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ANNEX VII CONTRIBUTING TO THE KYOTO PROTOCOL

German Modelers Look at Nuclear Phase-out

German modelers have analyzed the technological, economic and environmental effects of a planned phase-out of nuclear energy in Germany. Eleven models - including both bottom-up and top-down models - were used to examine the consequences of eight scenarios differing in power plant lifetimes, carbon dioxide emission restrictions, and future energy prices. Qualitatively similar results were obtained with the bottom-up models, but the top-down models projected higher phase-out costs. The study concluded that a combination of both types of model is needed.

An agreement between the German government and the electric utilities on 14 June 2000 capped the total lifetime output of each nuclear plant, leading to an average operating time of 32 years from the beginning of commercial operation. Coincidentally, the results of Model Experiment II (MEX II) of the Forum for Energy Models and Energy-Economic Analysis (FEES) were announced on the same day. Some of the model results had been published earlier and received much attention during the political discussion.

Uwe Remme and Alexander Zafiriou of the Institute of Energy Economics and the Rational Use of Energy (IER) at the University of Stuttgart reported on the results of MEX II at the ETSAP workshop in Baden, Switzerland, in October 2000. Among the MEX II conclusions:

- Nuclear energy will be replaced by hard coal or, especially with future restrictions on carbon dioxide emissions, natural gas.
- In the absence of emission restrictions, the carbon dioxide produced will increase by an amount about equal to one year's emissions from Germany by 2030.
- Electricity production will drop by 4 percent, and electricity prices will rise from 8 to 12 percent, according to the top-down models. Growth in GDP will be 0.2 to 0.6 percent lower.
- There would be a slight increase in renewable energy, in the form of wind and biomass, only in a scenario with Kyoto restrictions extrapolated to 2030.

The eleven models, listed in Table 1, included four top-down models and seven bottom-up models, of which three were energy system models and four were restricted to the electricity sector.

ETSAP Welcomes Greece

Greece has become the most recent nation to join ETSAP. Greece will be represented by George Giannakidis of the Center for Renewable Energy Source (E-mail: ggian@cres.gr). Welcome!

Visit ETSAP on the www:
http://www.ecn.nl/unit_bs/etsap/

Information on ETSAP, its activities and members is also provided on the Internet. The home page contains the latest news, general information on ETSAP, and links to: ETSAP members; ETSAP 'outreach' activities; description of the MARKAL model and its users; archives of new items; selected publications and the ETSAP Newsletter.

Around the World

In **Australia**, a team led by Ken Noble at the Australian Bureau of Agricultural and Resource Economics is making substantial enhancements to their Windows-based ANSWER interface for MARKAL, with funding provided by the U.S. Energy Information Administration (USEIA). These enhancements are being carried out in two phases. The first phase, which is nearing completion, is focusing on enhancing single-region ANSWER, with the most notable new feature being the implementation of a technology data library concept.

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The essence of the technology data library concept is the notion of a “master” library database which incorporates MARKAL technology data for a variety of typical conversion, process and demand technologies. Once such a technology library database has been created, the technology library feature being implemented in ANSWER will allow one or more energy analysts to link to this database and readily incorporate selected technologies within their local MARKAL databases. Furthermore, if technology attributes within the master library database are updated, then the corresponding attributes for these technologies in the local MARKAL databases will be automatically updated.

The second phase of ANSWER enhancements will focus on extending single-region ANSWER to create a multi-region ANSWER to allow the USEIA’s analysts to work more productively with multi-region MARKAL.

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During 2000, the MARKAL model was extensively used to contribute to the definition of the ‘climate policy’ of **Belgium** regarding the Kyoto Protocol. Besides evaluating the cost of reaching the Kyoto target, these studies focused on the distribution of emission reductions within the country and on the choice of policy instruments. Late in 1999, the Catholic University of Leuven (CES) and the Flemish Institute for Technological Research (VITO) published *Prospective Study of the Emissions in Belgium until 2008/2012 of the Greenhouse Gases included in the Kyoto Protocol: Cost and Potential of*

IER provided three of the models: the general equilibrium model NEWAGE, the energy system model E^3NET, and the electricity sector model TIMES-GES, an application of the TIMES model developed by ETSAP. The Programme Group Systems Analysis and Technology Evaluation (STE) at Research Center Jülich ran the energy system model IKARUS-MARKAL.

FEES is sponsored by the German Federal Ministry of Economics and Technology, which was also responsible for

Table 1. Models used in Model Experiment II (MEX II) of the Forum for Energy Models and Energy-Economic Analysis (FEES)

Model	Institution	
Electricity sector models:		**Bottom-up models**
- DIOGENES	(ZEW, Mannheim)	
- EMS	(Bremer Energie-Institut)	
- PERSEUS-ICE	(IIP, University of Karlsruhe)	
- TIMES	(IER, University of Stuttgart)	
Energy system models:		
- IKARUS	(STE, FZ Jülich)	
- PLANET	(Wuppertal Institute)	
- E3Net	(IER, University of Stuttgart)	
Energy economic models (top-down models):		
- LEAN	(University of Oldenburg)	
- PANTA RHEI	(GWS, Osnabrück)	
- PACE	(ZEW, Mannheim	
- NEWAGE	(IER, University of Stuttgart)	

