European Environment
Eur. Env. **8**, 94–101 (1998)

SWISS ENERGY TAXATION OPTIONS TO CURB CO_2 EMISSIONS

Olivier Bahn[1*], Emmanuel Fragnière[2] and Socrates Kypreos[1]

[1]Paul Scherrer Institute, Switzerland [2]HEC – Lausanne, Switzerland

This study offers insights into the design of economically efficient policies to curb carbon dioxide (CO_2) emissions in Switzerland and in other European countries. The method uses a model of the energy system to investigate various options for taxation to reduce CO_2 emissions. This study proposes as a first option the introduction of a 'hedging tax', that balances the risks of delaying measures to reduce CO_2 emissions against those of premature reduction measures. It then assesses multinational policy options and considers as a second alternative international co-operation to curb joint CO_2 emissions by means of a uniform tax applied in different countries. The simulation of such a strategy among three European countries (Switzerland, the Netherlands and Belgium) suggests that there may be significant benefits to be gained when CO_2 reduction takes place in the countries where it is relatively cheap to do so. © 1998 John Wiley & Sons, Ltd and ERP Environment.

*Correspondence to: Dr Olivier Bahn, Paul Scherrer Institute, Energy Economics, CH-5232 Villigen PSI, Switzerland.

CCC 0961-0405/98/030094–08 $17.50

INTRODUCTION

Sustainable development requires avoiding drastic climate change. To this end, the United Nations Framework Convention on Climate Change (UNFCCC) called in 1992 for the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. What level has to be reached remains unclear, but stabilizing concentration at a 'safe' level may require significant CO_2 emissions reduction.

This in turn might require major changes in energy markets and systems, and consequently have serious impacts on the world economy. It is therefore important to design economically efficient policies to curb CO_2 emissions. This paper gives some insights for Switzerland. The methodology has also been applied for other countries (Kram and Hill, 1996). It is based on MARKAL (Fishbone and Abilock, 1981), a bottom-up engineering model describing the energy system. MARKAL focuses on the energy sector of the economy from extraction of primary energy up to end-use markets. It captures in particular substitutions of energy forms (e.g., switching to low-carbon fossil fuels) and energy technologies (e.g., use of renewable power plants instead of fossil ones) following the increase of energy prices due to a carbon tax. The strength of the model is to analyse scenarios of economic development and technological innovation to help policy makers design least-cost strategies (in terms of taxation level and timing) to reach specific CO_2 reduction targets. It enables also one to identify key abatement technologies in the energy system, whose development could be fostered by research subsidies. Furthermore recent model improvements allow us to address uncertainty (Fragnière, 1995) and regional distribution of CO_2 reduction costs (Bahn, 1994; Berger et al., 1992), two key factors of decision making for addressing the climate change issue.

This paper studies specifically alternative CO_2 emissions taxation options for Switzerland. First, based on a scenario-by-scenario analysis, it examines two cases of CO_2 emissions control (stabilization and 20% reduction to be reached by 2030) by means of a carbon tax. This approach is the usual way of dealing with the uncertain level of CO_2 reduction necessary to prevent climate change. It does so by analysing one after the other alternative reduction targets that constitute contrasted views (scenarios) about the future. The scenario-by-scenario analysis enables policy makers to compare different taxation options, but does not provide them with a unique policy recommendation for today, namely a unique tax level.

In this context, a second and more appropriate approach, the stochastic programming method, considers simultaneously the different CO_2 control scenarios. It assumes probabilities for the reduction targets to be reached by 2030, that correspond to a possible likelihood of the targets' enforcement, and a particular date (here after 2005) by which it will become clear which control policy should be followed. The stochastic programming approach proposes policy makers a 'hedging taxation' strategy, that has 'least regret' under all outcomes of uncertainty. This means a single taxation level to be imposed between 2000 and 2005, before the uncertainty—the level of CO_2 reduction to be reached by 2030—is resolved. It is a hedging strategy in the sense that it triggers energy technology changes that facilitate adaptation, after 2005, to the CO_2 control policy that shall be imposed.

Besides uncertainty, another important issue is to co-ordinate at an international level national CO_2 reduction efforts. As a third option for the design of efficient taxation policies, this paper proposes the introduction of an international uniform carbon tax to reach an overall CO_2 reduction target. This strategy distributes reduction efforts among several countries by equalising their marginal abatement costs. The benefits to be gained by imposing a uniform carbon tax are illustrated by simulating a co-operation among Switzerland, the Netherlands and Belgium to reach jointly an overall 20% CO_2 emissions reduction by 2030.

