Volume 7, No. 4 December 2000

IEA OECD ETSAP news

ANNEX VII CONTRIBUTING TO THE KYOTO PROTOCOL

USEIA to Adopt ETSAP Models

The United States Energy Information Administration (USEIA) is adopting the ETSAP family of models and methodology to prepare its annual report *International Energy Outlook* (IEO). ETSAP participants will cooperate in making their models and data available, and in training USEIA personnel in their application.

"In the past, we have used simple spreadsheet models and a Delphi approach to prepare regional forecasts for the IEO," said Barry Kapilow-Cohen of the Office of Integrated Analysis and Forecasting, USEIA, at a recent ETSAP workshop. "However, we now have to answer new policy questions for the U.S. Congress. What will be the price of carbon in an emission trading environment? What are the merits of specific projects under the Clean Development Mechanism of the Kyoto Protocol? The MARKAL models provide the kind of technological detail that we need to answer these questions."

The arrangements are being coordinated by Phillip Tseng of the U.S. Department of Energy and ETSAP Executive Committee chairman, ETSAP project head Tom Kram, Gary Goldstein, ETSAP's primary software coordinator, and several ETSAP participants. GianCarlo Tosato of Italy's Agency for New Technologies, Energy and the Environment (ENEA) will assist in training new employees at USEIA to begin to meet the publication schedule. USEIA has begun funding user-interface software at the Australian Bureau of Agricultural and Resource Economics (ABARE) where Ken Noble is upgrading ANSWER, and at GERAD/HALOA Inc. in Canada where Amit Kanudia is developing TIMES-ANALYST.

"We are primarily building a new set of regional models, with more or less country-level input depending upon the region," said Kapilow-Cohen. "We are using existing MARKAL models to help us learn about individual regional energy systems. However, a core feature of the revised ANSWER software will be a common technology repository database. This will be used for the local regional databases, modified as appropriate for regional differences in the cost and availability of new technologies.

"Our goal is to have a world MARKAL model for forecasting and policy analysis. The present plan is to have a fifteen-region model of the international energy system in operation by the fall of 2001, with the results published in the 2002 edition of the IEO."

The model will represent energy use in each region, together with international trade in fuels and carbon dioxide emission credits. It will be based on the multiregional MARKAL-ED model developed by Richard Loulou and Amit Kanudia of GERAD/HALOA Inc. The model has recently been used to project energy and emissions trading among twelve Canadian provinces with future restrictions on greenhouse gas emissions.

"There will be two types of activities," according to Tseng. "The individual national and regional models will need to be made available. Second, we expect to demonstrate further that integrating the models really works."

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.

In this issue

ABB hosts joint seminar on China

ABB, the Swedish-Swiss industrial giant, hosted a joint seminar of ETSAP and the China Energy Technology Program (CETP) at ABB corporate research center in Baden-Dätwill, Switzerland, on 16 October 2000. CETP is an international project run, financed and managed by ABB's Energy and Global Change Department in conjunction with the Alliance for Global Sustainability. Eleven organizations participate in the project: five in China, four in Switzerland, and one each in Japan and the USA.

Baldur Eliasson, Energy and Global Change Department head at ABB Corporate Research Ltd, chaired the seminar. Eliasson, who is responsible for overall coordination of CETP, described the program as "a new way of cooperation among industry, academic institutions, and government. In the past, ABB was concerned with generating electricity. Now it is generating knowledge."

Yam Lee, CETP program manager, said that the program has three objectives:

- To develop a globally applicable cradle-to-grave methodology to analyze the true impact of electric power generation on the environment, using the Shandong Province of China as a case study
- To develop a new and effective cooperative research mechanism between academia and industry
- To engage the active participation of stakeholders to ensure application of research results toward the ultimate goal of sustainable development in China

The key elements of the CETP are shown in the flow chart, Figure 1. The two-year program, started in May 1999, involves a team of 75 scientists, academics and engineers in four countries on three continents, from business, universities, and research institutions.

