertainty but not economic uncertainty;
- The method reveals hedging actions that are not predicted by any deterministic actions;
- A hedging strategy is robust with respect to several technological assumptions; and
- A 2.1ºC temperature increase is very difficult to achieve, while a 2.7ºCincrease is achievable at reasonable cost.

ETSAP is the principal sponsor of this work. Additional financial support is provided by Natural Sciences and Engineering Research Council of Canada (NSERC), and data support including biological carbon sequestration information was supplied by US Environmental Protection Agency.

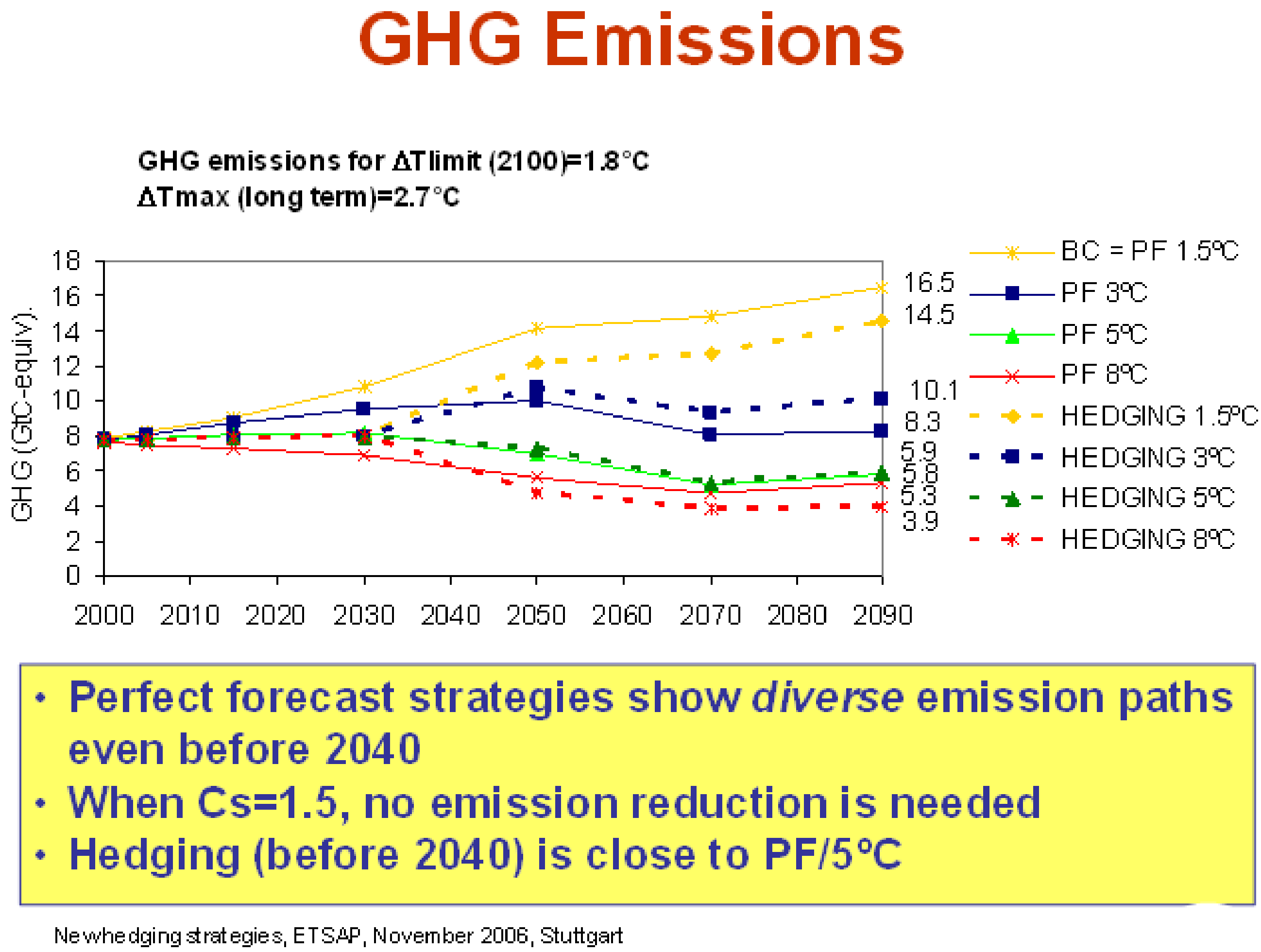

Figure 8: Hedging vs. non-hedging strategies: GHG emissions before 2040

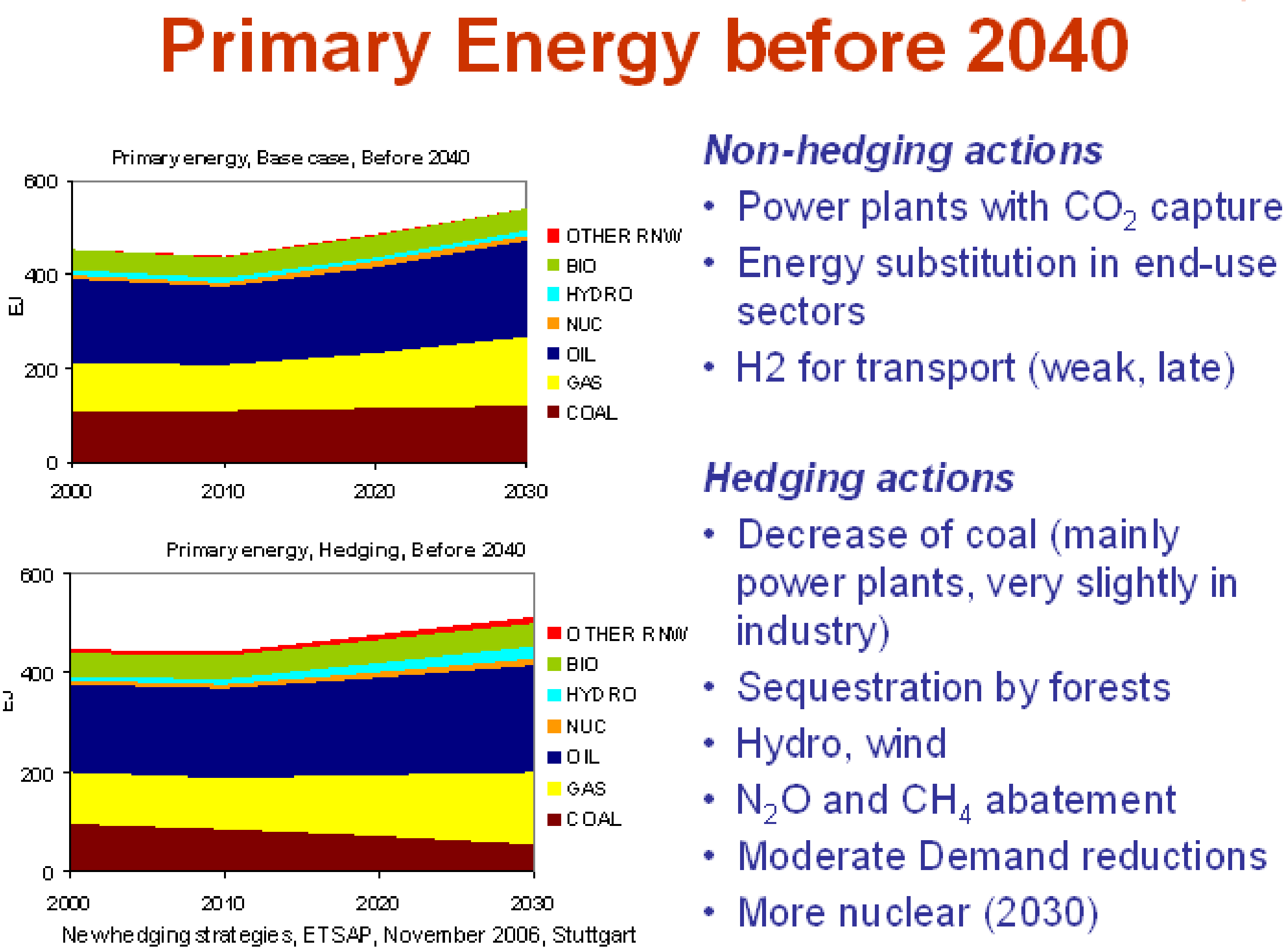

Figure 9: Hedging vs. non-hedging strategies: primary energy before 2040

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1.4. Myopic TIMES Prototype Version

Uwe Remme, Markus Blesl

TIMES so far assumes perfect foresight regarding the future, i.e., the model is optimized in one model run over the entire model horizon. In doing so, at each time period the future development of the model input data is completely known, so that this information about the future is taken into account when determining the optimal solution. Perfect foresight models are therefore also called clairvoyant models. Far away developments in the future thus influence nearby decisions in the model. Therefore, the strategies derived under perfect foresight are assuming a long-term planning horizon and behavior of the decision-takers. A critical aspect of a perfect foresight model is the circumstance that future exogenous framework conditions of the model, e.g. the demand vector or energy import prices, are assumed to be known today for the entire model horizon, although uncertainty regarding these projections increases the farther one looks into the future.

A different view of the future is embedded in so-called recursive-dynamic (also called time-step) model concepts. To determine the optimal decisions in a model period only a limited part of the future model horizon is known. In a recursive-dynamic model, the model is not optimized in a single run over the entire model horizon, but through a number of successive model runs, each covering only a few periods (often only one period) of the model horizon. The solution obtained in a model run, e.g. investment decisions, serves then as input information for the consecutive model run, until the end of the model horizon is reached. Thus, strategies derived under this time concept resemble more a short-term or myopic behavior of the decision-takers. It should also be noted that in contrast to a perfect foresight approach changes of model input data for future periods not contained in the current model run do not influence the solution.

To explore the differences of short-term versus long-term decisions obtained from an energy system model as

TIMES, a myopic model variant has been developed. A characteristic feature of this myopic version is the fact that the allowed foresight is not restricted to one period, but can be chosen to comprise an arbitrary number of periods as wished by the modeler. Thus, the transition from a very short-sighted behavior characterized by a foresight of only one period to the perfect foresight solution can be studied by sensitivity analyses with various foresight horizons.