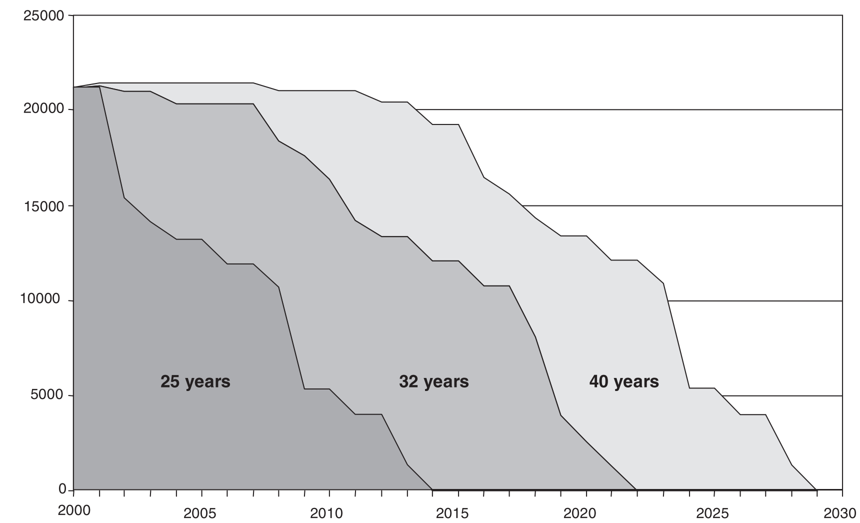

Figure 1. Net capacity of nuclear power as average plant life is reduced (megawatts)

recommending a policy for the future of nuclear power in Germany. Germany has nineteen nuclear power plants, the oldest dating from 1968, which generate about one-third of the country's electricity. Figure 1 shows the net remaining capacity as average nuclear power plant life is reduced from 40 to either 25 or 32 years after its connection to the electric grid.

The objective of MEX II was to evaluate the structural, economic and environmental effects of phasing out nuclear power. These included impacts on electric generation costs, electricity prices, the technology mix in the electric sector, generation structure including electricity imports, and the rest of the energy sector. Economic effects on GDP growth, employment, and the competitiveness of industry were quantified. The environmental focus was especially on energy-related greenhouse gas emissions.

To compare the modeling approaches, a set of harmonized assumptions was agreed to.

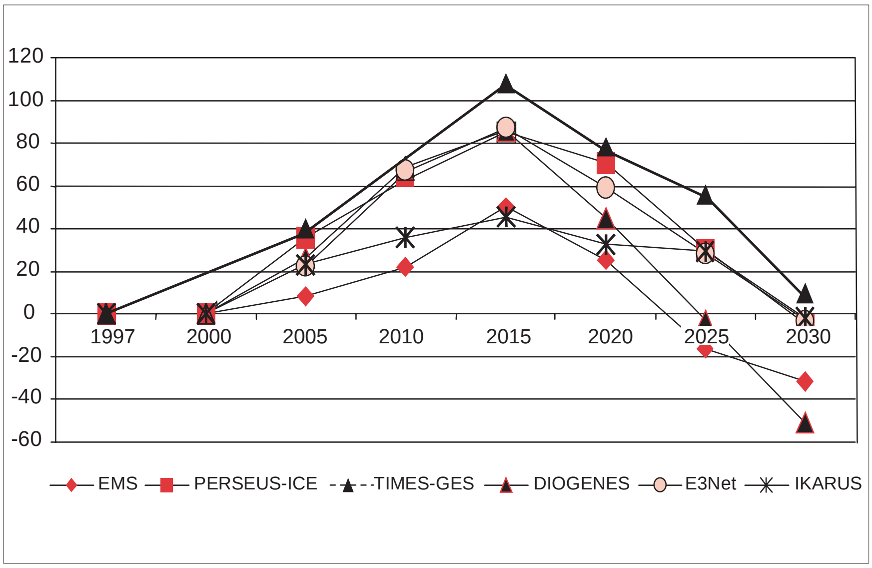

Figure 2. Difference in carbon dioxide emissions with a nuclear phase-out, absent emission restrictions (millions of metric tons)

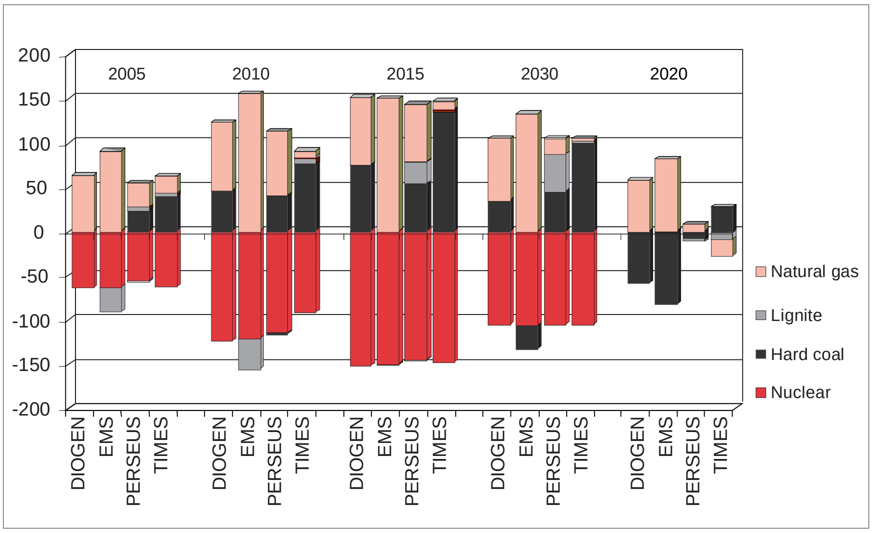

Figure 3. Changes in the sources of electricity with a nuclear phase-out and the level of carbon dioxide emissions maintained (terawatt-hours)

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Measures and Policy Instruments to Reduce GHG Emissions. Stefan Proost and Denise Van Regemorter of CES followed this with *How to achieve the Kyoto Target in Belgium, modelling methodology and some results*, in December 2000. They also completed a study that concentrated on the electricity sector, *What do the Ampere Results imply for Future Electricity Production in Belgium? – An analysis with MARKAL model* (October 2000), in which the implications of the Kyoto target and of a nuclear phase-out were evaluated in terms of cost and investment strategies.

