IEA OECD ETSAP news

In this issue

- Down the learning Curve with Emerging Technologies
- Briefing Note on the Kyoto Protocol
- Japan needs Nuclear Power to Reduce CO2 emissions
- Markal "most widely used" model, but...

Down the learning curve with emerging technologies

Promising new technologies that are still very expensive will become less costly if they are manufactured in large numbers. The exponential reduction in cost with increased production can be specified by an "experience curve". However, linear programming models of energy systems do not properly account for this nonlinearity. Initial steps with a nonlinear, nonconvex model, GENIE, that explicitly contains experience curves for emerging technologies, suggest that photovoltaics and fuel cells could come to dominate electricity generation if a long enough and broad enough view is taken, especially if future carbon dioxide emissions must be restricted.

Proponents of photovoltaic technology argue that expected reductions in its cost will make it more and more competitive as time goes on. This expectation is based on the observation that the unit costs of a manufactured product progressively decrease as more units are manufactured. The pattern of this reduction among many different types of technology has been remarkably consistent, following an exponential reduction variously named a learning curve, progress curve, or experience curve.

The rate of reduction in an experience curve can be defined by the percentage reduction in the unit cost with successive doubling of the quantity manufactured. For photovoltaics, for example, an 82 percent experience curve has been postulated based on early experience (Figure 1). The cost of the hundredth unit will be 82 percent of the fiftieth, the costs of the two-hundredth 82 percent of the hundredth, etc. While the reduction on an experience curve would theoretically continue indefinitely, the amount of the reduction between successive units eventually becomes minuscule, and at some point the unit cost can be considered constant.

Experience curves as an empirical fact must be ignored in linear programming formulations for the future development of the technologies comprising a national energy system, because they constitute a nonlinearity. Linearity requires that successive units each cost the same. This is an important problem when new technologies, far from the point where unit costs have levelled out, are to be considered.

In a dynamic linear programming model in which successive time periods are represented, it has been the practice to assume successively lower unit costs in future time periods for technologies initially high on the experience curve. The solution space remains bounded by a convex curve consisting of linear elements, with optimization at the intersection of two such elements assured. However, the solution may omit the early expensive applications of the technology, igno-ring the fact that the initial investment is necessary to bring down the subsequent cost. It is not a matter of time, but of continued production.

“Some have suggested that technical progress is a factor that may justify deferring carbon dioxide emission abatement”, notes Niclas Mattsson of Sweden’s Chalmers University of Technology. “Autonomous energy efficiency improvement over time is usually explicit in top-down models, and it is implicit in bottom-up models. However, new technologies do not appear automatically. Both technology push - such as publicly funded R&D - and market pull are needed for the dissemination of a new technology. The significance of market pull is that it enables learning by doing to take place. Unless the high initial costs of introducing emerging technologies are paid, they may be locked out before they can contribute to future carbon dioxide emission abatement”.

With the costs of individual technologies characterized by experience curves, determining the best mix of energy technologies to meet future requirements becomes a nonlinear, nonconvex optimizing problem. To address this problem, Mattsson and Clas-Otto Wene developed the dynamic, nonlinear model named GENIE (Global ENergy system with Internalized Experience curves). GENIE models long-term development of the global electricity system, spanning the years 1995-2075 with eight ten-year time periods. The objective of GENIE is to minimize the present value of the total cost of the global electric system, assuming perfect foresight. The main purpose of GENIE is to provide qualitative insights into the dynamics of technological development in the energy system. It is not intended as a complete tool for general energy policy analysis.

There are two conceptual ways to address the nonlinear, nonconvex optimization problem:

By keeping the continuous experience curve and solving the resulting nonconvex problem directly, using modern algorithms for global optimization.

By breaking the experience curve into successive discrete units, assuring the sequential order, and solving the problem using mixed-integer programming.

Mattsson and Wene began with the first approach, starting with an ad hoc optimization procedure. This alternative is very simple to implement and solves rapidly to a local optimum, according to Mattsson, but the global optimum cannot be proved. Many model runs from different starting points are therefore necessary to satisfy the user that the global optimum has indeed been found.

In subsequent work reported in his thesis for the degree of licentiate of engineering at Chalmers, Mattsson used GENIE in the second approach. The great advantage of this method is the guarantee of finding the global optimum. However, the implementation is more complicated, and solution times are several orders of magnitude larger.