Beside the motivation to study differences or benefits of short-term versus long-term planning horizons in energy systems, a more practical reason for the development of a myopic TIMES version is the model size. Depending on the number of model periods, the number of sub-annual time-slices within a year and the technological detail and size of the depicted energy system, the problem matrix of a perfect foresight model can become very large reaching the capabilities of the current computer hardware and software, especially in terms of physical working memory. Since a myopic model covers the entire model horizon by sequence of several model runs, each comprising only a few model periods, also large models may be solved in a reasonable time accepting the consequences of the short-sighted foresight on the model solution. A further application of this myopic version is the possibility to rerun the model only for a certain set of adjacent periods of the model horizon, once a solution from model runs for the previous periods is available. In terms of computation time, this feature is useful to calibrate some future periods to certain scenario assumptions or to perform a detailed sensitivity analysis for input assumptions in the considered set of periods.

The concept of the myopic TIMES version is shown in the figure 10 below for a foresight horizon of two periods. To ensure that for each period a solution is obtained having the same foresight, the individual model runs overlap. For the final model solution only the solution of the first period of each run is taken. Inter-temporal constraints of the TIMES model linking different periods have to be updated between the different model runs, e.g. by exchanging information on new installed capacity or by adjusting cumulative resource bounds.

A prototype of the myopic TIMES version has been used to study the oil production in the global ETSAP-TIAM model (see Figure 11).

With a foresight horizon of only one period (5 years) the scarcity of oil resources is not been taken into account in the decisions leading to a higher oil production compared to the perfect foresight solution. In later periods of the myopic run, unconventional oil resources in the USA and synfuel production are required to a much higher degree to compensate the higher early exploitation of conventional oil resources. These adjustment measures are also reflected in much higher oil prices in the myopic version compared to the clairvoyant version, as shown in Figure 12 for different foresight horizons.

1.5. Investment and cost bounds in TIMES

Antti Lehtilä, VTT, Finland

In TIMES, the total objective function is calculated from detailed annual payments related to investments, fixed O&M costs and variable costs, including taxes and subsidies on investments, operation, process flows or gross or net commodity production. Version 2.3.0 includes the facilities to specify various bounds on costs in the TIMES models.

New bound attributes

The following two attributes are available for specifying bounds on various types of cost components, by region and currency:

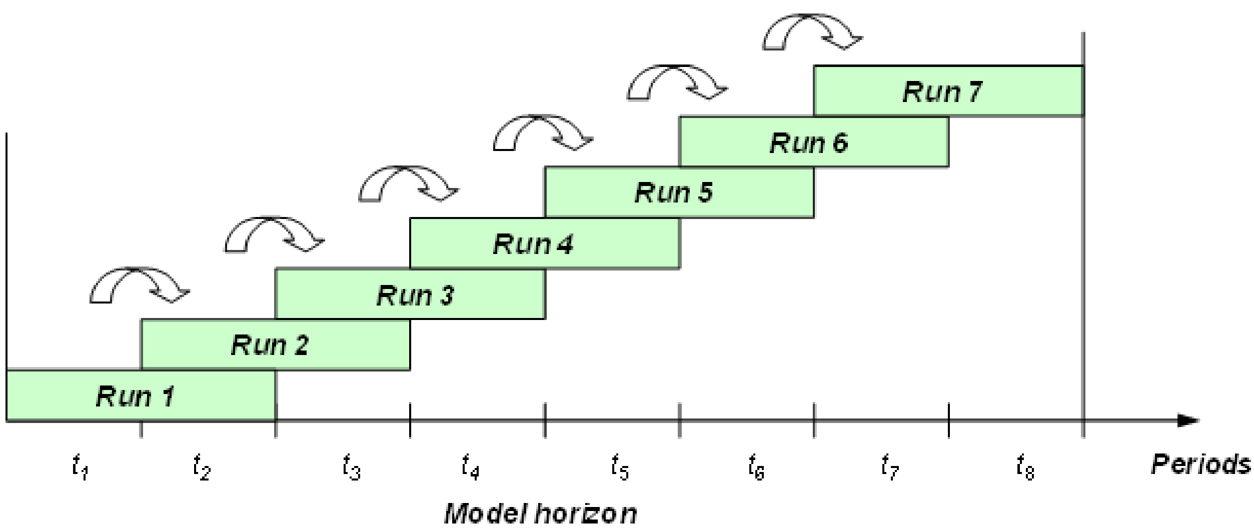


Figure 10: Sequence of myopic model runs

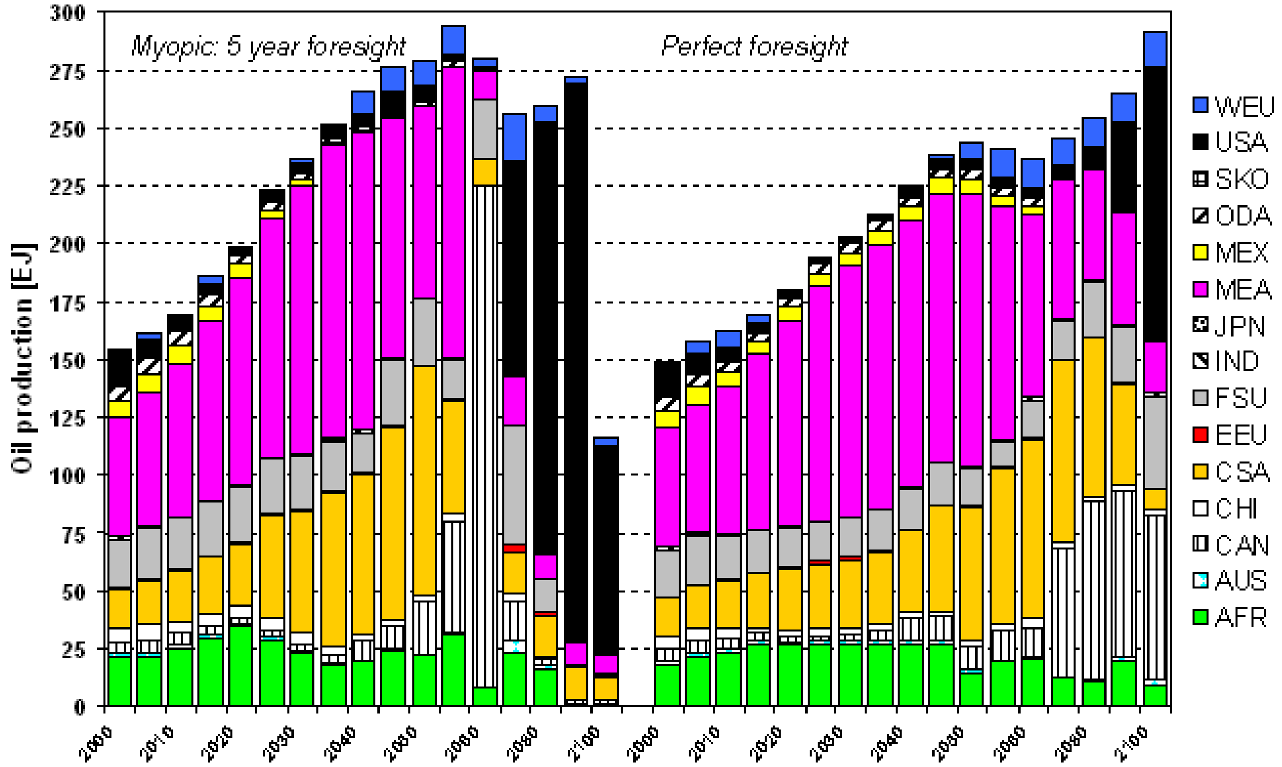


Figure 11: Global production by region for the myopic (left) and the clairvoyant case (right)

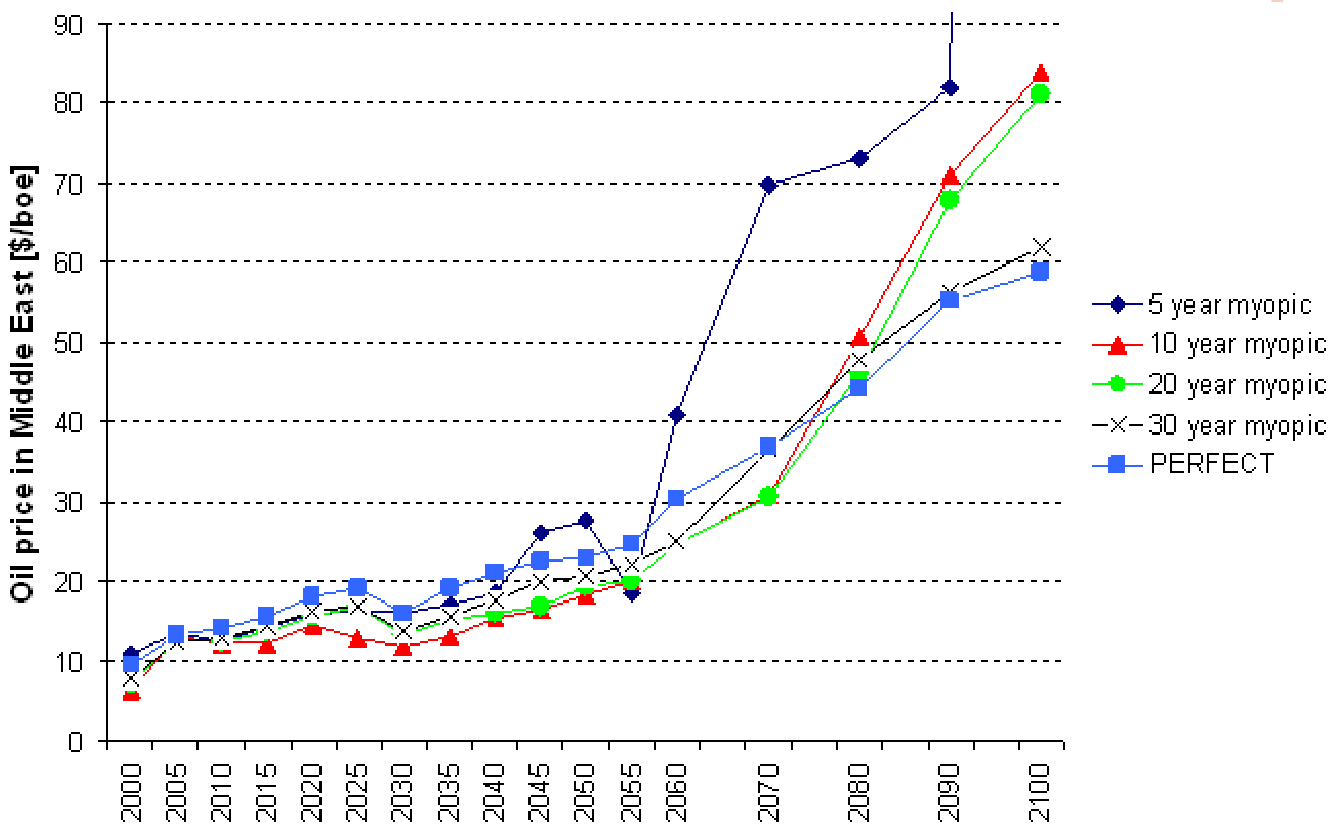


Figure 12: Oil price trajectories in the Middle East for different foresight horizons