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In **Canada**, Richard Loulou and Amit Kanudia of HALOA Inc. have been participating in the Canadian National Climate Change Implementation Process (NCCIP). HALOA was charged with the integration of the many measures and actions proposed by fifteen sectoral and thematic "issue tables" (See ETSAP News, Vol. 7, No. 4, December 2000, p. 5). The results were reported in a document made public in the fall 2000 entitled *Integrated Analysis of Options for GHG Emission Reductions with MARKAL*. The results were used together with the macroeconomic analysis for the final report of the NCCIP to the Canadian Government in October 2000.

As part of this study, HALOA performed several other pieces of work related to the Canadian Climate Change project:

- Several sensitivity analyses on various parameters such as: availability of natural carbon sinks, and of geological sequestration of CO_2, extent of interprovincial electricity trading, gas price, and availability of renewable biomass.

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- Sensitivity analysis on the availability of an improved nuclear technology (CANDU NG) with MARKAL, for the Canadian Nuclear Association.
- Analysis of an electricity sector covenant, whereby all new investments in the electricity generation sector must satisfy a portfolio standard for greenhouse gas emissions.
- In a project sponsored by the Alberta Department of the Environment, analysis of the impact of carbon policies on the oil and gas industry in Alberta, using the full North American MARKAL model.

With sponsorship by ETSAP and USEIA, HALOA is developing a MARKAL/TIMES analyst and report generator (VEDA). Version 1.0 of VEDA was issued to ETSAP members and the USEIA in the fall 2000; Version 1.2 is available for distribution this spring. Also under development is an initial version of a front-end shell (VEDA Front End) for the multiregional TIMES model.

HALOA is also preparing computer software to automate the capture and processing of energy data to populate the World MARKAL model under development at USEIA. Sectoral data templates are being developed to facilitate the construction of new MARKAL and TIMES models, using standardized data sources. Development of a WORLD TIMES model is advancing, using these templates and the computer software, also including the Canadian module for the World MARKAL/ TIMES project with the additional support of Natural Resources Canada.

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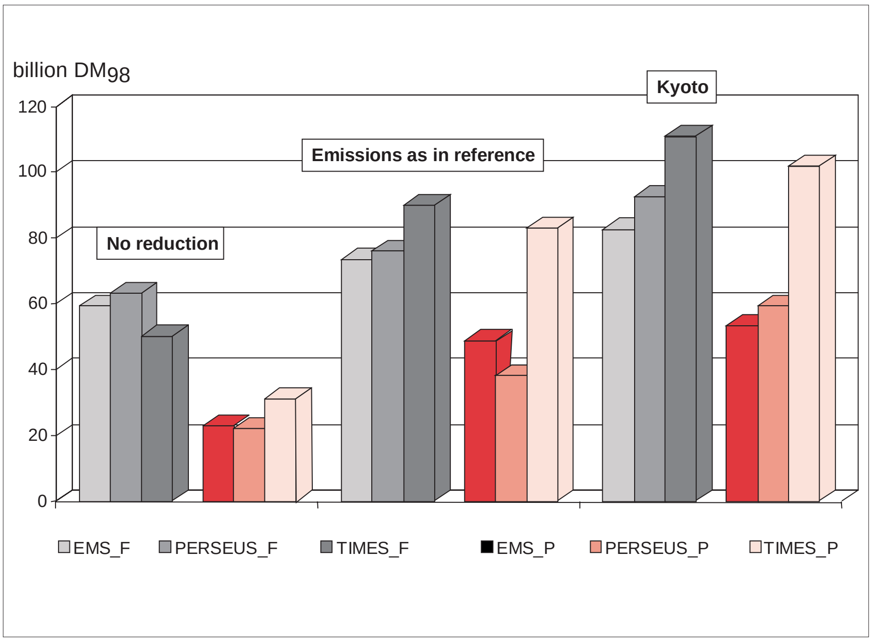

Figure 4. Cumulative costs of a nuclear phase-out (not discounted), according to models of the electricity sector

These consisted of:

- Demographics and economic development
- Two sets of primary energy price projections
- Electricity demand for the electricity sector models
- Electricity net imports
- Lower bounds on the use of renewables
- Energy political restrictions related to the use of domestic lignite and hard coal
- Technical and economic data for nuclear and future power plants
- Carbon dioxide emission reduction paths.

A business-as-usual scenario, with nuclear power plants assumed to have a 40-year life after being connected to the electric grid, was taken as a reference. In three phase-out scenarios, nuclear power plants were assumed to be limited to a 25-year life. The phase-out scenarios were:

- No emission restrictions
- Emissions the same as the business-as-usual scenario
- Emissions reduced by 21 percent by 2010, following the Kyoto Protocol burden-sharing agreement within the European Union, extrapolated to a 43 percent reduction by 2030.

Each of these four scenarios was run with two different energy price projections.

Bottom-up Model Results

If carbon dioxide emissions were not restricted, the differences from the business-as-usual case would increase by up to 100 million metric tons of carbon dioxide in 2015, according to the bottom-up models, as shown in Figure 2. Differences decline after 2015, because the nuclear plants would also be replaced then in the business-as-usual scenario.