NATIONAL TAXATION OPTIONS

To study the curbing of Swiss CO_2 emissions by means of a carbon tax, we first follow a scenario-by-scenario analysis with a MARKAL model for Switzerland (Kypreos, 1992). In a MARKAL analysis, a scenario represents a possible evolution of the energy system's environment. We usually distinguish five groups of hypotheses: socio-economic parameters such as economic and population growth, demand for energy services (e.g., heat and transportation), existing and future technological options (e.g., cogeneration or hybrid car) with their associated cost and efficiency, forecasted prices for imported energy and finally environmental regulations such as CO_2 reduction targets (see also appendix A). The assumptions of the baseline scenario are those recommended by the International Energy Agency (IEA/ETSAP, 1997). Furthermore, MARKAL considers rational economic agents with perfect foresight that react solely on price signals, for instance a carbon tax, and supposes that energy markets are under perfect competition.

We analyse three scenarios for CO_2 emissions control: baseline (no reduction), cumulative stabilization (relative to 1990, between 2000 and 2030), and cumulative 10% reduction (relative to 1990, between 2000 and 2030) to reach by 2030 a 20% reduction (from the 1990 level). The associated CO_2 emission paths, as computed by Swiss MARKAL, are given in Figure 1. Another valuable piece of information given by Swiss MARKAL is the marginal costs of CO_2 reduction, namely the additional costs to reduce the last tonne of CO_2 within the specified reduction goals (stabilization or reduction). They correspond to taxes to be imposed on CO_2 emissions to reach these targets, as defined in the 'pricing and standard approach' of Baumol and Oates (1971). Table 1 reports on the undiscounted marginal costs of reduction.

The resulting taxes are high, especially in the reduction scenario. Even for the first two periods, the reduction of CO_2 emissions requires a tax of around 0.23 to 0.29 CHF/litre of gasoline (for which the current December 1997 consumer price is about 1.2 CHF—with one CHF equal to 0.7 USD). Indeed, compared with other industrialized countries, the Swiss energy system is already

Eur. Env. **8**, 94–101 (1998)

Table 1. Undiscounted marginal costs of reduction (CHF/tonne CO_2)

	2000	2005	2010	2015	2020	2025	2030
Stabilization	23	30	38	49	62	79	101
20% reduction	101	129	165	210	268	343	437

rather efficient in terms of CO_2 emissions. For instance, Switzerland produces 98% of its electricity from power plants (hydro and nuclear) that do not emit CO_2, the other 2% being produced by 'classical' fossil power stations. In the future, to satisfy electricity demand (which is expected to increase despite demand side management measures) under the current nuclear moratorium and without increasing emissions, Switzerland would have to use alternative and expensive power systems (e.g., depending on the level of CO_2 reduction, cogeneration, wind, biomass and solar). Let us note that the Table 1 figures correspond to high estimates. Indeed, some aspects that would lower these tax levels are not considered in MARKAL. One aspect is the short-term behaviour of consumers that reduce their demands for energy services at higher energy prices. Another is the recycling of the carbon tax revenue to subsidy the development of abatement technologies. These two aspects are addressed for Switzerland by Kypreos (1995) with an extension of MARKAL. However the tax levels computed by MARKAL may serve as a guideline for policy makers to design taxation policies.

We believe that the cost of curbing CO_2 emissions in Switzerland goes beyond the limits of the Swiss willingness to pay for avoiding climate change, which is still perceived as an uncertain threat (Kypreos, 1995). Alternative taxation policies should therefore be found. This paper proposes as a first option a hedging taxation strategy. It is designed with a two-stage stochastic version of Swiss MARKAL (Fragnière and Haurie, 1996) (see also appendix B). The stochastic process describing the unfolding of uncertainty—the level of CO_2 reduction to be achieved by 2030—is represented by a two-stage event tree. It consists of a first stage or trunk that describes the measures (e.g. tax level) to be implemented between 2000 and 2005, and a second stage or branches that describe recourse adaptations (updated tax levels) to be taken between 2010 and 2030. Branches correspond indeed to alternative CO_2 emissions control policies (no reduction, cumulative stabilization and 10% reduction) that define three states of the world (SW1, SW2 and SW3, respectively). A probability is associated to each of them (25%, 50% and 25%, respectively). We have chosen this probability distribution following a 'Bayesian approach' ('subjective' or 'personal' probabilities). It reflects our level of confidence in the different outcomes. In other words, it represents our (maybe naïve) belief in the likelihood of these CO_2 targets being enforced by 2030. Ideally, these probabilities should have been determined by a sample of environmental experts, following the ability of the proposed control policies to prevent a drastic climate change. In an attempt to overcome this shortcoming, we shall examine later alternative probability distributions, as a mean of sensitivity analysis, to cover alternative believes on this issue. Following the stochastic programming approach, the decisions to be taken between 2000 and 2005—before the resolution of all uncertainties related to climate change—are unique, whatever the realization of one of the three states of the world SW1–3. They constitute the hedging strategy. After 2005, once it becomes clear which control policy needs to be followed, the stochastic programming proposes also least cost measures to adapt to the occurring state of the world. The measures are defined by minimizing the expected energy and CO_2 control costs of SW1–3 (cf. appendix B). The resulting undiscounted marginal costs of reduction are reported in Table 2.