1. EG_BNDCST(r,y,item,cur,bd) is the regional bound on costs of type item in year y, specified in currency cur; and
2. REG_CUMCST(r,y1,y2,item,cur,bd) is the regional cumulative bound on costs of type item during the period from y1 to y2 (inclusive), specified in currency cur.

Note that the bounds specified by using the attribute REG_BNDCST always apply to milestone years only. However, the bounds specified by the attribute REG_CUMCST apply to any range of years, which need not be milestone years. Consequently, one can also define a bound on any single year by using the cumulative bound attribute with equal years (y1=y2).

All important cost components in TIMES can be bounded.

Example 1. Set an upper bound X on the total investment annuity payments in year 2005 (or milestone year of the period including 2005) in the region WEU:

REG_BNDCST('WEU','2005','INV','CUR','UP') = X;

Example 2. Set a fixed bound 0 on the net sum of total fixed taxes and subsidies (the amount of taxes subtracted by the amount of subsidies) paid within the period 2005–2025 in the region WEU:

REG_CUMCST('WEU','2005', '2025','FIXTAXSUB','CUR','FX') = EPS;

New UC Attributes for referring to investment annuities

TIMES allows now also incorporating into user constraints the total investment cost annuities related to any process and paid in given milestone years. This requires that a corresponding UC_ATTR is specified for the NCAP component of the user constraint. The new UC_ATTR attributes related to using investment cost annuities in user constraints are listed in Table 2.

As indicated in the table, all the three new UC_ATTR attributes INVCOST, INVTAX and INVSUB, which can be specified on the NCAP components, automatically imply also the attribute CUMSUM for the same component. This means that the NCAP component for any milestone T year consists of the cumulative sum of the new capacities installed up to the year T. And, when combined with e.g. the INVCOST attribute, the resulting NCAP component represents the cumulative sum of annuities related to all new capacities installed up to the year T, and paid in year T. The SYNC attribute can be additionally used in dynamic constraints to synchronize the RHS milestone year to be the same as the LHS year. The user can also specify several of the cost attributes (INVCOST, INVTAX, INVSUB), which results in the summing of the cost types. Subsidies are always treated as negative.

Referring to **Example 1** above, an equivalent way of specifying an upper bound X for the total investment annuity payments in the WEU region in year 2005 would be to make the following UC specifications:

SET UC_N / INVBND /;

UC_NCAP('INVBND', 'LHS','WEU','2005',PRC) = 1;

UC_ATTR('WEU','INVBND','LHS','NCAP','INVCOST') = YES;

UC_RHSRTS('WEU','INVBND','2005','ANNUAL','UP') = X;

In the example above, the set PRC refers to all processes.

Example 3. In the WEU region, the total amount of subsidies on wind power investments should be limited to a maximum of 5% of all investments in the power sector between 2005 and 2030. This can be formulated as follows:

SET UC_N / WINDSUBS /;

UC_ATTR('WEU','WINDSUBS','LHS','NCAP','INVSUB') = YES;

Table 2: New Attributes for referring to investment annuities in the User Constraints

Attribute	Description	Applicable UC components
INVCOST	Multiply by investment cost annuities; Implies CUMSUM.	NCAP
INVTAX	Multiply by investment tax annuities; Implies CUMSUM.	NCAP
INVSUB	Multiply by investment subsidy annuities; Implies CUMSUM.	NCAP
CUMSUM	Sum over all periods up to current period (or previous period if specified on the RHS of dynamic constraint).	All
SYNC	Synchronize the RHS and LHS sides in a component of dynamic constraint (i.e. use the same T index); Applicable to the RHS side only.	All (RHS side only)

UC_ATTR(’WEU’,’WINDSUBS’,’RHS’,’NCAP’,’INVCOST’) = YES;

UC_ATTR(’WEU’,’WINDSUBS’,’RHS’,’NCAP’,’SYNC’) = YES;

UC_NCAP(’WINDSUBS’,’LHS’,’WEU’,T,WINDPRC) = -1;

UC_NCAP(’WINDSUBS’,’RHS’,’WEU’,T,ELCPRC) = .05;

UC_RHSRTS(’WEU’,’WINDSUBS’,’0’,’ANNUAL’,’UP’) = 1;

UC_RHSRTS(’WEU’,’WINDSUBS’,’2005’,’ANNUAL’,’UP’) = EPS;

UC_RHSRTS(’WEU’,’WINDSUBS’,’2030’,’ANNUAL’,’UP’) = EPS;

Remark 1: In this example, both the LHS and RHS sides are needed to formulate the constraint. Using any attribute on the RHS will automatically imply that the constraint is dynamic, but we want both sides to refer to the same milestone years. Therefore, it is necessary to use also the SYNC attribute for the NCAP component on the RHS side.

Remark 2: In the above, the sets WINDPRC and ELCPRC denote sets of wind power technologies and all electricity production technologies, respectively. In VEDA-FE you should be able to use the various filters for the UC_NCAP parameters, to define these sets in an implicit way.

Example 4. In the WEU region, the growth in total investment costs should be limited to a maximum of 3% per annum. As a seed for the growth, the investment costs can be in 2005 at most 9000 million. This can be formulated as follows:

SET UC_N / INVGROW /;

UC_ATTR(’WEU’,’INVGROW’,’LHS’,’NCAP’,’INVCOST’) = YES;

UC_ATTR(’WEU’,’INVGROW’,’RHS’,’NCAP’,’INVCOST’) = YES;

UC_ATTR(’WEU’,’INVGROW’,’RHS’,’NCAP’,’GROWTH’) = YES;

UC_NCAP(‘INVGROW’,’LHS’,’WEU’,T,PRC) = 1;

UC_NCAP(‘INVGROW’,’RHS’,’WEU’,T,PRC) = 1.03;

UC_RHSRTS(’WEU’,’INVGROW’,’0’,’ANNUAL’,’UP’) = 12;

UC_RHSRTS(’WEU’,’INVGROW’,’2005’,’ANNUAL’,’UP’) = 9000;

Remark 1: Using any attribute on the RHS (e.g. GROWTH) will automatically imply that the constraint is dynamic, and that is exactly what is wanted here.

Remark 2: In the above, the interpolation option 12 is used to set the seed to zero in all periods other than the one including 2005.

2. VEDA [Versatile Data Analyst]

Amit Kanudia, KanORS, New Delhi, India

VEDA satisfies the needs of modellers and analysts using complex models which require extensive manipulation of input data and results. It is a powerful, user-friendly set of tools designed to facilitate the creation, maintenance, browsing, and modification of the large data bases required by complex mathematical energy/economic models, as well as exploration of results and the creation of reports. VEDA was explicitly conceived and designed to support multi-region modelling. VEDA supports both the MARKAL and TIMES models.

VEDA features:

- Highly modular design;
- Reliance on flexible Excel spreadsheet workbook templates integrated with a core database;
- Direct linkage to existing data sources such as IEA energy balance statistics, USEPA eGRID, and EuroStat;
- RES diagramming with data views;
- Powerful filter and search facilities;
- Quick graphing capabilities, and
- Integration with various MS-Office components.

VEDA consists of two applications, the front-end (VEDA-FE) for handling the model data, and the back-end (VEDA-BE) for analyzing model results. The “heart” of VEDA-FE is the VEDA-Navigator (see Figure 13). It monitors and manages the various workbooks comprising a particular TIMES model, providing direct access to the workbooks and ensuring consistency of the various components.

Power search and filter facilities are combined with a dynamic data cube (pivot table), depicted in Figure 14, facilitate viewing data and organizing the data.

Digesting and quality control the underlying system is facilitated by means of a RES diagramming capability that allows one to cascade through the RES, displaying the related data along the way (see Figure 15).

Other advanced features support calibration, demand projections, technologies repository and inheritance of technologies, and powerful scenario definition facilities.

VEDA-BE also relies on the dynamic data cube, combined with user-defined sets (as well as the standard model sets) and tables. The tables can be grouped into reports which in turn may be spooled to Excel for post-processing (see Figure 16).

Both VEDA-FE/BE also support quick analysis graphics as well (see Figure 17).