With the same level of carbon dioxide emissions maintained, nuclear power is replaced primarily by hard coal and natural gas, according to the four electricity sector models, as shown in Figure 3. With the Kyoto restrictions of carbon dioxide emissions, highly efficient natural gas combined cycle plants predominate.

The bottom-up models give similar results for the cost of a nuclear phase-out, which increases when there are also emission reductions, as shown in Figure 4. With no emission reduction, the additional costs range from 23 to 63 billion DM_{98} undiscounted (or 17 to 39 billion DM_{98}, discounted at 5 percent to the year 2000). With the Kyoto restrictions, the additional costs range from 53 to 111 billion DM_{98} undiscounted (or 24 to 69 billion DM_{98}, discounted to 2000).

Sensitivity analyses of the bottom-up models reveal that:

- Shorter nuclear lifetimes increase costs.
- Fuel prices, especially of natural gas, have a strong influence on costs and emissions.
- Costs decline when nuclear-generated electricity can be shifted among generators, from older to newer, and smaller to larger plants.
- Variation in electricity demand among the electricity models does not affect phase-out costs.
- Free trade in electricity leads to more imports when nuclear is phased out.

Top-down Model Results

The top-down models generally indicate more severe effects from a nuclear phase-out. While the bottom-up models indicate little effect on the level of electricity consumption, the top-down models show a decrease of 4 percent, with 8 to 12 percent higher electricity prices. German GDP would continue to grow, but at a 0.2 to 0.6 percent lower rate. These effects were amplified when carbon dioxide emissions must also be reduced. The four top-down models differed somewhat in their results for the effect of a phase-out on employment and imports and exports.

However, the top-down results were robust. Only slight changes in the electricity sector and negligible changes in the entire economy resulted from variations in fuel substitution elasticities, use of renewables, electricity price levels, or import possibilities. Only the lifetimes of nuclear power plants influenced the results substantially.

"Even though a nuclear lifetime of 25 years was assumed in MEX II instead of the 32 years finally decided upon," said Remme, "the results can still be used to give a qualitative picture of the effects of a phase-out. Sensitivity analyses done by some of the groups showed that increasing the lifetime, which postpones the replacement of nuclear in the future, reduces the phase-out costs. However, the technological choice in the different models is rather independent of the plant lifetime."

The results of MEX II will be published by Physica. In the ongoing model experiment MEX II, the topic "Environmental and Climate Protection in Liberalized Markets" is being studied.

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Finnish participation in the ETSAP work is coordinated by the Energy Institute of the Technical Research Center of **Finland** (VTT). VTT Energy carries out development and research on energy, economy and emissions models, and uses these models in scenario analyses for the Government of Finland and other contractors. In model development and scenario analysis work, VTT Energy cooperates on an equal basis with Helsinki University of Technology (TKK), with the Government Institute for Economic Research (VATT), and with the private Research Institute of the Finnish Economy (ETLA).

In the year 2000, VTT, VATT and ETLA carried out a series of extensive scenario analyses of the costs and effects on the national economy of various policies proposed to meet the targets of the Kyoto Protocol, extended to the year 2020. The analyses were prepared for an official national working group, consisting of representatives of the Ministries of Finance, Environment, and Trade and Industry. The research institutes reported their results in February 2001.

Two different approaches were taken: VTT and VATT linked together the EFOM/ENV energy and emissions model of VTT and the econometric model (KESSU) of the Finnish economy developed by VATT. EFOM/ENV gave immediate effects and costs of the scenarios, and KESSU shows impacts on the whole national economy.

To analyze the same scenarios, ETLA and VTT developed a stationary computable general equilibrium model of the Finnish economy, which has a very detailed representation of the energy sector based on individual technologies, not on the usual smooth production functions. The results computed by the

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two approaches are in reasonable accord with each other.

VTT and TKK have begun to develop and install a Finnish TIMES model. A prototype was developed by TKK in cooperation with IER Stuttgart, and a full-scale version is now under way.

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In **Germany**, research at the Institute of Energy Economics and the Rational Use of Energy (IER) at the University of Stuttgart focuses on three activities. The first is the development of methods and tools to study complex tools on different levels of detail with respect to time and geographical resolution. The second is assessment of existing and new technologies in the power supply sector. The third is technological and microeconomic analysis of energy systems to answer energy-related questions such as climate change protection strategies and the consequences of liberalization of energy markets.

To facilitate the planning and analysis process of energy systems, the system theory and modeling group of Christoph Schlenzig developed the MESAP software system. MESAP integrated different databases, models, and database tools into one coherent modeling environment. Currently, activities are concentrated on developing the new generation MESAP 4.0 with a fully multidimensional database management system based on the latest software standards. The new software design improves the flexibility to integrate new models and tools. Through a public dy-

Multiregional Technological Learning with MARKAL

Similar technologies in different regions of the world may benefit jointly from the cost reductions that accompany manufacture and use on a larger scale. Leonardo Barreto and Socrates Kypreos of Paul Scherrer Institute, Switzerland, have extended the MARKAL model to assess the effects of such technological "learning" across several geographical regions. An example illustrates the changes in the optimal choice of technologies in a multiregional global electricity system when there is shared learning and when carbon dioxide emissions are constrained.

The interaction between technological learning and trading carbon dioxide emissions, both of them affected by geographical boundaries, exerts a significant influence on the final outcome of the model. In the example, the choice of photovoltaic electric generators is found to depend in part upon whether successive reductions in their cost occur separately in individual regions, or more substantially through the joint benefits of use in several regions. The choice also depends upon whether there is carbon dioxide emission trading between industrialized and developing regions.