For the years 2000 and 2005, the stochastic Swiss MARKAL model provides—in contrast to the scenario-by-scenario analysis, cf. Table 1—only one set of marginal costs (row labelled 'Hedging'). This defines a hedging taxation strategy, namely a unique tax to be imposed on CO_2 emissions to hedge for climate change. This tax is low (around 0.1 CHF/litre of gasoline) and thus more easily acceptable by taxpayers. Its introduction corresponds to a least-regret strategy, that balances present regret of imposing premature and costly emission reduction with future regret of neglected reduction in the past. After 2005, when uncertainties about climate change are resolved, taxes are either removed (when SW1 occurs), or adjusted to meet the CO_2 reduction

Table 2. Undiscounted marginal costs of reduction (CHF/tonne CO_2)

	2000	2005	2010	2015	2020	2025	2030
Hedging	38	49					
SW2			34	43	55	70	90
SW3			182	233	297	379	484

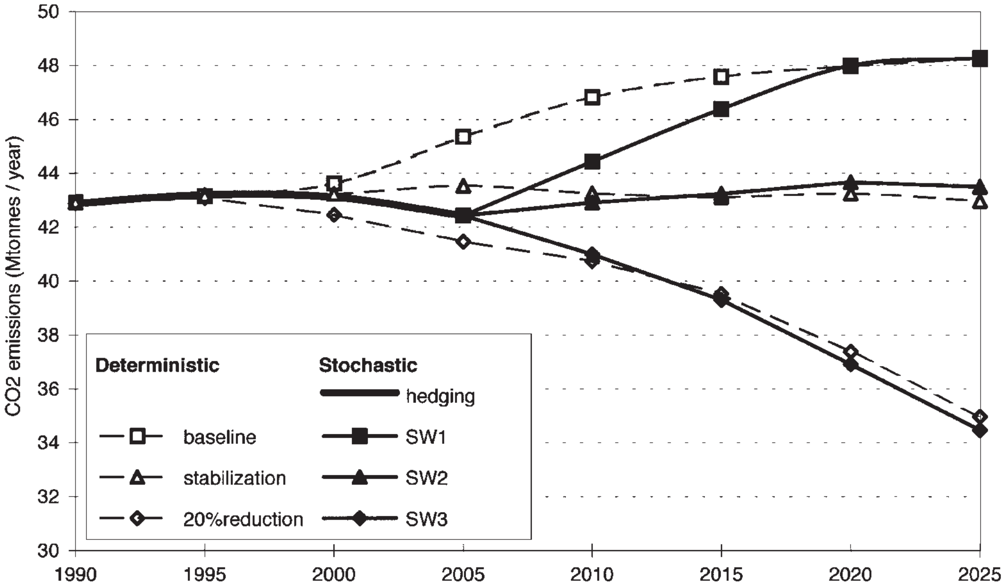

Figure 1. CO_2 emission paths for deterministic (dashed lines) and stochastic (solid lines) cases.

targets (SW2 and SW3). The corresponding CO_2 emission levels are also given in Figure 1. For simplicity, the three cases (scenarios) of the scenario-by-scenario analysis will be from now on referred to as the deterministic cases. The word deterministic means that in each of these cases the CO_2 control policy to be followed is fully determined from the beginning.