The model consists of four world regions; North, South, East and West. The nonconventional electricity generation technologies for producing electricity are advanced coal power, e.g. pressurized fluidized bed combustion or integrated gasification combined-cycle gas turbines (CCGT), wind power, fuel cells using natural gas, photovoltaics (PV), and photovoltaic hydrogen production (PV-H2). PV generates electricity intermittently, when the sun is shining. PV-H2, on the other hand, provides power on demand as it uses PV electricity to electrolyze water, stores the resulting hydrogen and oxygen, and when required recombines them in fuel cells.

To minimize computational difficulty, only technologies with a large potential for experience-based cost reduction are treated in the model by experience curves. The modular technologies PV, PV-H2 and fuel cells were assumed to have the steepest progress ratios (0.82, 0.85 and 0.85, respectively), the small-scale technologies CCGT and wind power slightly less steep ratios (both 0.88), while the large-scale technologies display little (advanced coal, 0.95) or no experience-based learning (all others). The reduction in cost is approximated by linear segments in the cumulative investment cost curve, i.e., the integral of the experience curve. The maximum allowed growth rate for all technologies was taken as 30 percent per year.

Results

Results were produced first for a base scenario, for which two different solutions can be obtained. The first solution, a local optimum, appears in Figure 2. It can be described as a business-as-usual development of the global electricity system, with total system costs amounting to $9,117 billion. In this solution, conventional fossil technologies are phased out and initially replaced by CCGT and hydro-power. Later, possibly due to increased gas prices, CCGT is replaced by advanced coal power, which eventually becomes the dominant technology of the system. Carbon dioxide emissions from this system almost double by the middle of the next century, as shown in Figure 6.

A completely different solution to the same scenario appears in Figure 3. This is the true optimal (least cost) solution which has a total system cost of $9,106 billion, marginally lower than the first case. In case 2, fuel cells swiftly gain market share and eventually become the largest source of electricity. Photovoltaic cells (PV) contribute substantially to global electricity production, and non-intermittent PV-H2 also enters the system. Total carbon dioxide emissions increase by a maximum of 30 percent, but are later reduced below 1995 levels.

The lower costs, lower emissions and increased technological diversity of case 2 suggest that this path can be viewed as a no-regrets policy, making it the preferred choice. But the choice must be made early: in case 1, there are no investments in PV or fuel cells. In case 2, these technologies grow at the maximum rate from the first time period on. During the first decades, however, these investments are not profitable, but they are necessary to ensure future (greater) profitability. This situation is illustrated in Figure 4, which shows annual investment cost profiles for the two solutions.

This figure emphasizes the risk of technology lock-in. Case 2 requires approximately 30 percent more investment capital than case 1 in the year 2025. If capital is a scarce resource in the future, a fairly safe assumption, there is danger that capacity will be built up with established technologies as in case 1, the business-as-usual future. There will then be no opportunity to gather cost-reducing experience with emerging technologies because they will be effectively locked out by established technologies.

“However”, says Mattsson, “implicit in the model representation is the assumption that large grid-connected electricity systems will bear the costs of introducing the emerging technologies. In practice, nursing and bridging markets may provide a natural growing ground for the emerging technologies. The burden of technology development on the grid-connected systems may then be eased and lock-in prevented".

In a second "greenhouse" scenario, a limit was placed on accumulated emissions of carbon dioxide equivalent to 50 years of emissions as the current level, with the resulting emission trajectory shown in Figure 6. A local optimum is shown in Figure 5. The value of the emerging technologies PV and fuel cells is much higher in the limited carbon dioxide emissions scenario, and consequently both technologies are developed as quickly as possible in both cases. Total system costs are $9,232 billion. Thus, the demanding limits on carbon dioxide emissions raise the cost only slightly more than 1 percent.

To obtain a local optimum which is different from the global least-cost solution, Mattsson introduces extra constraints that make the global optimum infeasible and force the solver to find another optimum. For example, case 2 in the base scenario is the true global optimum. To obtain case 1, PV and fuel cell capacity were temporarily constrained (to less than 20 GW in 2025) but not explicitly forbidden. The constrained solution was not to invest in these technologies at all. Since the capacity constraint of 20 GW was inactive, this was a local optimum to the original problem. This can occur in a nonlinear problem with several local optima, whereas in a linear problem any such additional constraint would automatically be binding.

"The GENIE results illustrate that plausible locally optimal solutions can show deviating paths that lead to drastically different future energy systems", says Mattsson. "Timely support of emerging technologies is probably necessary to avoid lock-in of established technologies and build a diverse, flexible energy system".

Mattsson and Wene plan to study future electricity options for Sweden by soft-linking GENIE with MARKAL. To facilitate this linking, GENIE was designed to be as compatible with MARKAL as possible.