"Technological change is one of the key driving forces of global energy systems," say Barreto and Kypreos. "Understanding its dynamics is essential for conceiving policy instruments to stimulate the transition towards more productive and clean energy systems. Both regional differences and multiregional interactions must be understood to promote the diffusion of new technologies."

Thus, it is important to have adequate analytical tools to explore how regional boundaries affect energy technology dynamics, particularly shared learning across geographical regions.

Earlier, Kypreos and Barreto incorporated learning curves - the successive reduction in investment cost with more widespread use - in the single-region MARKAL using the technique of mixed integer programming (IEA ETSAP News, October 1998). The model allows early up-front investments to introduce promising, but initially expensive, technologies that prove to be cost-effective in the long term. Another member of the MARKAL family of models is the multiregional RMARKAL, which allows the examination of several coupled energy systems. Here, to consider the possibility of a spillover of learning between regions, modifications are made to the multiregional RMARKAL to allow technologies to learn across regions.

A typical learning curve describes the cost of a technology as a function of cumulative installed capacity. This may represent learning-by-doing, learning-by-using, or learning-by-interaction. Learning curves characteristically decline exponentially, that is, the greatest cost reductions occur initially, tailing off with increased amounts. On double logarithmic grids, this relationship appears as a straight line (Figure 5).

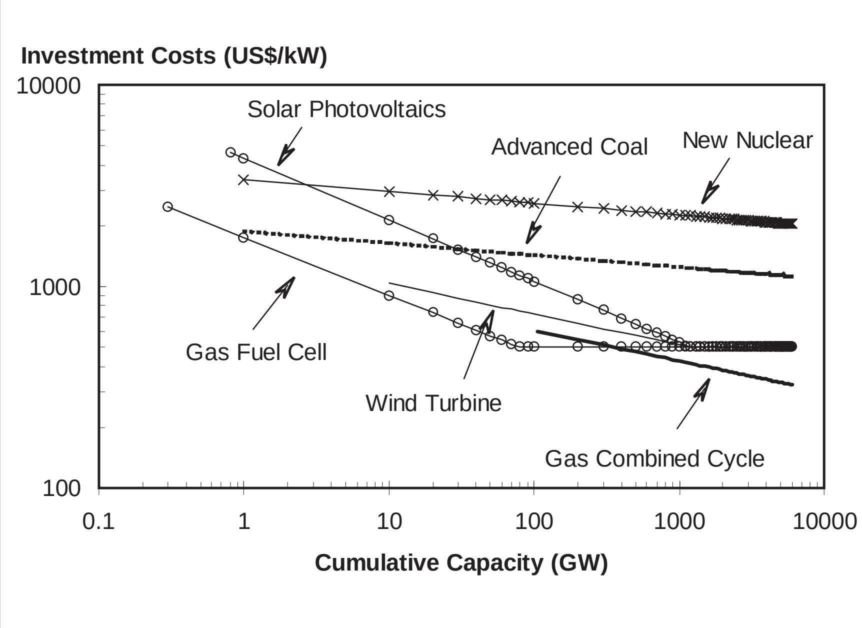

Figure 5. Assumed learning curves for new electric generation technologies

In the multiregional model, the use of related technologies in different regions can be assumed to contribute to their joint cost reduction. Globalization of energy markets may promote a global learning process. International cooperation in R&D, demonstration, and deployment (the so-called ERD^3 strategy) of new technologies may stimulate spillover of learning between countries, reducing cost barriers to the introduction of new echnologies.

However, Barreto and Kypreos warn, international learning cannot be taken for granted for all technologies.

The global electricity generation system is represented in the model by nine regions. Five industrialized regions represent the countries identified as Annex I in the Kyoto Protocol, and four developing regions represent the non-Annex I countries, listed in Table 2.

Barreto and Kypreos examined the choice among thirteen electricity generation technologies. Six of these are considered to be on learning curves that will reduce their cost as shown in Figure 5.

Table 2. The world modeled as nine regions

Annex I		
	USA	United States
	OECDE	Western Europe
	CANZ	Canada, Australia and New Zealand
	JAPAN	Japan
	EEFSU	Eastern Europe and the former Soviet Union
Non-Annex I		
	CHINA	China
	INDIA	India
	MOPEC	Mexico and OPEC
	ROW	Rest of the world

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namic link library (DLL) concept, the user can benefit from all MESAP functions in other software applications as well. Within the TIMES working group, IER is working on the specifications for a TIMES shell and its integration into MESAP 4.0. Further activities include the design and analysis of local energy systems based on a simulation approach.

The energy economics and systems analysis research team led by Ulrich Fahl initiated the creation of the Forum for Energy Models and Energy Economic Analysis (FEES). FEES, which is funded by the German Ministry of Economics and Technologies, is intended to be an open communication platform for energy modelers and analysts in Germany by conducting harmonized case studies using different modeling approaches. The central element of the activities of the Forum is the model experiment. The objective of the model experiments is to demonstrate similarities and differences in the existing methodological approaches of energy models, and to identify possibilities and necessities of future model development activities in energy modeling. The results of the second model experiment, MEX II, are reported in this issue of ETSAP News.

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Researchers at the Institute for Advanced Methodologies of Environmental Analysis in **Italy** are validating the R-MARKAL model for local-scale applications. The research group consists of Vincenzo Cuomo and Maria Macchiato (coordinators), Carmelina Cosmi, Lucia Mangiamele, Gerardo Marmo, Filomena Pietrapertosa and Monica Salvia. Stakeholders in the research are the National Council of Research, University of Basilicata, University of Naples,

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the National Institute for the Physics of Matter, and the local authority in the Basilicata region. The work is done within the framework of Annex 33 of the Energy Conservation in Buildings and Community Systems Programme of the International Energy Agency.