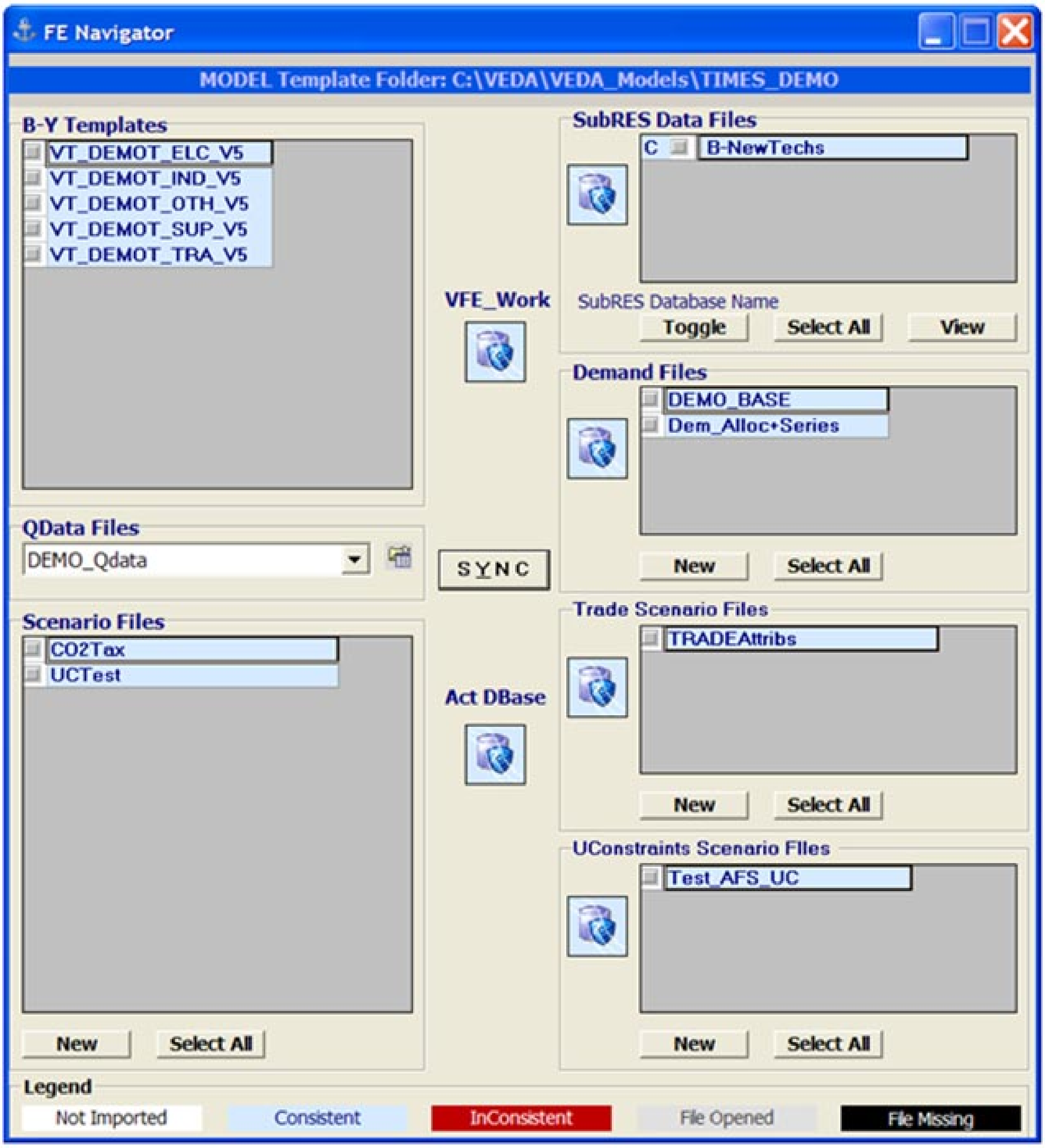


Figure 13: VEDA Front-End Navigator Screen

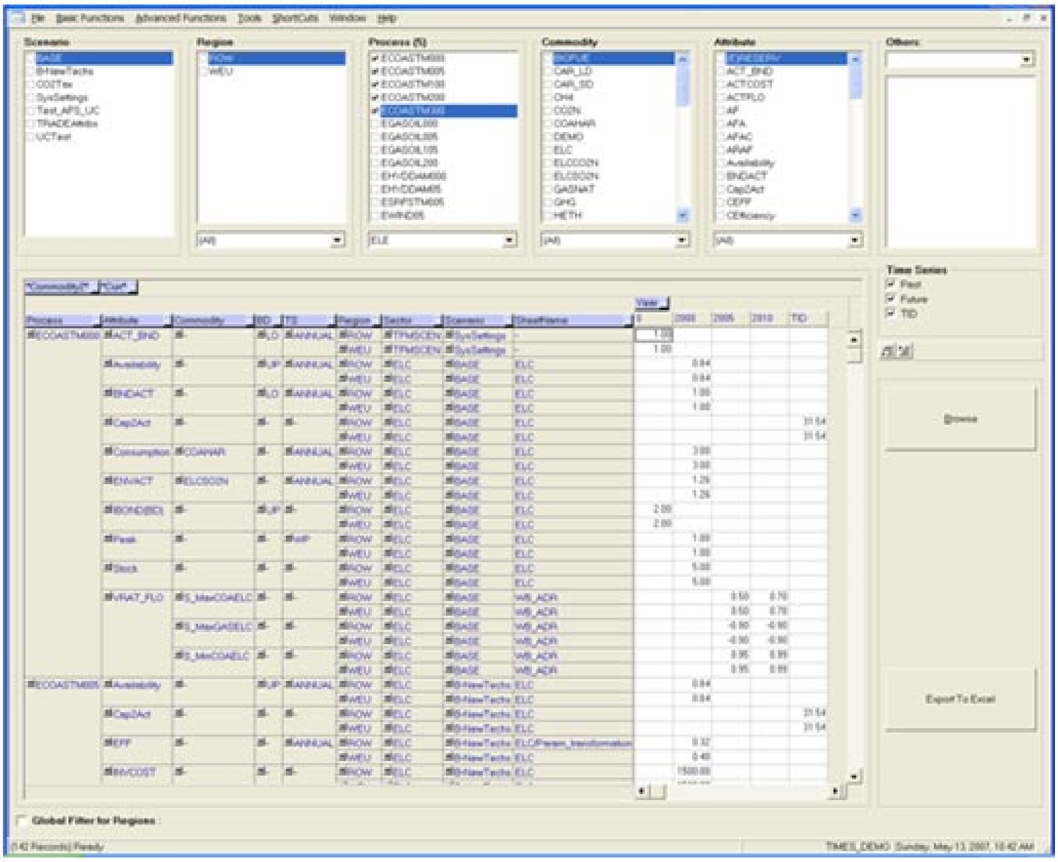


Figure 14: VEDA Front-End model browser-editor main screen

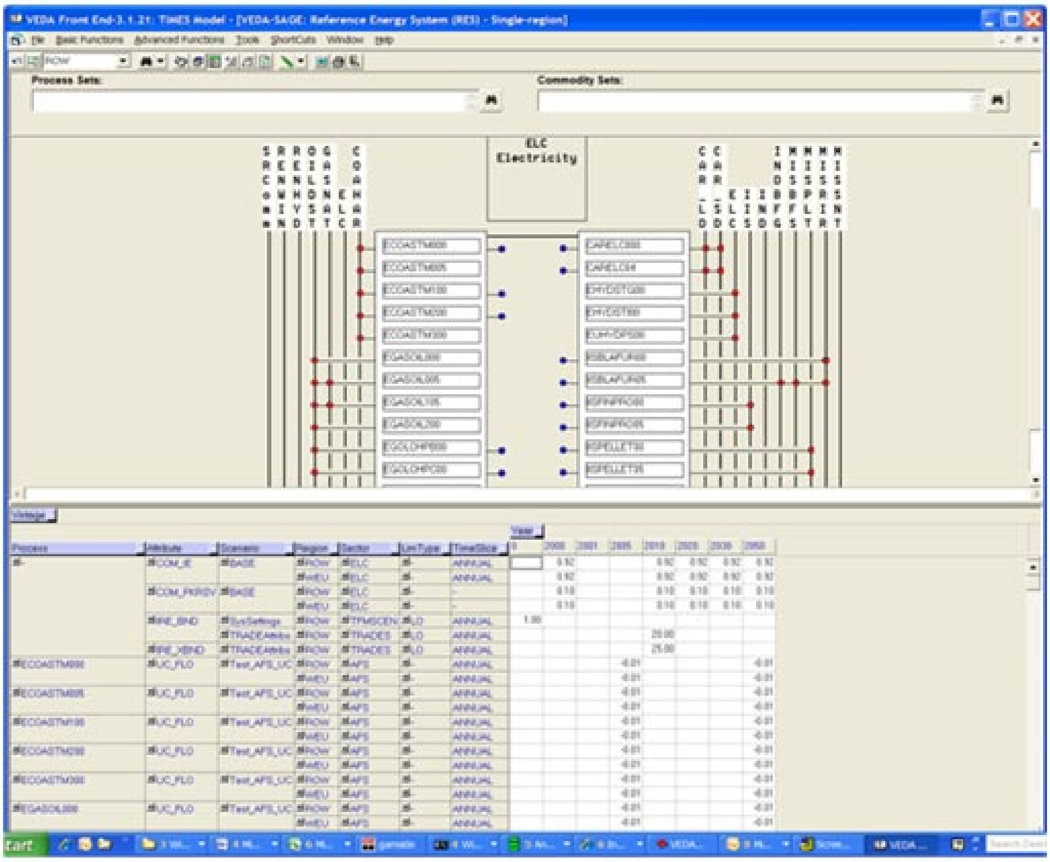
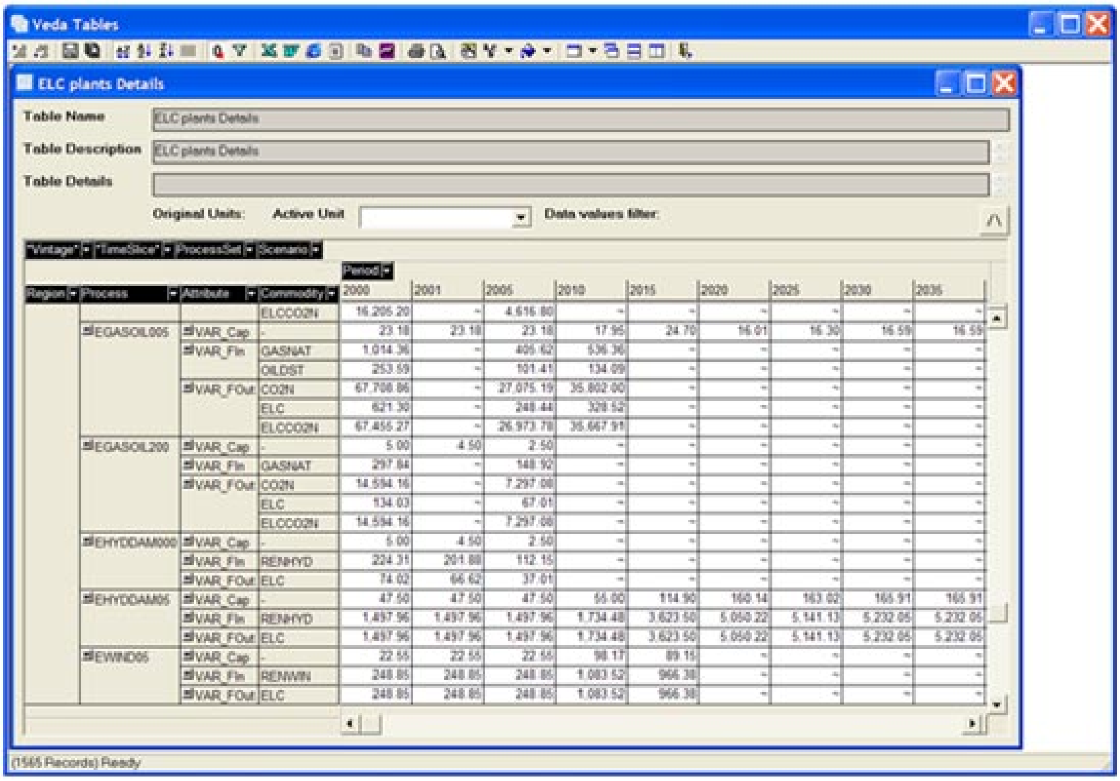