References

N. Mattsson. Internalizing technological development in energy systems models. Thesis for the degree of licentiate in engineering. Chalmers University of Technology. November 1997.

N. Mattsson and C.-O. Wene. Assessing new energy technologies using an energy system model with endogenized experience curves. International Journal of Energy Research, Vol. 21, 385-393 (1997).

R.H. Williams and G. Terzian. A benefit/cost analysis of accelerated development of photovoltaic technology. PU/CEES report no. 281, Princeton University, New Jersey, USA.

Briefing Note on the Kyoto Protocol

Perhaps the most remarkable property of the Kyoto Protocol is its mere existence, despite the seemingly insurmountable differences between various (groups of) Annex-1 countries and between those and non-Annex-1 parties still existing by December 8, the start of the high-level meeting of COP3 in Kyoto. The closing sentence of US vice president Al Gore (not included in the write-up of his opening address) seemingly restored some hope of reaching an agreement by instructing the US delegation to show more flexibility in the negotiations. Indeed, in the following days various sets of reduction targets for the main

Annex-1 players US, Japan and EU were circulated, that migrated substantially from their initial positions (US 0%, Japan 2.5% and EU 15%).

As everyone knows by now, the final result implies a 5% reduction for Annex-1 on aggregate; 6% reduction for Japan, 7% for the US and 8% for the EU. Australia negotiated a +8% target, while Norway accepted +1% and Switzerland went along with the EU target of -8%. Canada's -6% is slightly less stringent than the US.

Of the non-OECD Annex-1 Parties (former Soviet republics and countries in Central and Eastern Europe) the two biggest, Russia and Ukraine, negotiated a stabilization. With a few exceptions going for -5 to -6%, the others conceded to the EU target of 8%.

Main Elements of the Protocol

Following the Berlin Mandate adopted at COP1, the Protocol sets legally binding targets. These relate to emissions of all six (families of) known greenhouse gases not bound by the Montreal Protocol. Besides CO_2, CH_4 and N_2O, the other three gases in the basket are HFCs (hydrofluorocarbons; replacements for the ozone depleting substances banned under the Montreal Protocol), PFCs (perfluorocarbons; primarily from aluminum production) and SF_6 (sulphur hexafluoride; an excellent thermal and electric insulating gas). All gases are recalculated into CO_2 equivalents, following IPCC guidelines. For the latter three gases the year 1995 may be chosen as base year to overcome the worst data problems and to account for the HFCs that grew strongly in recent years. The commitments made relate to the average for the period 2008-2012, so that the sum over that period shall not exceed five times the limit fixed by the Protocol.

Emissions/sinks associated with land-use changes are also covered in the Protocol, for the time being only those associated with reforestation, afforestation and deforestation activities since 1990. Net emissions, positive or negative, are part of the future commitment. For the base year from which to calculate the future limits, only positive net emissions are to be included, no net sinks.

As the list of commitments shows, a certain level of differentiation is adopted, although the rationale is not always very clear. The EU strongly urged the US and Japan to accept similar reduction targets for all, reflecting its notion of a "similar effort". However, as is well known the baselines are already very different: for example today the US emits some 13% more than in 1990, while the EU total falls 2% below the 1990 level. Likewise, projections for 2010 end up very different. In addition the EU will retain the internal differentiation principle, permitted by the Protocol.

Flexibility is the name of the game in the Kyoto Protocol: besides the already mentioned commitment period and differentiation, several internationally cooperative instruments are adopted to that end. Emission trading between Annex-1 parties is allowed, but also banking of unused "permits" to help meet commitments in future periods. Although the term Joint Implementation (JI) is no longer used, the Clean Development Mechanism (CDM) is introduced that essentially builds on the JI concept. Projects implemented between Annex-1 and non-Annex-1 Parties can, subject to many -as yet undecided- rules and regulations, lead to crediting of part of the resulting emission reduction to assist the Annex-1 Party involved to comply with its commitment. CDM projects can start from the year 2000, and agreed credits can be "saved" by the Annex-1 country. Similarly, Annex-1 countries can exchange emission reduction units arising from projects in other Annex-1 countries, but logically only from 2008 onwards. Contrary to earlier expectations, reflected by many activities implemented jointly under the pilot phase, early starting

JI projects with crediting in Central and Eastern Europe are thus no option under the Protocol.