In two recent studies, the R-MARKAL model, which is usually used for supranational analysis, was applied to an urban case study of Potenza and its surroundings and to the analysis of the Basilicata region energy system. In the first study, R-MARKAL was used to investigate the feasibility of supplying district heating for the newly built Bucaletto district with heat recovered from waste incineration in Potenza. The second application began with the WAMMM model, which was developed from M-MARKAL for analysis of only the waste management system. The model is being extended for a comprehensive optimization of the entire region's supply and demand systems, including both energy and material flows.

The choice among these technologies was determined in twelve scenarios. In addition to business as usual, the scenarios examined included a Kyoto trend, that is, restrictions on carbon dioxide emissions according to the Kyoto Protocol through 2010, with a further reduction of 5 percent per decade to the end of the model horizon. Three different assumptions were made both as to the extent of international emissions trading and the extent to which technological learning is shared, as shown in Table 3.

Photovoltaic electric generation proves to be a marginal technology in this example, as shown in the table. Its dissemination depends upon the geographical limits within which learning is assumed to take place, and the extent of emissions trading. With business as usual - no restrictions on carbon dioxide emissions - photovoltaics are never selected by the model. With global learning, however, photovoltaics are always selected - in both Annex I and non-Annex I groups of countries - when emissions are restricted to the Kyoto trend. With full emissions trading, photovoltaics are also chosen when learning is assumed to spill over separately only among the Annex I countries, on the one hand, and among non-Annex I countries, on the other. If the economies of learning are restricted only to the individual nine world regions, however, photovoltaics are never selected.

The difference in the dissemination of photovoltaics among the Annex I and non-Annex I groups is shown in Figure 6. With global learning, photovoltaics are used more in non-Annex I countries as the range of emissions trading widens (right set of black bars). With separate learning in the two groups of countries, on the other hand, photovoltaics are used more in the Annex I group (left white bar) and less in the non-Annex I group (right white bar).

If Annex I regions can profit from emission reduction measures in the non-Annex I group, they have less incentive to make reductions themselves. Non-Annex I regions, on the other hand, have incentives to reduce emissions in order to sell permits. The effects of these two countervailing trends depend on the presence (or absence) of learning spillover between the two groups.

With global learning, each group benefits from cost reductions in the other.

Table 3. Circumstances that favor the introduction of photovoltaics in the example Kyoto trend

Learning boundaries	Business as usual	Kyoto trend: No emissions trading	Kyoto trend: Trading only among Annex I regions by 2010	Kyoto trend: Full emissions trading by 2030
Global learning		✓	✓	✓
Two learning regions: Annex I and non-Annex I				✓
Single-region learning				

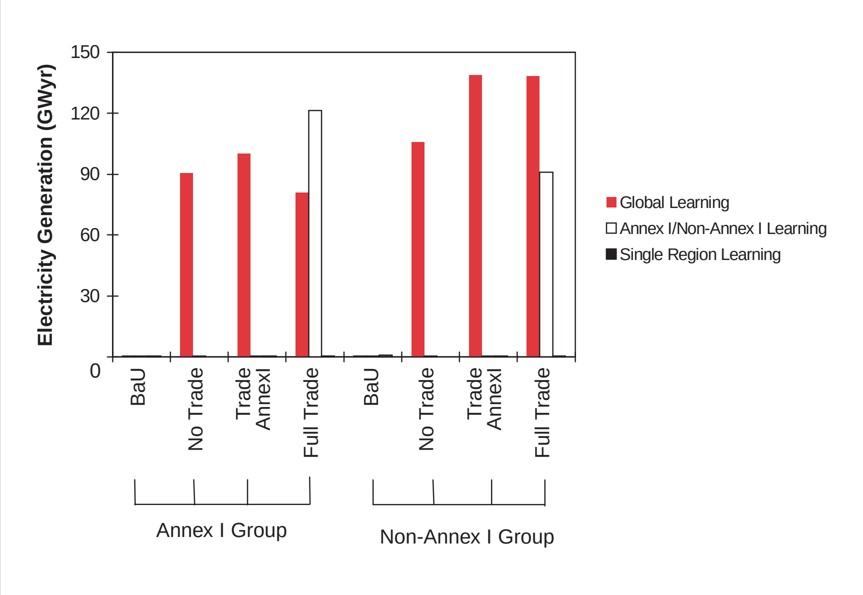

Figure 6. Electricity generation of photovoltaics in 2050 in Annex I and non-Annex I groups of countries