Figure 15: VEDA Front-End Reference Energy System diagramming capability



Region	Process	Attribute	Commodity	2000	2001	2005	2010	2015	2020	2025	2030	2035
			ELCCO2N	16,205.20	-	4,616.80	-	-	-	-	-	-
	EGASOIL005	VAR_Cap	-	23.18	23.18	23.18	17.95	24.70	16.01	16.30	16.59	16.59
		VAR_FIn	GASNAT	1,014.36	-	405.62	536.36	-	-	-	-	-
			OILDST	253.59	-	101.41	134.09	-	-	-	-	-
		VAR_FOut	CO2N	67,708.86	-	27,075.19	35,802.00	-	-	-	-	-
			ELC	621.30	-	248.44	328.52	-	-	-	-	-
			ELCCO2N	67,455.27	-	26,973.78	35,667.91	-	-	-	-	-
	EGASOIL200	VAR_Cap	-	5.00	4.50	2.50	-	-	-	-	-	-
		VAR_FIn	GASNAT	297.84	-	148.92	-	-	-	-	-	-
		VAR_FOut	CO2N	14,594.16	-	7,297.08	-	-	-	-	-	-
			ELC	134.03	-	67.01	-	-	-	-	-	-
			ELCCO2N	14,594.16	-	7,297.08	-	-	-	-	-	-
	EHYDDAM000	VAR_Cap	-	5.00	4.50	2.50	-	-	-	-	-	-
		VAR_FIn	RENHYD	224.31	201.88	112.15	-	-	-	-	-	-
		VAR_FOut	ELC	74.02	66.62	37.01	-	-	-	-	-	-
	EHYDDAM05	VAR_Cap	-	47.50	47.50	47.50	55.00	114.90	160.14	163.02	165.91	165.91
		VAR_FIn	RENHYD	1,497.96	1,497.96	1,497.96	1,734.48	3,623.50	5,050.22	5,141.13	5,232.05	5,232.05
		VAR_FOut	ELC	1,497.96	1,497.96	1,497.96	1,734.48	3,623.50	5,050.22	5,141.13	5,232.05	5,232.05
	EWIND05	VAR_Cap	-	22.55	22.55	22.55	98.17	89.15	-	-	-	-
		VAR_FIn	RENWIN	248.85	248.85	248.85	1,083.52	966.38	-	-	-	-
		VAR_FOut	ELC	248.85	248.85	248.85	1,083.52	966.38	-	-	-	-

Figure 16: VEDA Back-End multi-dimension table system.

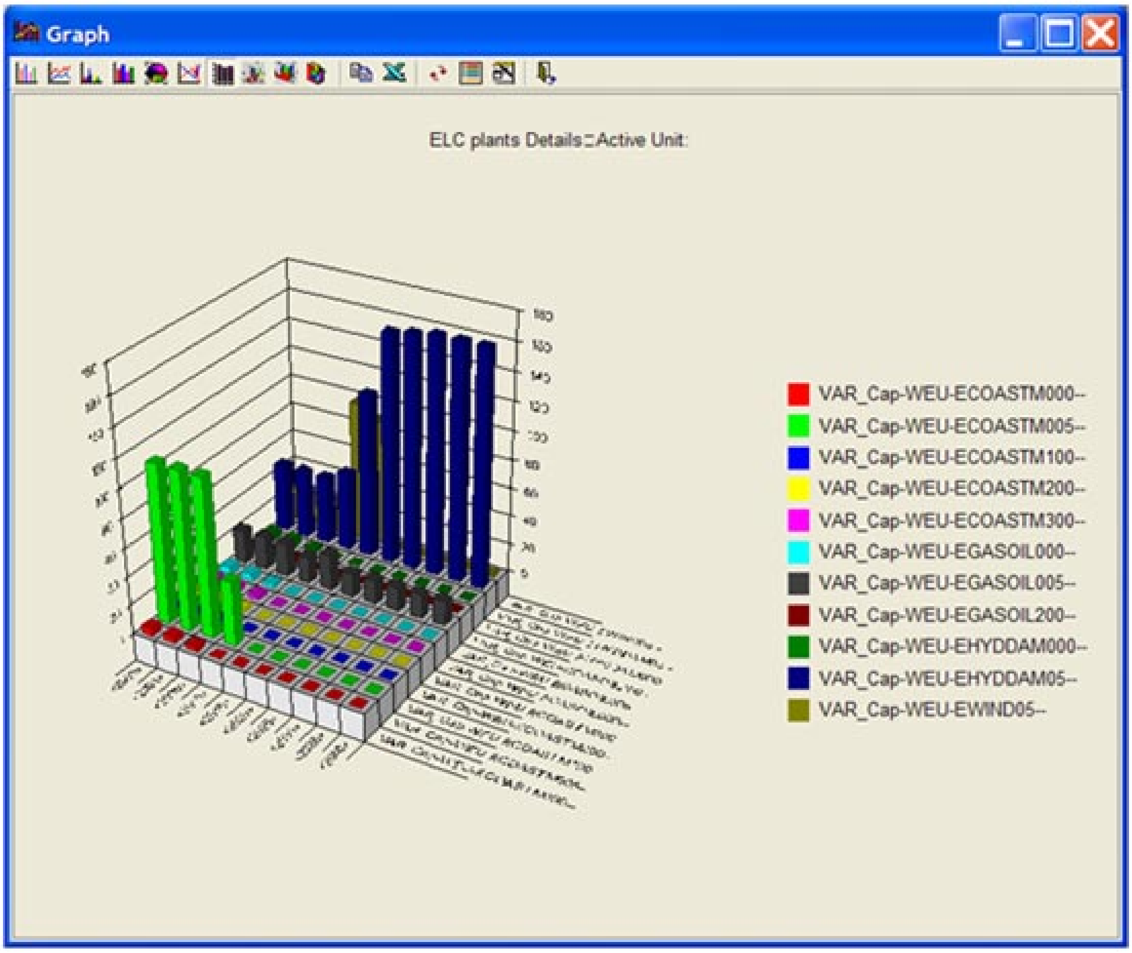


Figure 17: VEDA Back-End graphing capabilities

3. Some Early TIMES Applications

3.1 ETSAP Activities in EMF-22 (2004-2008)

Richard Loulou, Maryse Labriet, Amit Kanudia, Gerad, Montreal, Canada

In Summer 2004, ETSAP mandated Richard Loulou (KANLO) and his team (Amit Kanudia, Maryse Labriet) to participate in the Energy Modeling Forum (EMF-22) on behalf of ETSAP, and to use ETSAP's TIAM (TIMES Integrated Assessment Model) to provide inputs into the EMF-22 process.

EMF-22

The Energy Modeling Forum is a long standing international forum based at Stanford University, which regroups the main global energy modellers. In the last three decades, EMF has defined and organized 22 work programs, each on a specific theme. The last in date EMF-22, is about long term climate stabilization and policies to achieve such. It has four Work Groups, each tackling one aspect of the central theme:

- WG1: Hedging Strategies for long term climate stabilization
- WG2: Transition Policies in the context of Climate Stabilization
- WG3: Black Carbon / Organic Carbon, and their effect on radiative forcing
- WG4: Land-use changes and their effect on emissions

ETSAP participated in WG1 from 2004 to 2006 (with additional tail activities in 2007) and is participating in WG2 starting 2006 (but delays occurred within WG2).