Prominent among the latter is the Paul Scherrer Institute (PSI) which also represents Switzerland in ETSAP. PSI is charged with leading the efforts in life-cycle assessment, environmental impact assessment, risk analysis, and energy/economy system modeling. Among the day's speakers were four representatives of PSI: Alexander Wokaun, Roberto Dones, Stefan Hirshberg, and Socrates Kypreos.

The energy/economy modeling work is the responsibility of the Energy Economics group of PSI, headed by Kypreos, in cooperation with the Global Climate Change Institute of Tsinghua University. The primary tool used in the study is the MARKAL model developed by ETSAP. To enable macroeconomic feedback, the MARKAL-MACRO model will also be used. This model defines the interactions between the economy and the energy system under a set of environmental constraints.

Wei Zhihong of Tsinghua University described the MARKAL-China model and energy demand projections. After his visit to Brookhaven National Laboratory in 1998, the university decided to use MARKAL in order to communicate better with the international community, Wei said. Early guidance on the MARKAL formulation was provided by Phillip Tseng of the U.S. Department of Energy. In the CETP, Kypreos of PSI has advised on the model development.

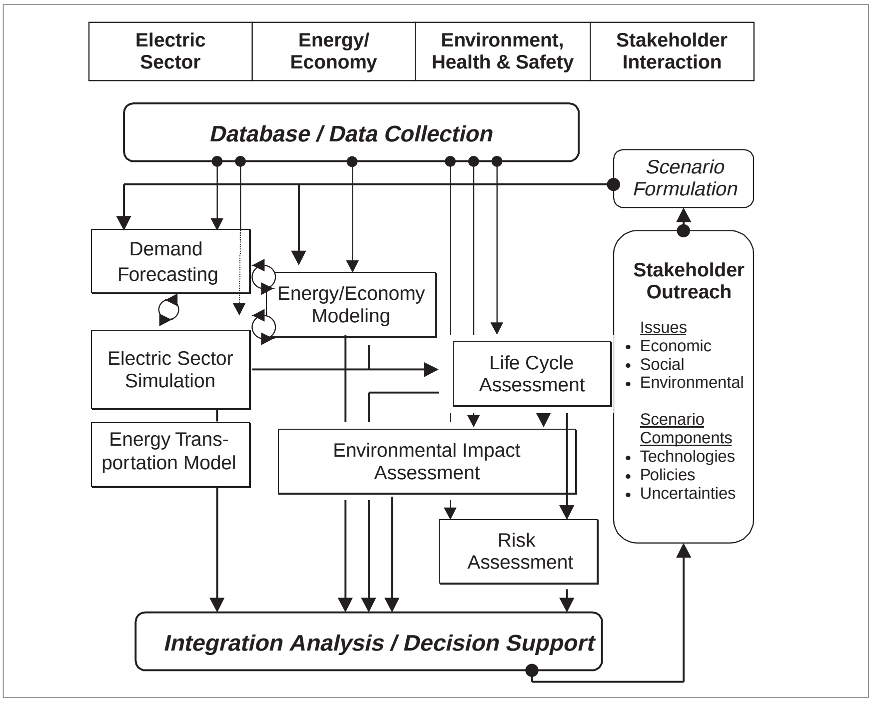

Figure 1. Flow chart of the China Energy Technology Program showing the relationships among the various tasks of the program

Kypreos also presented some insights from the China Regional Energy Trade Model (CRETM). Energy intensity - that is, energy consumption per unit of economic activity - has been declining rapidly in China, but it remains two or three times higher than in the USA. Coal will continue to be the dominant fuel in China, causing sulfur dioxide air pollution and high emissions of carbon dioxide. If you can control carbon dioxide emissions, sulfur dioxide is automatically reduced. However, this is expensive. Advanced coal technologies, at $1,200 per kilowatt, are about twice as expensive as the present inefficient coal technologies. The cost of reducing sulfur dioxide emission is modest, and the Chinese are primarily concerned with sulfur dioxide, not global warming.