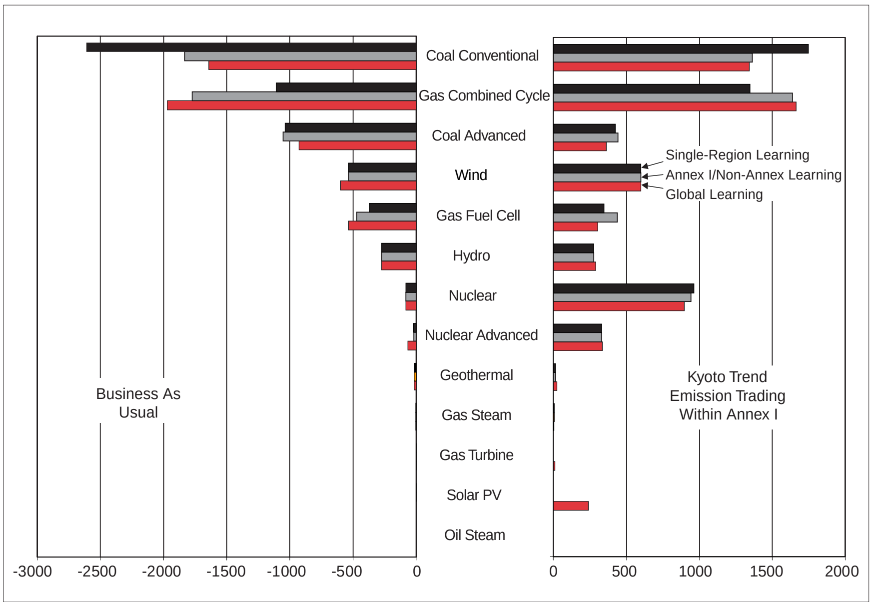

Figure 7. Electricity generation in 2050 (gigawatt-hours), as affected by carbon dioxide emission restrictions and geographical sharing of learning. Technologies are ranked in decreasing order for business as usual with single-region learning

Nevertheless, the use of photovoltaics in the Annex I regions declines with full trade (left set of black bars) but increases in non-Annex I regions (right set of black bars). If learning occurs only separately in the two groups, installations in the non-Annex I group occur only if there is the stimulus of full trade.

Although the Annex I group has less incentive to invest in low-carbon technologies at home, it still finds it attractive to introduce photovoltaics. Not being able to benefit from the experience accumulated in the non-Annex I group, however, a higher cumulative installation is required to achieve the necessary cost reductions.

Trade and learning interactions are complex, Barreto and Kypreos note, and should be studied more profoundly.

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In the reorganization of the central government of **Japan** on January 6, 2001, the Ministry of Education, Culture, Sports, Science and Technology became responsible for managing ETSAP activities. Under this ministry, at the Japan Atomic Energy Research Institute (JAERI), the Research Group for Energy System Assessment headed by Osamu Sato is continuing energy systems analysis as in the past. The specific focus of the ETSAP study in Japan is the assessment of nuclear energy from a long-term and broad perspective. On the one hand, the characteristics and future potential of nuclear energy are assessed in comparison with other energy sources; on the other hand, advanced nuclear technologies and systems are evaluated from the viewpoints of resources, economics, and environment.

Currently, a study is in progress to analyze macroeconomic impacts of a possible nuclear phase-out in Japan. Katsuhiko Kunii is in charge of this study in collaboration with an economic modeling group of Mitsubishi Research Institute. Masanori Yamaguchi, a temporary staff member from Hitachi Research Laboratory, is making a detailed survey of basic technical information on technology learning in decentralized power generation systems. Kenji Tatematsu and Yoji Tanaka, a temporary staff member from Mitsubishi Heavy Industries, Ltd., are engaged in the assessment of advanced nuclear systems with reduced moderation water reactors (water-cooled breeder reactors).

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At the **Korea** Institute of Energy Research, MARKAL was used to obtain the optimal national energy balance with technology options in 1998. Under

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Heesung Shin, the technology database is now being updated for a more current analysis by Jongchul Hong. MARKAL has also been used to model Korea's iron and steel sector.

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On January 8-9, 2001, a workshop was held in Shanghai, **China**, on "A Sustainable Future for Shanghai." Chen Changhong of the Shanghai Academy of Environmental Sciences (SAES) presented the first results of MARKAL runs on the energy and emissions prospects for Shanghai in various policy scenarios. Although the present emphasis is on local pollutants, carbon dioxide is receiving increasing attention. MARKAL modeling in the project is performed under the Dutch Global Change Program, with collaboration between the SAES and Energy research Centre of the **Netherlands** (ECN). The purpose of the project is twofold: to set up an analytical tool for policy support, and to evaluate the potential for emission reductions.

ECN is currently participating in a project on learning curves, SAPIENT, sponsored by the European Union. This project is the successor to the TEEM project (see ETSAP News Vol. 7, No. 3 September 2000, p. 3). SAPIENT focuses on the effect of research and development on technology learning. ECN has developed an indirect approach to estimate the impact of public R&D on the technology's progress ratio, that is, the slope of the learning curve. With the indirect approach, the mixed integer programming (MIP) formulation can be retained for learning-by-doing in MARKAL.

In addition, ECN has conducted experiments to investigate the feasibility of Monte Carlo uncertainty analysis (MCUA) for the MARKAL model of the European Union. The Monte Carlo analysis focuses on the uncertain parameters describing the learning curve, but is not necessarily restricted to them. First results show that such an uncertainty analysis is feasible, even with a complex MARKAL model and the MIP formulation needed for endogenous technology learning. MCUA can provide information on the spread in the results and on correlation between uncertain inputs and results for a particular scenario.

The latest study of the Energy Modeling Forum (EMF), based at Stanford University in California, focuses on the potential role of new technologies to mitigate greenhouse gas emissions. Technologies and technological change are explicitly addressed in the models and approaches used by the participants in the study. Some models have global coverage, with or without a regional breakdown; others cover only one major region. The latter include the

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Some results for the other twelve technologies are illustrated in Figure 7, in which business as usual is compared with the Kyoto trend scenario and emissions trading only among Annex I countries. With business as usual, shared learning beyond the single regions greatly benefits gas combined cycle at the expense of conventional coal (compare bars on the left). With single region learning, emissions trading also favors gas combined cycle, closely followed by nuclear power (compare black bars on the left and right).

With both global learning and emissions trading, the principal beneficiaries of the reduction in coal are gas combined cycle, nuclear power and photovoltaics (compare black bars on the left with light bars on the right).

"The results highlight the importance of fostering international cooperation on ERD[3] to stimulate the learning process of emerging energy technologies," said Barreto in reporting the work to the October 2000 ETSAP workshop in Baden, Switzerland.