Hedging Strategies for Climate Stabilization with ETSAP-TIAM

The following main experimental assumptions – an alternate experiment assumes a more gradual resolution of uncertainty, but was not being treated with TIAM – were defined by WG1, to be followed by all modellers in that WG:

- Stabilization of global temperature to 2ºC or 3ºC
- Horizon length left to the choice of each modelling team, but recommended to be as long as possible. For TIAM: horizon extends to 2100.
- GDP growth reference scenario is chosen by each modeling team. For TIAM, we chose a reference GDP scenario close to the B2 storyline of the IPCC-SRES, i.e. moderate economic growth of GDP world population almost stagnating after 2050
- Uncertainty of the Climate Sensitivity parameter (Cs) is assumed. The probability distribution of Cs is described in Table 1, with a range of possible values from 1.5 ºC to 8ºC
- Uncertainty prevails until 2040, and is fully resolved in 2040
- Economic development (represented by GDP growth rate) is assumed known until 2040, and uncertain after 2040, with two equally probable values, namely:
  - GDP = 2/3 * GDP_{ref} with probability 0.5
  - GDP = 4/3 * GDP_{ref} with probability 0.5
- In 2040, GDP rate is revealed for all years of the horizon
- The Climate Sensitivity (Cs) can have values 1.5 ºC, 3 ºC, 5 ºC, 8 ºC with probabilities 0.25, 0.45, 0.15 and 0.15 respectively.

The above scenario was implemented in TIAM via Stochastic Programming in extensive form, using the event tree of figure 18. This feature was developed by Richard Loulou, Antti Lettila and Amit Kanudia in view of the application to EMF-22, and was especially adapted and coded by Antti Lettila (VTT, Finland). In particular, the TIMES code was modified to allow Cs and several other parameters to be uncertain (for details, refer to the documentation of the Stochastic feature on ETSAP web site).

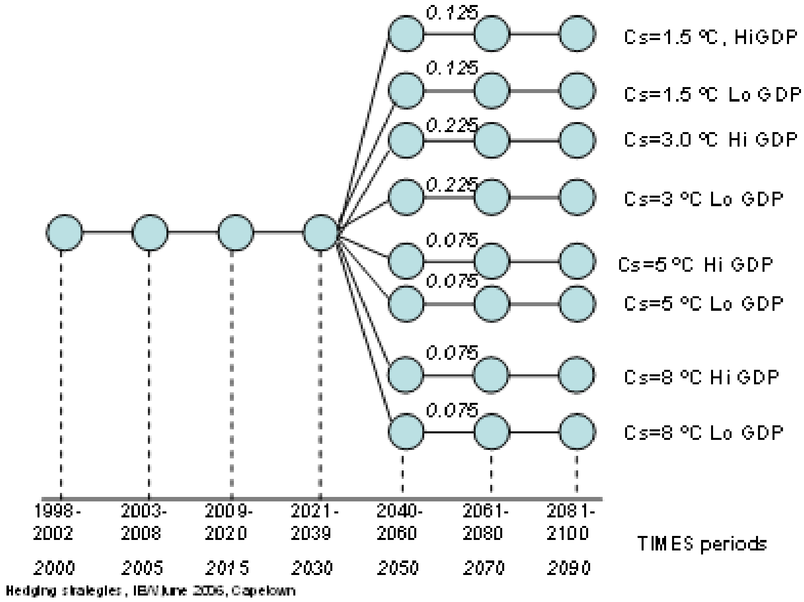


Figure 18: Event Tree implemented in ETSAP-TIAM for EMF-22

Main findings

1. Hedging for climate uncertainty is required, but hedging for economic uncertainty is not (i.e. wait-and-see is not a good strategy as far as Cs uncertainty is concerned, but is OK for GDP uncertainty).
2. As shown in Table 3, six long range temperature change targets were attempted, ranging from 2.1 to 3.3 °C. Targets 2.1°C and 2.3°C are very expensive to attain, and target 3.3°C is quite easy to attain.
3. Target 2.7°C was investigated in more detail, and the following brief comments apply to that target:
   - NPV of overall expected cost is equal to 1692 G$ (to be precise, the cost is to be understood as loss of total surplus);
   - Main hedging actions before 2040 are:
     - replacement of coal power plants by wind, hydro, and gas plants
     - biological CO2 sequestration by forestry measures
     - many targeted CH4 and N2O abatement actions
     - slightly more nuclear power plants
   - note that CCS actions and hydrogen are not part of the hedging strategy prior to 2040
   - if uncertainty were resolved in 2020 rather than 2040, overall expected cost would be reduced by 27% to 1230 G$, and if resolution date were 2005 (i.e. now), expected cost would be reduced by 33% to 1135 G$. Thus early information would be quite valuable.

Table 3: NPV of total cost for six alternative stabilization targets

ΔT_{2090}	ΔT_{max} (long term)	Cost ($G\$_{2000}$)	Annuity ($G\$_{2000}$)
1.4°C		*Infeasible*	
1.5°C	2.1°C	25283	$1,274
1.6°C	2.3°C	9075	$457
1.8°C	2.7°C	1692	$85
2.0°C	3.3°C	249	$13
2.3°C	4.6°C	Base Case	

Conclusion: this set of runs has shown that hedging is a useful concept when facing climate uncertainty, and Stochastic programming a powerful way to compute hedging strategies. The alternative approach of using alternate scenarios is not an effective way to resolve the dilemma facing policy makers when confronted to an uncertain

3.2. The Pan European Energy Model and Scenarios of the EC-NEEDS Project

Lina Cosmi, CNR-IMAA, Potenza, Italy

The activities of the Integrated Project NEEDS concerning the Research Stream "Modelling Pan European Energy Scenarios", in which some ETSAP partners are involved, have been addressed to three main issues:

- Implementation of TIMES- based energy system models for 28 European countries and their harmonisation into a multi-region Pan EU modelling platform
- Definition of the policy scenarios to be examined at Pan EU level
- Integration of data and models, with particular concern to LCA and ExternE.

As concerns the TIMES modelling activities, the 28 country models were implemented taking into account the main energy – environmental policies at national level and the Business As Usual –country scenarios have been analysed (time horizon 2000 – 2050). In this framework, particular attention was given to the implementation of a reference energy technology database that includes a fairly complete set of technologies with default technological and economical parameters to be used to perform any model development or scenario analysis. All data were assembled in Excel format and converted into a model's user interface ready format that allows direct import into the models. The country models have been subsequently harmonised to the Pan European model's requirements in order to achieve a multiregional integration aimed at examining the crucial policy issues at EU level. To this purpose, suitable spreadsheet interfaces have been implemented to link the country models representing energy and emissions trades between countries as well as to increase the model's flexibility. The work in progress is addressed to the implementation of the Business as Usual Scenario for the Pan EU model.

As concerns the scenarios definition, the topics addressed, in agreement with the stakeholders, were the environmental issues like climate policy and local pollution that are linked to energy use and energy policies aimed at reducing the EU-dependency on energy imports. Four main scenarios were thus defined:

- A Reference BAU Scenario (Baseline) whose basic assumptions were adapted from the DGTREN 2005 projections,
- A Post-Kyoto climate policy to stabilize CO2 concentration in agreement with the EU COM (2007)2,
- The Enhancement of endogenous energy

resources by constraining imports of fossil fuels,

- The improvement of environmental quality by indogenizing externalities related to local air pollution.

Some variants are willing to be examined (among which a crisis scenario representing a moderate economic growth and pessimistic technological change assumptions) to explore the stability of solutions and to identify the robust options.

In the framework of a multi-lateral integration of data, the input-output information flows among the Research Streams were defined (see Figure 20). In particular, a common set of technologies for the electricity generation sector was agreed, to be used as input to the TIMES modelling work, including besides the usual techno-economic data, additional information concerning LCA and externalities for the technologies concerned.

Using the common technology database and the scenario information, the NEEDS Pan-EU model will be able to determine the optimal technology and fuel pathways corresponding to each scenario. The results will in turn, constitute new input data for both LCA and ExternE, to be used for iterative, convergent evaluations.

The main expected results are concerned with the assessment of target-based policies (e.g. setting thresholds for CO_2 emissions) at national as well at EU level and identification of regulatory instruments and price mechanisms for their implementation, the development of coherent long-term strategies and sound climate protection policies at Pan-European level, the evaluation of the expected long-term results of LCA (dynamic, regionally and policy dependent, fuels mix, technologies innovation, demand levels), the internalisation level of external costs in order to reach policy goals.

Acknowledgements and further information:

The NEEDS Integrated Project is funded by the EU under the Sixth Framework Programme (Priority 6.1: Sustainable Energy Systems Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy) More information on the project and the consortium can be found on http://www.needs-project.org/index.asp

Figure 19: Countries included in the multi-regional Pan-EU-model for NEEDS.