In terms of CO_2 emissions, the scenario-by-scenario analysis gives three paths. These paths result from the imposition of three levels of taxation. By contrast, the hedging strategy proposed by the stochastic approach gives for the years 2000–2005 a single CO_2 emission path lying between the deterministic stabilization and reduction cases. This path results from the imposition of the hedging tax. After 2005, if SW1 happens, no reduction is necessary and emissions catch up with the level of the deterministic baseline case. If a cumulative stabilization is required (SW2), CO_2 emissions are however allowed to increase slightly relative to the deterministic stabilization case, because of early reductions made between 2000 and 2005. Notice that consequently the associated carbon tax levels are lower than those of the deterministic scenario. Finally, if a cumulative 10% reduction is imposed (SW3), CO_2 emissions are curbed a little more than in the deterministic reduction case, to compensate for the extra emissions of 2000–2005. In that case, the associated carbon taxes are higher than for the deterministic reduction scenario.

Let us stress again that the stochastic programming approach provides policy makers with a single recommendation for the years 2000–2005, namely a unique low-level carbon tax. Varying slightly the probability distribution, the hedging tax remains almost unchanged. Following again a Bayesian approach, we have also considered two different probability distributions reflecting alternative views on the climate change issue. The first distribution (50%, 30%, 20%) gives a hedging tax of 30–38 CHF/tonne CO_2, the second one (20%, 30%, 50%) 62–78 CHF/tonne CO_2. When the probability associated with SW3 increases significantly, the hedging tax does increase but remains well below the tax given by the deterministic reduction case (101–129 CHF/tonne CO_2, cf. Table 1). After 2005 however, if a cumulative 10% reduction is imposed, carbon taxes to

Table 3. Target CO_2 emission levels (in million tonnes)

Belgium	Netherlands	Switzerland	Coalition
470	719	193	1382

achieve such a reduction are again high. We believe thus that the hedging taxation strategy is a good short-term strategy, but in the longer term, if the necessity to reduce significantly CO_2 emissions is confirmed, another taxation policy should be found.

INTERNATIONAL UNIFORM TAX

An efficient alternative taxation policy for Switzerland can be designed at the international level. International co-operation has been advocated by the UNFCCC as an effective option to reduce CO_2 emissions. It enables one to take into account differences in national emission reduction costs, due to structural differences of the energy systems. For industrialized countries committed to reducing their emissions by a given level, a suitable strategy is to introduce a uniform carbon tax. This enables one to reach the committed overall reduction target at least cost. The idea is to share reduction efforts among the participating countries, such as to equalize their marginal abatement costs. This level gives the value of the uniform tax to be imposed in each country.

To illustrate the benefits to be gained from harmonization of marginal reduction costs, we have simulated a co-operation among Belgium, the Netherlands and Switzerland using a multinational MARKAL model (Bahn et al., 1996) (see also appendix C). Two scenarios related to CO_2 emissions are considered: baseline (no reduction), and cumulative 10% reduction (relative to 1990, between 2010 and 2030) to reach by 2030 a 20% reduction (from 1990 levels). Along with this reduction scenario, two situations are simulated. When each country reduces separately its CO_2 emissions, and when the same overall reduction is obtained at the international level. This second situation is simulated by the multinational MARKAL model. Table 3 gives the cumulative reduction targets (in million tonnes), country by country and for the coalition formed by the three countries.

The associated undiscounted marginal costs of reduction are reported in Table 4. The 'coalition' cost, computed by the multinational MARKAL model, corresponds to the uniform carbon tax.

Table 4. Undiscounted marginal costs of reduction (USD/tonne CO_2)

	2010	2015	2020	2025	2030
Netherlands	16	21	26	34	43
Coalition	26	33	43	54	69
Belgium	36	46	58	74	95
Switzerland	98	124	159	203	259

Table 4 shows the national differences in marginal abatement costs, that constitute a strong incentive for co-operating. Belgium and Switzerland have higher marginal reduction costs than the Netherlands, when each one individually curbs its emissions. With the co-operation, the level of the carbon tax is reduced in Belgium and especially in Switzerland. It is thus more likely to be accepted in these countries by national taxpayers. For the Netherlands, however, the tax is increased. This situation is due to the new national reduction 'targets'. When co-operating, Belgium and Switzerland are 'allowed' to emit more CO_2, whereas the Netherlands has to compensate by reducing further its emissions. This situation is illustrated in Figure 2, that reports on national CO_2 emissions for the year 2030.

When harmonizing their emission reduction efforts, Belgium, the Netherlands and Switzerland can expect savings of about two billion dollars (USD, 1990). These benefits are given in Table 5, that reports also the total abatement costs (discounted at an annual 5% rate, in million dollars) of reaching the targets specified in Table 3.