The Alliance for Global Sustainability is a collaboration of three universities: The Swiss Federal Institutes of Technology, Massachusetts Institute of Technology (MIT), and the University of Tokyo. At the seminar, Stephen Connors of MIT described the electric sector simulation task being performed by the MIT Energy Laboratory and the Swiss Federal Institute of Technology at Zurich. A comparative analysis of alternatives, under various circumstances, is made to search for robust, long-term technological strategies and related policies. MIT will engage the project's stakeholders to identify the relevant attributes and the technology scenarios to meet desired short and long-term goals.

Takeo Imanaka described the energy transportation model developed at the University of Tokyo to simulate the electricity sector for Shandong Province. The model takes fossil fuel transportation and electricity transmission into account to optimize the distribution of electricity generated in the province to satisfy demand. Both short-term and long-term environmental impact scenarios are evaluated.

Others on the program were Tom Kram of the Netherlands Energy Research Foundation, Paul Freund of the International Energy Agency Greenhouse Gas R&D Programme, Barry Kapilow-Cohen of the U.S. Energy Information Administration, Amit Kanudia of HALOA Inc., Canada, and Alan Manne of Stanford University.

The partners in the CETP are:

- Energy and Global Change, ABB Corporate Research, Baden Switzerland
- ABB China, Beijing
- ABB China, Jinan
- Energy Research Institute of the State Development Planning Commission, Beijing
- Massachusetts Institute of Technology
- Paul Scherrer Institute, Villigen, Switzerland
- Policy Research Center for Environment & Economy of the State Environmental Protection Administration, Beijing
- Swiss Federal Institute of Technology (ETHZ), Zurich
- Swiss Federal Institute of Technology (EPFL), Lausanne
- Tsinghua University, Beijing
- University of Tokyo

ABB already has a major presence in China, consisting of 20 sales offices, 22 companies, and 5,200 employees. Their products and services include power generation, power transformers, switchgears, electric drives and motors.

CO_2 Emission Reduction: Sooner or Later?

James Hansen, one of the gurus of climate change, recently surprised the world by proposing that the emphasis in the next 50 years be placed on reducing of emissions of other greenhouse gases, such as methane, rather than carbon dioxide (CO_2). On the other hand, Alan Manne and Richard Richels, well known for their studies of the economics of climate change, find that emissions of methane, a short-lived greenhouse gas, are unimportant in the near term if the goal is to minimize the long-term rise in global temperature. Methane is generally considered to be the second most important greenhouse gas, after CO_2.

Hansen and his colleagues at the Goddard Institute of Space Studies found that the rapid global warming in recent decades has been driven mainly by non-CO_2 greenhouse gases such as chlorofluorocarbons, methane, and nitrous oxide. The climate forcing of CO_2 is less important because it is partially offset by aerosols, such as sulfates and black carbon, that are also by-products of burning fossil fuel.

The growth rate of non-CO_2 greenhouse gases has declined in the past decade. If sources of methane and ozone precursors were reduced in the future, according to Hansen, the change in climate forcing by non-CO_2 greenhouse gases in the next 50 years could be near zero. Combined with a reduction of black carbon emissions, principally from diesel fuel and coal, and what he calls "plausible success in slowing CO_2 emissions," this reduction of non-CO_2 greenhouse gases could lead to a decline in the rate of global warming.

Hansen bases his conclusions on a comparison of climate forcings, measured in watts per square meter, of greenhouse gases, other anthropogenic forcings such as changes in clouds and land cover, and natural forcings such as the sun and volcanic aerosols. These apparently do not take into account when the forcing takes place. However, Hansen notes that the approximate global balancing of aerosol and CO_2 forcings cannot continue indefinitely, because as long-lived CO_2 accumulates, continued balancing would require a greater and greater load of short-lived aerosols.