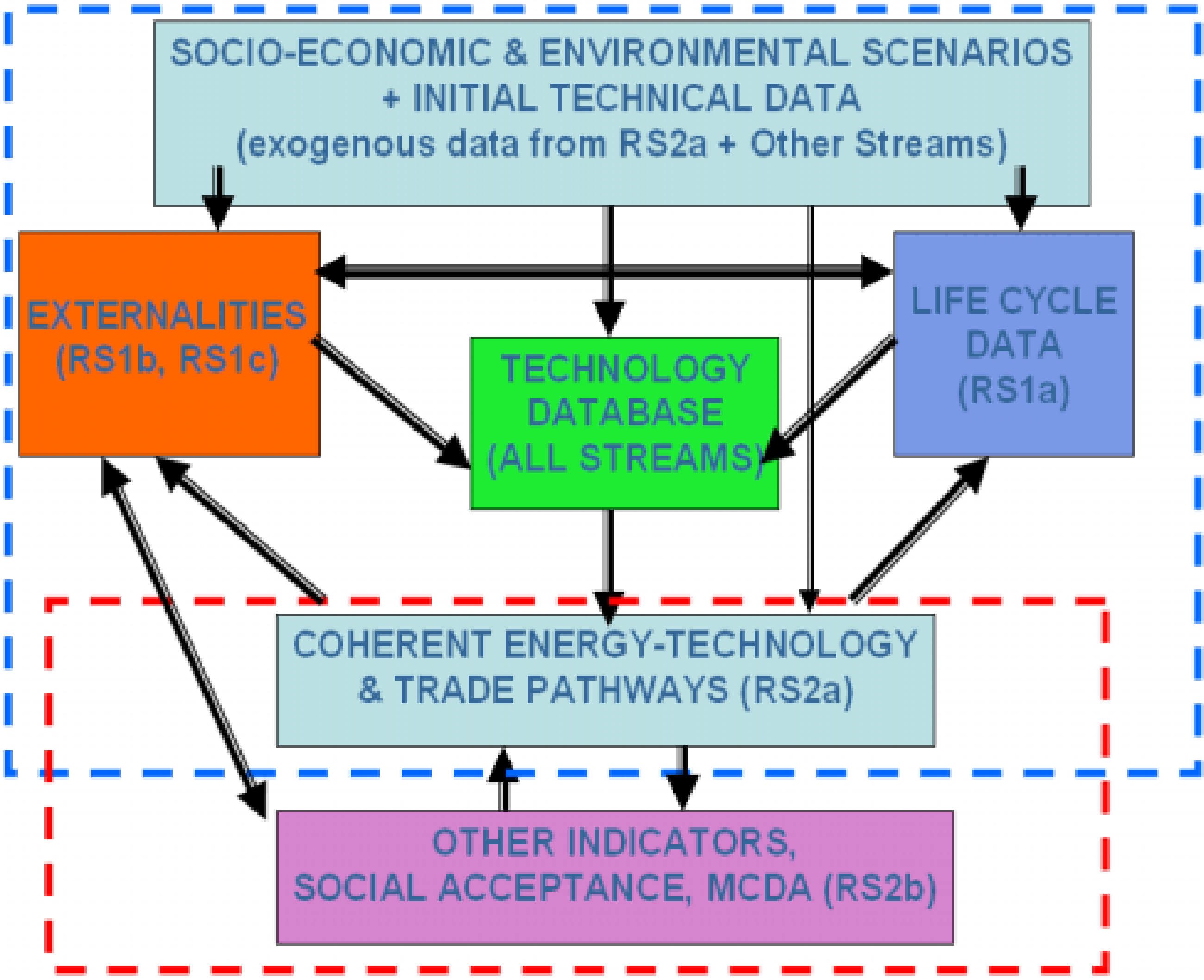


Figure 20: Information flows among the IP NEEDS Research Streams (source: R. Loulou)

3.3 The Italian electricity sector: a regional and multi grid TIMES model

Maurizio Gargiulo, POLITECNICO DI TORINO - Energy Department, Torino, ITALY

In the framework of a national research program promoted by Italian government, a TIMES regional model has been developed, from a research group composed by Politecnico di Torino, AIEE (Italian Association of Energy Economists), Politecnico di Milano and coordinated by CESI RICERCA (Italian Electrotechnical Research Centre), for evaluating long term scenarios (30 years) for the Italian electric system, with the aim to focus on the relevant drivers (economic development, technology advances, primary sources, environmental impact) and to support the decision making process of the Public Authorities and other stakeholders of the electric system.

The increasing sensitivity about the strategic role of energy system and the relevance of its impact on the environment, drive national energy policies to consider as a priority not only energy security of supply, but also to support the development of a sustainable energy system. The mission to find an useful compromise among environmental, economic and social instances can be considered more than a challenge for energy policies.

The description of the system is very detailed: 5 sectors, 32 energy services and 150 end-use technologies in the demand side and about 450 power plant units in the supply side; 20 Regions, 5 electricity commodities spread over 4 types of grid for transport, transformation and distribution. Inter-regional exchange technologies are described with costs, installed capacity and efficiency of transportation.

The paper presents a selection of results concerning scenarios with different role of electricity import, renewable sources, emission permit developments and "end-uses technologies."

The model for the Italian electricity sector

The multi-regional MATISSE model uses the "bottom-up" approach TIMES, with a time horizon 2004 – 2030, with 5 annual periods and 6 four-year periods for the time period length and with 8 time slices (4 seasons, and day-night) and an high "space dimension" description: the supply and demand sides for the electrical sub-system are integrated and described for each of the 20 Italian regions.

The electrical supply side, generation power plants, is described with great detail, instead the electrical grids are described in more synthetic but innovative way with 4 different tension levels. This allows to identify geographically the load and so, also is approximated, to study the evolution of the electrical network.

The regionalisation of the supply side, beyond allowing the study of the impact of the power plants close to the final demand, allows also the study of the interregional electricity exchange between the 20 Italian regions.

In the existing framework the MATISSE model preview only the electrical commodity. In this way the final energy use are considered only for the fraction satisfied from the electrical energy and so the competition between different fuels is considered only in a undirected way. Such fraction is exogenously fixed for each demand segment. The results are the electricity consumption for each Regions, for the Demand side, the technologies mix of electric power plants generation ("centralised" and "distributed") for the Supply side in terms of capacity and typology, and the preliminary development of the electrical networks for transport and distribution between the Regions.

Demand side

The demand forecast for goods and services are part of the MATISSE input based on a modelling of the end uses subdivided in five areas: industrial, agriculture and fishing, transportation, service and residential. In order to represent in a realistic way the Italian market, for each area an original appropriate database of electrical technologies has been developed. This database is organised so that in each consumption area the same group of technology, composed by those available in the starting year and those available afterwards, is present for each of the 20 Italian regions. For example, residential sector comprises 44 "existing" and 20 "new" household types: boilers, refrigerators, deep freezers, washing machines, clothes dryers, dishwashers and air conditioning systems.

Global electric consumption arises from the energy needed to satisfy the demands for both comfort/lifestyle in homes and productivity in factories and offices and for each sector is due to the sum of the electricity consumption of all electric appliances used, that in turn depends on the supplied service levels and on the efficiency of each device. These last two parameters are the main drivers of the consumption growth because they depend respectively from the consumer specific requests (i.e. comfort, quality and quantity of industrial production) and from the technology of devices used.

A reference scenario has been implemented relating the energy services to basic assumptions concerning some appropriate economic and demographic drivers (Population, Number of families and Value added). For each demand sector, the following markers are considered:

- Residential sector: growth of the resident population, average number of persons per family and number of families;
- Industrial sector: value added at constant money and electric intensity of the value added;
- Service sector: valued added for the specific sector and the number of employers;
- Transportation sector: trend of demand expressed as number of passengers per kilometres of route; and
- Agriculture and fishing sector: electric intensity and the value added.

As output, MATISSE provides, for each region, the electricity consumption of all the technologies.

Electric production

The power system implemented in MATISSE is consistent with the year 2004 plants appraisal (detailed plant census: more than 350 plants set in 20 region). In this year the breakdown of the generation system is as follows: condensing steam cycle 26 % of national power, combined cycle 31%, gas turbines 3 %, other thermal plants 11%, hydro (both regulating and run-of-river) 26%.

In each region hydroelectric large plants are aggregated according to usual categories and described with a detailed availability factor, in order to reproduce the seasonal/diurnal variability of source abundance. Increasing in hydroelectric power is not expected before 2030.

A special focus on renewable sources different from hydroelectric (geothermal, mini-hydro, wind, solar, biomass, biogas and waste) is set, even if the role of these technologies is negligible nowadays in Italy, in order to evaluate the role that renewable sources can assume as a sustainable option versus fossil fuels; moreover an evaluation of efficiency of economic subsidies can be investigated.

For each renewable source a potential exploitation rate is defined as a bound for each region.

The Grid

Four voltage levels are modelled in MATISSE to represent respectively the very high voltage transmission (380-220 kV), the high voltage transmission (132-150 kV), the medium voltage supply (15-20 kV) and low voltage supply (380 V). These voltage levels are schematised by five regional electric "commodities". The conversion of an electricity commodity into another having different voltage level is allowed by technologies mainly characterised by costs (investment, operation and maintenance), efficiencies (fraction of energy transmitted), life (technical and economic) and transmission capacity limits parameters.

Moreover MATISSE takes into account the annual limits of the energy transfer (trade) across two neighbouring regions. These limits depend from the efficiency of transportation, the local maximum transmission capacity and the maintenance costs.

Results

Assuming a fixed demand scenario, different scenarios for the electric supply, deriving from the introduction of different bounds, have been considered: reference scenario, BAU (minimum industrial cost), and white certificate one.

Reference and BAU scenario

In this framework a relevant role is played by petroleum, and other fuel, prices. The fuel prices, used for reference, BAU and white certificate scenarios as exogenous variable, are presented in Table 4. Fossil fuel availability on market is assumed to be large enough to satisfy thermoelectric needs, thus no bounds are inserted to constrain fuel use.

BAU scenario (minimum industrial cost), is a non realistic scenario, but it shows system response in the case of no regulatory or environmental policy (no regional bound, no GHG limitation, no environmental bonds).

Reference scenario (REF), consider more bounds to electric system evolution: it acknowledges the environmental legislation about GHG [1-5] and it assumes some agreement on post-Kyoto period.

Figure 21 reports national electricity production according to fuels. Figure 22 shows difference among model choices for generation technologies in REF and BAU scenarios. Combined effects of Kyoto GHG bound and costs, and subsidise renewable, drives REF scenario towards wind and biomass plants instead of oil ad natural gas ones. Regional feature of these results can be derived from model. Figure 23 shows CO2 emissions from BAU and REF scenarios. Both the scenarios do not evaluate to fulfil Kyoto objective only by domestic action In the figure the relevance of flexible mechanism contribution is evidenced: for example, in 2030 it is about 60 t(CO2) that corresponds to 3 thousands euro saved (assuming a price of 50 •/t CO2).

REF scenario sets also a relevant quota for renewable energy (25,6% in 2014, 21,2% in 2030).

White Certificate Scenario

The aim of this analysis is to explore the possibility of an energy saving through an increase of the technologies' performances. This may be considered as a purely technological analysis because it assumes the existence of a perfect market where the more suitable technical solutions can be immediately applied.

The two specific cases simulated for this analysis are both based on REF scenario using the same energy services demand and the same evolution of economical and demographical parameters. In REF, fixed shares on end-uses technologies have been introduced, to take into account hedonistic behaviours of consumers. Unlike REF, in both these new two cases the constraints on the competition of technologies have been removed.

The only difference between these two cases is that the case called "white certificate scenario" adopts as general national targets an annual cumulative savings to promote energy end-use efficiency and to ensure the continued growth and viability of the market for energy services. This obligation shall be expressed in terms of an amount of energy that should be saved as a result of these energy efficiency measures. Taking into account the Italian legislation that prescribes the annual amount of the energy saving until 2009 and the EU Energy Efficiency and Energy Services Directive [1-5], a realistic energy saving trend has been supposed.