Table 5 indicates also the national outcomes of a uniform tax. Belgium and Switzerland have a direct profit from the co-operation, whereas the Netherlands has to bear an increase in its total abatement costs.

To secure the co-operation of the Netherlands, it must be compensated for its total abatement cost rise. Belgium and Switzerland can offer the Netherlands (through compensation payments) a 'fair' sharing of their co-operation dividends, to ensure that every country receives a net benefit from the co-operation. This sharing can be computed using the Shapley values (Shapley, 1953), a game theoretic solution concept for allocating the benefits of collaboration among the various participants. An alternative would be to consider an international market of emission permits and to value the transfer of permits between the countries (Bahn et al., 1997), but this may yield a different distribution of the co-operation benefits.

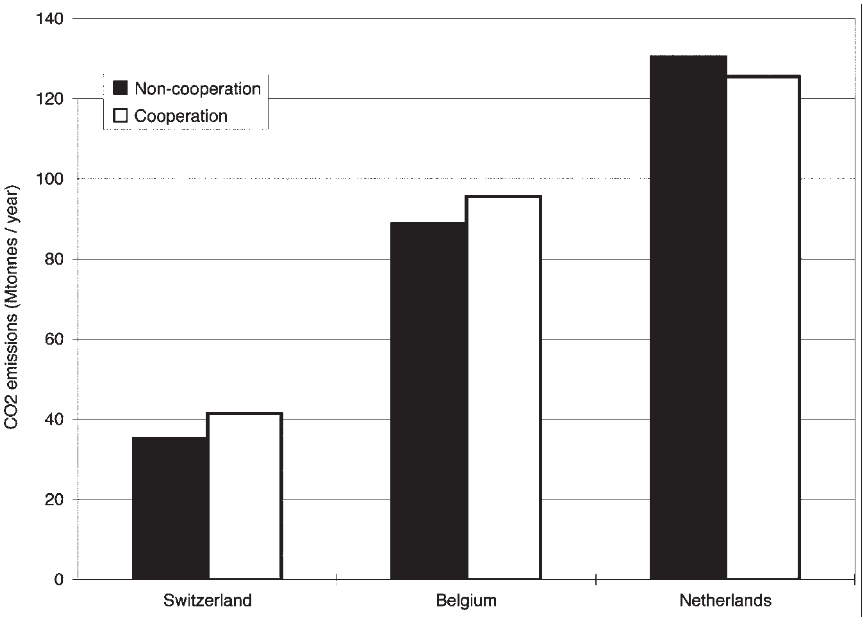

Figure 2. CO_2 emissions in 2030 (20% reduction scenario).

Table 5. Total abatement costs and co-operation benefits (in million US dollars 1990)

	Belgium	Netherlands	Switzerland	Coalition
Non-co-operation	2727	5644	2974	11 345
Co-operation	1749	7038	826	9613
Benefit	978	− 1394	2148	1732

Table 6. Net co-operation benefits (in million US dollars 1990) as Shapley values

Belgium	Netherlands	Switzerland	Total
\$270	\$696	\$766	\$1732
16%	40%	44%	100%

The Shapley values are given (in million dollars) in Table 6.

Notice that these outcomes depend on the way national initial reduction targets are agreed upon. In our case, we have considered a uniform reduction that favours countries with high emissions per capita (here the Netherlands). With 'differentiated' initial reduction targets, alternative distributions of the co-operation benefits will be obtained.

CONCLUSIONS

From a decision analysis perspective, the MARKAL and multinational MARKAL models enable one to explore scenarios concerning in particular the consequences of imposing CO_2 reduction targets on the structure of the energy system. Moreover the representation of risk as a set of stochastic contrasted scenarios provides an adaptive policy that is much closer in spirit to the way decision makers have to deal with uncertain futures. This gives also recommendations on the hedging tax levels required to achieve the emission reductions.

What are the policy implications of our analyses? Curbing CO_2 emissions in Switzerland turns out to be costly, compared with other industrialized countries. We believe that the high carbon tax necessary to achieve a cumulative 10% reduction between 2000 and 2030, as estimated by the Swiss MARKAL model, is not likely to be accepted by the Swiss taxpayers. As a first alternative taxation policy, we propose introducing a low-level carbon tax, as computed by the Swiss stochastic MARKAL model, to hedge for climate change. This would gain time to resolve scientific and policy uncertainties surrounding the climate change issue, and to proceed with future more efficient (both in terms of emission and energy) technologies (Manne and Richels, 1992). In the longer term, if the necessity to significantly reduce CO_2 emissions is confirmed, an efficient taxation policy could be designed at the international level (uniform carbon tax, as estimated by the multinational MARKAL model), by harmonizing emission reduction efforts among willing (industrialized) countries.