A draft article allowing for strictly voluntary participation by non-Annex-1 Parties was dropped when members of the "G-77 and China Group" of developing countries challenged it as being in conflict with the Berlin Mandate. Clearly this decision is not favorable for the US position, as the US Senate had ruled before Kyoto that 'meaningful participation by developing countries' is required before ratification can be considered.

The Protocol will not enter into force until at least 55 UNFCCC Parties have signed up and ratified, and provided the signatories represent at least 55% of the base year emissions of all Annex-1 Parties. This to ensure a meaningful level of participation, while reducing the risk of just a few Parties to block the process.

Many Open Questions and Issues

Clearly, a score of technical and regulatory issues remain unsolved in the current Protocol. All rules, regulations, conditions and modalities regarding international cooperative actions and their monitoring, certification, etc. are still to be settled. Only the main principles are agreed at this stage. Many issues are deferred to the next meeting, COP4, to be held in November 1998 at Buenos Aires. Even decisions on the Meetings of the Parties will be deferred until after the Protocol has entered into force. Advice and guidance from UNFCCC Subsidiary Bodies, from IPCC and other organizations like OECD/IEA is sought.

Implications for Modeling, Analysis and Policy

Many details are as yet unresolved, and at least for some time it will remain uncertain if the Protocol will ever will be implemented at all. However, the principles adopted indicate a need for extended modeling and analysis. Assuming that the Protocol will eventually become operational, it raises several new and/or underexposed questions:

What are the implications of dealing with a 'six-gas basket' commitment to limit GHG emissions from fossil fuel consumption, industry, agriculture, waste management and forestry instead of the far more thoroughly analyzed issue of CO2 (or three-gas basket) emissions associated with the energy sector?

How to estimate what policies and measures to implement nationally and to what level, in light of prospects for flexible options like emission trading and/or joint projects with other Annex-1 Parties, CDM projects with non-Annex-1 Parties (including "saving" of credits from 2000 onwards), and banking for future periods?

What should still to be developed arrangements for such international and intertemporal instruments look like; and vice-versa: how will future arrangements affect their potential, feasibility and impact?

Concluding Remarks

The fact that a Kyoto Protocol was adopted by the COP3 meeting is a very important, but first step on a road leading to concerted, worldwide attempts to mitigate climate change. The legally binding commitments made by Annex-1 Parties may seem very ambitious and (too) drastic at first glance to some, and utterly insufficient to solve the problem to others. Strictly speaking the latter is correct: the expected growth in emissions in non-Annex-1 countries will more than offset the committed reductions in the industrialized World. Rapid stabilization of atmospheric concentrations will require something like a 60%

cut in emissions worldwide. Nonetheless, if and when entered into force the Kyoto Protocol in all likelihood marks an unprecedented and irreversible turning point for economic, energy and environment policy thinking.

Considering the various options for enhanced flexibility (emission trading, joint projects and CDM) and the inclusion of all six GHGs and land-use changes, it is not inconceivable that the currently agreed commitments can be met at limited overall costs. The relatively weak commitments of Russia, Ukraine and other non-OECD parties offer favorable prospects for low-cost, cooperative strategies. Very tentative estimates at ECN Policy Studies, using ETSAP results and other sources, seem to confirm this notion. In addition, successful development of the CDM can further broaden the scope for relatively low-cost emission reductions. More than ever, exploration and assessment of such international actions calls for the widespread use of well-established and comparable tools and databases, as well as for new modeling approaches. To follow up on the directions set out by the Kyoto Protocol, there is a clear need for encompassing other sectors than energy supply, conversion and end-use, for more comprehensive treatment of all greenhouse gases, and for multi-country analyses.

GianCarlo Tosato
Project Head ETSAP

Japan needs Nuclear Power to Reduce CO2 Emissions

A study was made of the Japanese energy system using the MARKAL model to determine what technologies are needed to reduce future carbon dioxide emissions. Nuclear energy can make the greatest reduction by the year 2010, and is essential to further reduce emissions below the 1990 level. Continued expansion of nuclear power after 2010, together with energy conservation, renewables, and especially greater use of natural gas, would continue to lower emissions. Even with a choice of the more than 200 energy technologies considered in the model, however, no drastic emission reduction can be achieved in Japan with the assumed growth in energy and the national economy.

Nuclear energy痴 potential for long-term emission reduction was evaluated by improving the database used in the Japanese model for the ETSAP Annex VI common assessment and extending the model time horizon to 2050.