Reference

L. Barreto and S. Kypreos. Multiregional Technological Learning: Some Experiences with the MARKAL Model. Proceedings of the Workshop on Economic Modeling of Environmental Policy and Endogenous Technological Change. November 16-17, 2000. Amsterdam.

MARKAL models of the USA, presented by Phillip Tseng of the U.S. Department of Energy, and the single-region representation of OECD-Europe developed at ECN. The analyses with the MARKAL-Europe model at ECN build on earlier work on very long-term scenarios done for the EU fusion program. Preliminary analyses indicate that a good fit was obtained between MARKAL-Europe and the Second Generation Model (SGM) of Pacific Northwest National Laboratory.

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Socrates Kypreos and Olivier Bahn of the Paul Scherrer Institute in **Switzerland** have developed a special version of the MERGE model (MERGE-ETL) that includes endogenous technological learning. MERGE-ETL is a general equilibrium, flexible prototype model with perfect foresight, used to study global carbon mitigation policies. Experience with technologies, either “learning by doing” or “learning by using,” is considered a prerequisite for diffusion and implementation of productive and clean energy systems. The model is being extended to include “learning by researching” where R&D spending is considered a control variable for endogenous growth. MERGE-ETL is being linked with MARKAL-MACRO of key world regions.

Interim results with MERGE-ETL indicate that early support, either in the form of R&D spending or demonstration projects, is needed to stimulate technological learning of promising technologies such as wind, new nuclear, biofuels, fuel cells, and photovoltaics. The model shows that the combined effects of carbon trade and global spillovers of learning is a win-win policy for both industrialized and developing countries.

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U.S. MARKAL-MACRO was selected by a U.S. interagency working group as the model for the preparation of the 3rd **United States** National Communication required under the UNFCCC. Phillip Tseng worked very closely with John Lee of Brookhaven National Laboratory (BNL) to establish a baseline for the analysis of the impacts of policy and measures on the U.S. energy consumption and carbon emissions. In February and March of 2001, US DOE and EPA developed a list of policy and measures, using the US MARKAL-MACRO to quantify impacts on the energy and carbon emissions.

U.S. Department of Energy and U.S. Agency for International Development will assist El Salvador, Honduras, and Panama in building a MARKAL model for each country. Brookhaven National Laboratory will provide a two-week MARKAL training workshop in May 2001 to two experts from each country.

Correction

Thanks to Neil McIlveen of Natural Resources Canada for pointing out errors in Table 2 of the article *How Will Greenhouse Gas Emission Reductions be Shared Domestically?* in the December 2000 issue of ETSAP News.

Here is the corrected table:

Table 2. Incremental cost breakdown for the petroleum refining sector, relative to business as usual, normalized to the theoretical optimum (Path 2)

	Path 1 Each sector capped	**Path 2 Theoretical optimum**	Path 3 Large fuel emitters capped	Path 4 Path 3 + energy producers capped
Fuel cost	-0.18	**-0.038**	+0.19	-2.21
Purchase: price effect	-0.02	**-0.01**	-0.02	-0.01
Purchase: demand effect	-1.23	**-0.75**	-1.14	-0.49
Sales: price effect	-0.55	**-0.11**	+0.07	-2.25
Sales: demand effect	+1.61	**+0.84**	+1.27	+0.54
Investment + O&M	-0.15	**-0.067**	-0.14	-0.07
TOTAL	-0.33	**-0.105**	+0.05	-2.27

ECN Policy Studies

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Around the World - continued -

U.S. AID and DOE plan to hold a workshop in September 2001 in these three countries. Experts from these three countries will present the national model and exchange modeling experiences.

Representatives of USEPA and BNL recently met with Secretary of the Environment Carlos Padin of the Commonwealth of Puerto Rico to discuss building an advanced version of the MARKAL model which will incorporate energy and material flows. Edward Linky of the USEPA provides ongoing project guidance, while John Lee of BNL will build the initial version of the model under contract to the Commonwealth's Department of Natural and Environmental Resources. Puerto Rico is part of the jurisdiction of the USEPA Region II Office.

Future plans for the completed model include a local energy planning analysis of the greater San Juan metropolitan area. The model will permanently reside at Metropolitan University of San Juan, where Secretary Padin was formerly the Dean of the School of Environmental Affairs. The model will be part of a Sustainable Development Institute at the University. It is anticipated that the Institute and the model will play a significant role in sustainable development planning to the greater Caribbean Basin and Central America.

USDOE and BNL are participating in the development of a MARKAL-MACRO model of Bolivia. The Bolivia model will be used to identify greenhouse gas emission targets under sustainable development, and evaluate afforestation as potential projects under the Clean Development Mechanism.

The USEIA is developing a new time-stepped version of the MARKAL-based world energy model patterned after the Time-stepped Energy System Optimization Model (TESOM) which was developed by Andy Kydes while at BNL. Gary Goldstein and GianCarlo Tosato will work with the USEIA to implement and test the new model. Tosato is working with the USEIA on their World-MARKAL undertaking along with Amit Kanudia and Goldstein. MARKAL-TS will allow for adjustment in model assumptions between periods with respect to endogenous technology learning and market shares. This formulation of the model will be used for the USEIA's International Energy Outlook publications beginning 2002.

Goldstein and Lorna Greening conducted a one-week training course for the USEPA Office of Research and Development. The purpose of the training course was to lay the foundation for use of MARKAL within the USEPA. In addition to climate change issues, the EPA team will initially be using the model to examine proposals related to new clean air and diesel fuel regulations.