Manne and Richels, on the other hand, put the problem in an economic perspective. They take as the goal of climate policy a maximum allowable increase in global temperature, and calculate the importance of non-CO_2 gases by the incremental value of their emission rights - or price - relative to CO_2.

Because of the short life of methane in the atmosphere before breaking down into other compounds - about 12 years - the value of methane reductions remains very low in the next 50 years. Methane only becomes important later, when it remains in the atmosphere as the maximum acceptable temperature change approaches the assumed limits of 2°C or 3°C.

The situation is different for nitrous oxide which has a lifetime in the atmosphere of about 120 years, comparable to the 50 to 200 years of CO_2. The value of its emission rights is about double that calculated for CO_2 assuming the 100-year global warming potential, and it holds steady for the next century.

The Manne-Richels results were calculated with the MERGE model (a **M**odel for **E**valuating the **R**egional and **G**lobal **E**ffects of greenhouse gas reduction policies). MERGE is an intertemporal general equilibrium model. It integrates submodels that provide a reduced-form description of the energy sector, the economy, emissions, concentrations, temperature change, and damage assessment. Information on the model can be obtained on the Stanford University Web site: http://www.stanford.edu/group/MERGE/.

Manne reported these results at the October 16, 2000, joint meeting of ETSAP and the China Energy Technology Program of ABB Corporate Research Ltd in Baden-Dättwil, Switzerland. His paper, co-authored with Richard Richels of the Electric Power Research Institute in the U.S., was first presented at the Energy Modeling Forum Workshop EMF-19, in Washington, DC, in March 2000.

Some have suggested that climate change damages may be sensitive to the *rate* of temperature change as well as the absolute temperature change. Too rapid a change, for example, may not allow time for certain species of trees and even types of agriculture to "migrate" with the climate. To examine that possibility, Manne and Richels imposed an additional constraint on the two temperature scenarios. The allowable temperature increase during a single decade in the next century was limited to 10 percent of the total allowable increase. That is, decadal temperature change was limited to 0.2°C and 0.3°C, respectively.

With a 2°C limit on absolute temperature change, there are decades during the 21st century where the limit on rate of temperature change would be binding. The closer to the temperature constraint, the more valuable become methane emission reductions.

Thus, the Manne-Richel analysis of the importance of methane reductions supports that of Hansen if and only if near-term temperature changes are important.

Hansen's alternative scenario does not alter the desirability of limiting CO_2 emissions, he says, because the future balancing of forcings is likely to shift toward dominance of CO_2 over aerosols. The scenario calls for a moderate decrease in CO_2 emission rates in the next half century, stemming from the "plausible success in slowing CO_2 emissions." In the next 25 years, he expects that this can be achieved by improved energy efficiency and a continued trend toward decarbonization of energy sources, such as increased use of gas instead of coal. In the longer term, attainment of a decreasing CO_2 growth will require use of energy systems that produce little or no CO_2. Some renewable energy systems will be developed without concern for climate, says Hansen, but it is important to foster research and development now in generic technologies at the interface between energy supply and use, such as gas turbines, fuel cells, and photovoltaics.

In the Manne-Richels world, this might be called "autonomous energy efficiency improvement." Sooner or later we will see how autonomous CO_2 emission reductions may prove to be.

References

Hansen, J., M. Sato, R. Ruedy, A. Lacis, and V. Oinas. Global warming in the twenty-first century: an alternative scenario. Proceedings of the National Academy of Sciences, Vol. 97, No. 18 (August 29, 2000), pp. 9875-9880.

Manne, A.S., and R. G. Richels. A multi-gas approach to climate policy - with and without GWPs. Presented to the Energy Modeling Forum EMF-19, Washington, DC, March 22-23, 2000. (April 2000)

How Will Greenhouse Gas Emission Reductions be Shared Domestically?