Energy conservation measures considered by the model included efficiency improvements and new technology in the industrial and trans portation sectors, insulation and efficiency improvements in the residential and commercial sectors, and combined cycle and combined heat-and-power generation of electricity. Renewables included solar and geothermal energy for electricity and heat, and biomass for electricity and fuel. To reduce carbon dioxide emissions, the model can also switch from coal to oil to natural gas by changing technologies.

Nuclear energy is represented in the model by light-water and fast breeder reactors, and by high temperature gas reactors used to produce hydrogen as a fuel and heat at temperatures as high as 850 degrees C.

For the model runs, it was assumed that GDP would grow at 2.5% from 2000 to 2010, 1.75% to 2030, and

1.2% to 2050. Passenger traffic is expected to increase by 70 percent during the 50 years, and freight traffic by about half. Steel and cement production would decline about 15 percent.

The model sets an upper limit to the importation of oil, declining by one-quarter from its year 2000 level by 2050. Liquefied natural gas, on the other hand, may expand to triple its year 2000 value. The sources of carbon dioxide emission reductions were identified through a series of model runs in which greater use of natural gas and nuclear power were introduced, together with a penalty on emissions. The resulting carbon dioxide emission trajectories are shown in Figure 7.

A reference run, Case A, was made with no restriction on carbon dioxide emissions, allowing no nuclear investment after 2001, and energy and technology choices made only from an economical viewpoint. Under these circumstances, the use of coal would expand to become the dominant source of electricity and account for more than half the supply of primary energy. Japanese carbon dioxide emissions would be double their 1990 level by 2050.

For Case B, with the same restriction on nuclear energy, a penalty of carbon dioxide emission was introduced increasing from 5,000 yen per ton of carbon dioxide in 2005 to 50,000 yen per ton by 2050. In this case, the use of natural gas continues to expand, supplanting more than half of the coal for electric power generation by 2050. Carbon dioxide emissions would continue to grow but by 2050 they would be one-third less than in Case A.

In Case C, the assumed limitation on importing natural gas is removed after the year 2020. In this case, natural gas completely supplants coal for electric power generation by 2040 and accounts for half of Japan痴 primary energy by 2050. Carbon dioxide emissions level off and begin a slight decline after the year 2015.

For Case D, nuclear power, which had been assumed to phase out in the previous cases, is allowed to expand from 46 GWe capacity in 2000 to 125 GWe in 2050. With virtually no carbon dioxide emissions from nuclear power, Japan痴 carbon dioxide emissions level off about 15 years sooner and 10 percent lower than without nuclear. Then there is a gradual decline in emissions as nuclear begins to replace natural gas for generating electricity until they fuel about equal amounts of electricity by 2050.

Finally, in Case E, future high-temperature gas rectors are assumed to provide industrial process heat. This leads to a continuing decline in carbon dioxide emissions after about 2040 when they would otherwise level off.

The major reductions in carbon dioxide emissions stem from the electricity sector through the use of natural gas and nuclear power, as shown in Figure 8.

These model results were reported by Osamu Sato of the Japan Atomic Energy Research Institute at the ETSAP workshop in November 1997. They suggest that Japan will have difficulty in achieving the 6 percent reduction in greenhouse gas emissions during the 2008-2012 time period called for by the Kyoto Protocol strictly with domestic emission reductions. Thus, Japan seems likely to seek emissions trading opportunities under the Protocol that enable it to achieve additional emission reductions elsewhere.

Markal “most widely used” model, but...

A recent paper on the use of economic models in climate change policy analysis declares MARKAL “the most widely used” bottom-up model. The paper by The Royal Institute of International Affairs also evaluates macroeconomic and general equilibrium models which are usually specific to national economies. With its application to many countries, MARKAL must then be the most widely used of any economic model for climate change policy analysis.

Alas, the article fails to recognize that MARKAL-MACRO and MARKAL-MICRO have now been developed to overcome what it describes as some of the limitations of bottom-up models. In particular, MARKAL-MACRO (1) does allow for the feedback effects of the availability of capital and fuel markets on energy demands and GDP, and (2) endogenizes economic impacts of technical options and environmental requirements.

MARKAL-MACRO combines the bottom-up MARKAL model with MACRO, a long-term neoclassical macroeconomic growth model. It was MARKAL-MACRO, not MARKAL as the RIIA articles states, that was used by the U.S. Interagency Analytical Team in 1997 to help frame the U.S. position for the COP-3 negotiations (See IEA ETSAP News, August 1997).

Reference

J. Fisher and M. Grubb, The use of economic models in climate change policy analysis, The Royal Institute of International Affairs, EEP Climate Change Briefing Paper No. 5, October 1997.