As a consequence in white certificate case constrains expressed as an upper limit on the global annual energy consumption have been modelled.

A comparison between the white certificate case and the other case has been performed. Results show that, in order to fulfil both constrains on energy consumption and minimise the global

Table 4: Fuel Cost (M•/$GWh_{thermal}$)

	Period							
Fuel	**2007**	**2008**	**2010**	**2014**	**2018**	**2022**	**2026**	**2030**
coal	0.010	0.009	0.010	0.010	0.010	0.010	0.011	0.012
diesel	0.038	0.039	0.041	0.044	0.044	0.044	0.046	0.048
natural gas	0.026	0.026	0.029	0.032	0.033	0.034	0.037	0.039
oil	0.020	0.021	0.022	0.023	0.023	0.023	0.024	0.025

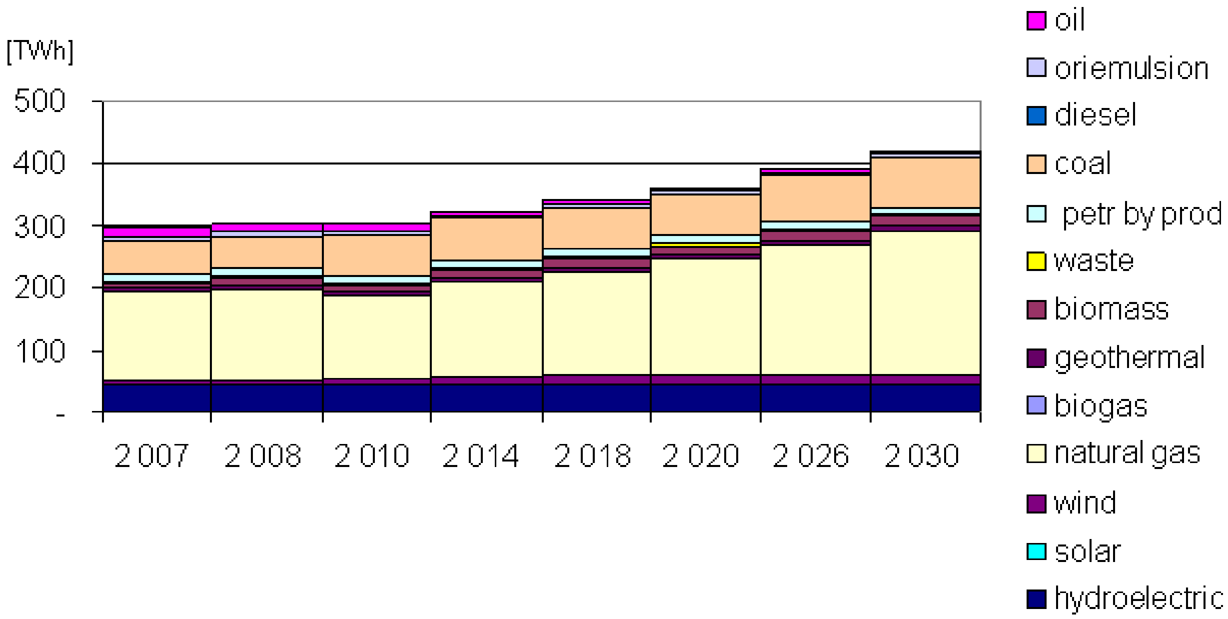


Figure 21: National production for different fuel types (TWh)

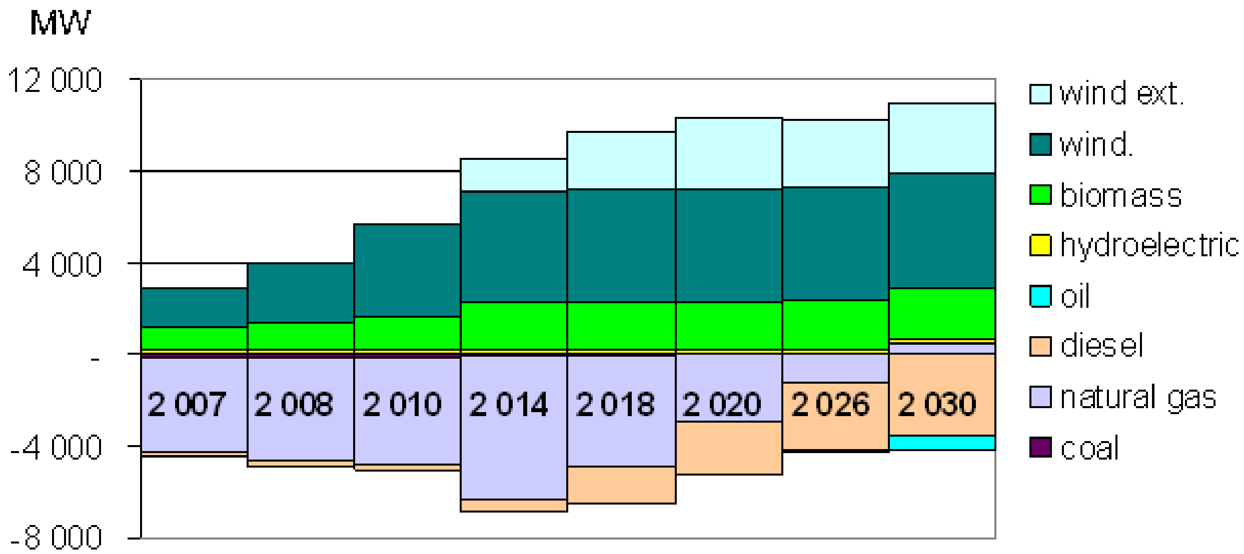


Figure 22: Power difference between REF and BAU scenario (MW)

cost, the objective function is 4% higher than the other case. The main contributions to energy saving arises from service sector until the milestone year 2014 and after that from residential sector. Figure 24 shows the evolution of energy saving for different technology groups.

Conclusions

This study has shown the capabilities of MATISSE, a powerful tool for the combined simulation and the analysis of electric supply and demand evolution, which allows to develop electric scenarios with high spatial resolution (20 different regions). These scenarios satisfy future demand projection for different sector. Local acceptability, tools to fulfil Kyoto protocol and renewable energy policies are assumed as bounds on local or national parameters.

Preliminary results, produced with a non-optimistic evolution in petroleum cost on international market, show the relevant role of gas and import, while coal is limited to fulfil bound on these power plant diffusion, according to the low social acceptance of this fuel.

The case study of white certificates performed to analyse the possibility of an energy saving through an increase of the technologies performances shows the different role of end-uses technologies in order to satisfy an obligation of energy saving and to minimize costs.

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

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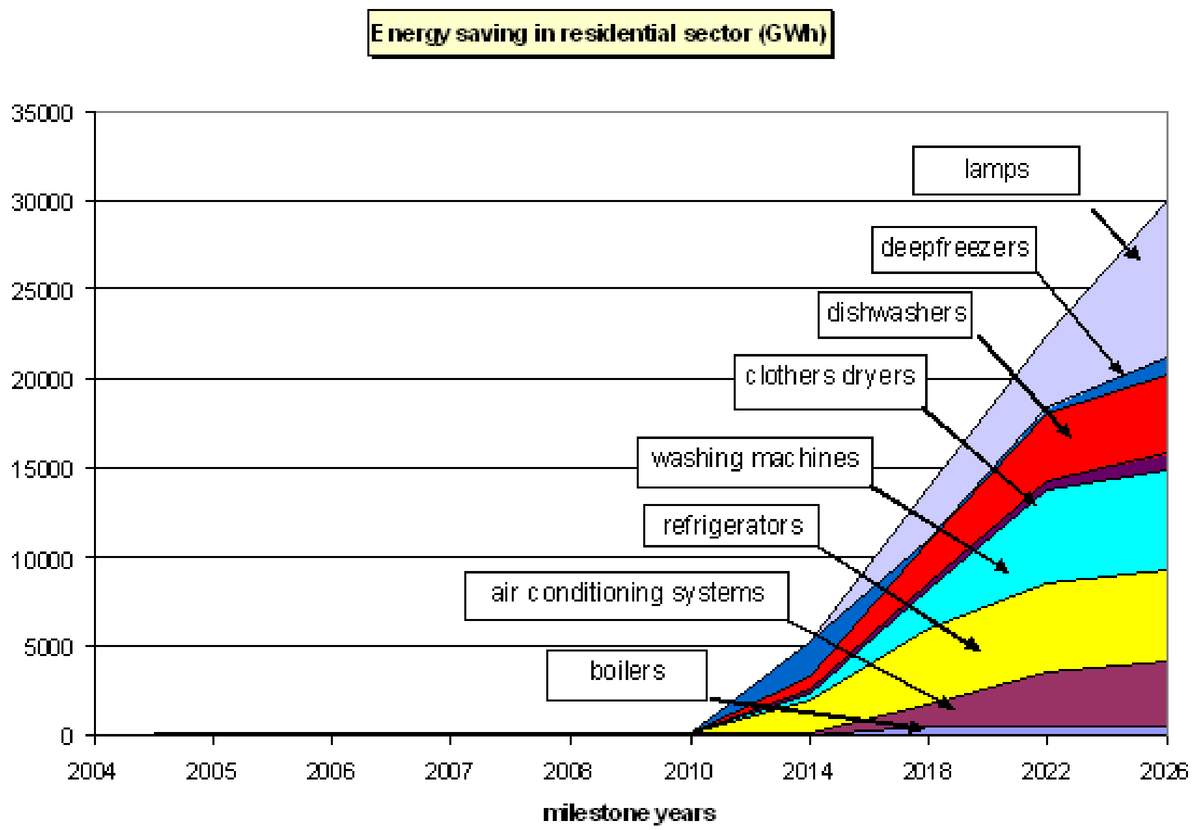

Figure 22: White certificate scenario: energy saving in residential sector for different technologies