The Kyoto Protocol specifies how greenhouse gas emission reductions will be shared among the industrialized countries. But how will these reductions be distributed within each country, and who will bear the costs?

The government of Canada addresses these questions in a comprehensive analysis of alternative ways to comply with the Kyoto Protocol. MARKAL is being used to compare various schemes for domestic emission trading. An innovative use of the model is to show how incremental costs of emission reductions will be distributed among energy sectors either through demand or price effects.

In April 1998, the Canadian government initiated the National Climate Change Implementation Process (NCIP) to provide "a thorough understanding of the impact, the cost and the benefits of the Kyoto Protocol's implementation and of the various implementation options open to Canada." More than a dozen "Issue Tables" were formed under the NCIP. Some were concerned with emission reduction policy in specific sectors. Others were tasked with economy-wide emission reduction policy or with other aspects of climate change, such as adaptation.

An Analysis and Modeling Group (AMG) was set up to assure consistency and comparability of the results coming from the individual analytical elements. AMG is directing the "roll-up" or whole-economy analysis of the Sector Tables' work. For one of two studies using different whole-economy models, AMG retained HALOA Inc. to use its multiregional and multisectoral MARKAL model of the Canadian energy system. Two of the principals in HALOA are Richard Loulou and Amit Kanudia who regularly represent Canada in ETSAP.

Several different paths were defined by which Canada could meet the Kyoto requirement to reduce its greenhouse gas emissions to 94 percent of the 1990 level by the 2010 time period. These consist of proposed measures grouped as:

- Transportation
- Industry/upstream
- Electricity
- Residential/commercial/institutional/municipal
- Other

The paths differ in the extent to which individual sectors must reduce emissions and the role of the sectors in domestic emission trading:

- *Path 1*: Each sector is required to reduce its emissions to 95.67 percent of its 1990 level. The remaining reduction is assumed to be met by growth in the forest sink
- *Path 2*: All sectors, including the forest sink, are *collectively* constrained to reach 94 percent of their aggregate 1990 emission levels. Path 2 represents the least-cost solution to meeting the national cap, but the precise control measures are not predefined. This path is a benchmark to which other paths may be compared.
- *Path 3*: Large final emitters are subject to a collective cap, and may trade permits among themselves. These emitters consist of power generation, petroleum refining, pulp and paper, iron and steel, chemicals, smelting and refining, cement, and most "upstream" oil and gas. These sectors produced about 35 percent of Canada's 1990 emissions.
- *Path 4*: The cap-and-trade system is extended to include industries producing fossil fuels. The difference from Path 3 is that the energy producing sectors (oil refining, gas production, coal) are responsible for the end-use emissions embodied in the fuel produced. Effectively, this brings the end-users of fossil fuels into the cap-and-trade regime. Only about 20 percent of Canada's 1990 sources are not covered, including upstream oil, methane from upstream gas, agriculture and landfill gas.

A preliminary set of results indicates the total costs of greenhouse gas reductions by sector and path as shown in Table 1, compared to the theoretical minimum calculated for Path 2.

Table 1. Total national abatement costs relative to business as usual, normalized to the theoretical minimum (Path 2)

	Upstream	Electricity	Refining	Industry	RCM	Transport	TOTAL
Path 1	+0.23	-1.12	-0.33	+1.00	+1.50	+0.77	+2.56
Path 2	**+0.21**	**-1.58**	**-0.10**	**+0.80**	**+1.10**	**+0.12**	**+1.00**
Path 3	-0.12	-1.33	+0.05	+0.74	+1.65	+0.44	+1.93
Path 4	+0.14	-1.50	-0.09	+0.77	+1.32	+0.14	+1.20

Notes: Upstream = fuel sources prior to processing
RCM = residential, commercial and municipal

It is apparent in Table 1 that the pro rata caps in Path 1 are inefficient, with the total cost more than double the theoretical optimum of Path 2. The comparatively low total cost of Path 4 recommends an approach that includes as broad as practical a cap-and-trade system coupled with additional local measures for subsectors not included in the trading system.

Each entry in the table is the sum of two types of cost:

- Investment and operations & maintenance (O&M)
- Fuel costs (fuel purchases minus fuel sales)

These sums may be positive or negative, because they are incremental costs compared to business as usual without greenhouse gas emission reductions.

Contrary to sectoral costs, the whole economy costs do not depend upon what economic instrument is used to effect the reductions, such as, for example, an emission permit system with a particular allocation scheme. However, the total national cost is dependent upon two key assumptions which, if relaxed, would probably change the cost values significantly:

- *No leakage*. It is assumed that Canadian consumers do not have the option of purchasing electricity or refined products from a country not subject to greenhouse gas pricing.
- *Constant output*. Economic output is generally assumed to be unaffected by greenhouse gas pricing

Sectoral Costs

The total economy-wide costs are unambiguously defined by the model, but the distribution of costs among the various sectors depends upon the policy instrument used and the pricing mechanism in the model. To make sectoral cost comparisons, certain assumptions must be made about the allocation of permits to the capped sectors.

Regarding permit allocation, the sectoral costs are based on the assumption that the actions taken in a particular sector are paid for by the same sector. Or equivalently, each sector is assumed to be allocated an amount of free emission permits exactly equal to the sector's emissions in that path. Thus, the sectors do not trade emissions among themselves or with the government.

Turning to pricing, the MARKAL model uses marginal cost pricing for all commodities. This means that a sector that incurs additional costs as a result of reducing greenhouse gas emissions will increase its output to reflect the marginal cost of the last unit of output. Thus, sectors may increase both costs and revenues. The revenues may increase more than the total cost incurred, because pricing is at marginal cost, not at average cost. Hence, some sectors (for example, electricity) may show a surplus.

Compared to business as usual, therefore, net costs are sometimes positive and sometimes negative. Considering the oil refinery sector, for example, in a transition from business as usual to Path 1:

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		**-0.04**		+0.19		-4.73	
Purchase: price effect		-0.02		**-0.01**		-0.02		-0.02
Purchase: demand effect		-1.23		**-0.75**		-1.14		-1.05
Sales: price effect		-0.55		**-0.11**		+0.16		-4.82
Sales: demand effect		+1.61		**+0.84**		+2.72		+1.16
Investment + O&M	-0.15		**-0.14**		-0.30		-0.15	
TOTAL	-0.33		**-0.22**		+0.11		-4.88	

Table 3. Incremental cost breakdown for the electricity 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	-1.27	**-1.66**	-1.24	-1.55
Purchase: price effect	+0.05	**+0.19**	+0.09	+0.18
Purchase: demand effect	+0.28	**+0.19**	+0.17	+0.20
Sales: price effect	-1.32	**-2.40**	-1.81	-2.28
Sales: demand effect	-0.29	**+0.37**	+0.31	+0.35
Investment + O&M	+0.15	**+0.07**	-0.09	+0.05
TOTAL	-1.12	**-1.58**	-1.33	-1.50

- Refining *cost* is pushed *up* due to in-plant investment and operation expenditures to reduce emission in response to the emission constraint
- Refining *cost* is pushed *up* because of the higher price of electricity used by refiners
- Refining *cost* is pushed *down* because of variable cost savings from processing less capacity, or from avoiding investment in new capacity
- *Revenues* are pulled *down* due to lower sales volume from demand reductions induced by the sales tax
- *Revenues* are pushed *up* due to higher plant gate prices

Tables 2 and 3 separate the effects of these various elements for two sectors: petroleum refining and electricity generation. Incremental sectoral cost is broken down into two components: investment and O&M, and fuel costs. Fuel cost is further broken down into four components, as follows:

- Incremental cost of fuel purchase - price effect: the incremental cost of the Path's *total* fuel purchases times the *price increase* from business as usual to Path
- Incremental cost of fuel purchase - demand effect: the incremental cost of the Path's *additional* fuel purchases, priced at the *business as usual price*
- Incremental loss of revenue - price effect: the incremental loss of revenue of Path's *total* fuel sales times the *price increase* from business as usual to Path
- Incremental loss of revenue - demand effect; the incremental loss of revenue of the Path's *additional* fuel sales, priced at the *business as usual price*

Using the model results, the difference in cost by sector between business as usual and a Path can be calculated as:

$$P_{path} * Q_{path} - P_{bau} * Q_{bau}$$

where P = price, Q = quantity, and the subscripts refer to the individual Path and business as usual. This amount can be decomposed into the sum of the price effect and the demand effect as follows:

- Price effect: $(P_{path} - P_{bau}) * Q_{path}$
- Demand effect: $(Q_{path} - Q_{bau}) * P_{bau}$

In the petroleum refining sector, shown in Table 2, the variation among Paths is the result of two opposing forces. On the one hand, the production volume decreases due to less demand in transportation and residential/commercial, resulting in less investment and operating costs, but also less output in physical units. On the other hand, the marginal production costs of refined products increase - due to greenhouse gas abatement actions - and therefore so do refinery-gate prices.

In Paths 1, 2 and 3, the price effect is small compared to the demand effect, because refined product prices vary only slightly from business as usual. Path 4, on the other hand, is quite different. Path 4 puts the onus of end-use reductions on the fuel producers. Oil producers will bear the cost of buying permits and will pass on these costs to fuel consumers. This is apparent in Table 2 where the price effect of fuel sales is very large, and it generates a surplus for the industry. A large portion of this surplus will be spent to buy permits in the first place.

The electricity sector shown in Table 3 is somewhat different. Revenue increases far exceed the gross costs of abatement, yielding large surpluses for the sector. Contrary to the oil refining sector, the price effect is the principal cause of the surplus in all Paths.

These MARKAL results are likely to be very different from those obtained with a model that assumes average cost pricing (as opposed to marginal cost pricing). In that type of model, no price effect would be observed.

In both cases, the extra greenhouse gas premium collected by fuel producers through fuel sales will be

ECN Policy Studies

The International Energy Agency ETSAP Newsletter is published under Annex VII of the 'Implementing Agreement for A Programme of Energy Technology Systems Analysis'. Operating Agent for ETSAP/Annex VII is the Netherlands Energy Research Foundation, acting through ECN Policy Studies, Petten.

Project Head:

Tom Kram, ECN Policy Studies

Netherlands Energy Research Foundation

P.O. Box 37154

1030 AD Amsterdam, The Netherlands

Phone: +31 224 564431

Fax: +31 20 4922812

www: http://www.ecn.nl/unit_bs/etsap/

e-mail: etsap@ecn.nl

Also for free subscriptions & changes of address

Editor:

Douglas Hill - USA

Phone: +1 631 421 5544

Fax: +1 631 421 2999

Please contact the Project Head if you would like to receive more information on ETSAP activities.

ISSN 13823264

ETSAP

OECD

IEA

spent buying permits if permits are auctioned. If permits are distributed gratis, the question of what to do with the large surplus is unresolved. In all cases, it is essential that the price consumers pay should reflect the full greenhouse gas price of the final combustion of fuels.

In the model runs, the end-use sectors in most Paths bear the brunt of the abatement costs, since they pay high prices for final energy, and they must also achieve greenhouse gas reductions in their own sectors. This need not be the case in the real economy, if redistribution policies are set up to equalize the burden of greenhouse gas reductions.

Reference

R. Loulou, A. Kanudia, M. Labriet, M. Margolick, and K. Vaillancourt. Integrated analysis of options for GHG emission reduction with MARKAL, final report. Prepared for the Analysis and Modelling Group of the Canadian National Climate Change Implementation Process. HALOA Inc. May 12, 2000.

ETSAP

OECD

IEA