We believe thus that high CO_2 reduction costs (typical for some industrialized countries like Norway and Switzerland) should not prevent policy makers from starting to address the climate change issue. Beyond 'no-regret options' (for instance energy conservation measures that are cost-effective), low carbon taxes can be imposed, on a national basis, to hedge for climate change, or internationally, to share efficiently the reduction burden among many countries.

The second option is of particular interest, since it enables one to implement the reduction in the countries where it is relatively cheaper to do so. Moreover, transfer payments can be set up to fairly divide the co-operation dividends among the participants, to ensure that each receives a net benefit. An alternative strategy, that may also be studied with a multinational MARKAL model (Bahn, 1994), would be to establish an international market of CO_2 emission permits. Such a mechanism harmonizes also emission reduction costs among the participating countries and does not require transfer payments. But one key issue is here to find an equitable initial distribution of permits among the participants.

APPENDIX A. MARKAL MODEL

MARKAL is a bottom-up model that simulates market competition of energy carriers and energy technologies in a given country or region. It describes a large number of end-use devices, that compete to satisfy useful demands (of energy services), and a variety of conversion technologies, that compete to produce energy carriers. MARKAL considers not only existing technologies, but also expected ones with improved characteristics (in terms of energy efficiency, for instance). The time horizon is usually 40 to 50 years, which enables one to study long-term structural changes of the energy system. It is a demand-driven model, in which a solution must satisfy the exogenously specified set of useful demands at all time periods. In a first approximation, these demands are inelastic with respect to energy prices. From this perspective, MARKAL computes a perfect foresight competitive market equilibrium for energy goods, defined as an optimality condition. MARKAL is indeed a multi-period linear programming model, and a single optimization, which searches for the minimal system cost, determines the equilibrium. The linear programming formulation of the model can be cast as:

$$\text{Min } c^T x : Ax \leq b .$$

where c is the cost vector of the energy system activities whose level vector is x, A the matrix of the constraints describing the energy system and b its associated right-hand side.

APPENDIX B. STOCHASTIC MARKAL MODEL

A two-stage stochastic MARKAL model can be described as follows. Let us consider S=3 alternative CO_2 emissions control policies (e.g., no reduction, stabilization and 20% reduction to be reached by 2030) that define three states of the world (scenarios). We associate with each scenario s=1, . . ., S a probability p_s. We assume furthermore that uncertainties related to the climate change issue will be revealed after the year 2005, so as to know by then which CO_2 policy to follow. The decision variables describing these policies can be grouped into two categories: x_1, the decisions to be taken up to 2005 and which are common to the S scenarios; and $x_{2,5}$ those to be made afterwards depending on the state of the world s that finally occurs. The hedging strategy is defined by minimizing the expected costs of all the different states of the world. The two-stage stochastic programming formulation of the model can be schematized as:

$$\begin{cases} \text{Min}\left[c_1^T x_1 + \sum_{s=1}^{S} p_s c_2^T x_{2,s}\right] \\ s.t. \\ \qquad A_0 x_1 \leq b_0 \\ \qquad A_1 x_1 + A_2 x_{2,s} \leq b_s,\ s=1,\ldots,S, \end{cases}$$

where the constraints are derived from the deterministic (i.e. without uncertainty) formulation of MARKAL, to insure the feasibility of decisions and to link first-stage decisions (x_1) with second-stage (or recourse) decisions ($x_{2,s}$). Matrices A_0 and A_1 describe the first-stage decision problem, and A_2 is the recourse matrix. Notice that uncertainty appears only in the right-hand side b_s, which includes a description of the alternative CO_2 emissions reduction policies.

APPENDIX C. MULTINATIONAL MARKAL MODEL

From different national MARKAL models, one can design a larger multinational MARKAL model, linking the previous models by a global constraint on CO_2 emissions, to study an international co-operation to curb emissions by means of a uniform carbon tax. The linear programming formulation of such a MARKAL model with N countries can be cast as:

$$\begin{cases} \min \sum_{r=1}^{N} c_r^T x_r \\ s.t. \\ \qquad \sum_{r=1}^{N} E_r x_r \leq e \\ \qquad A_r x_r \leq b_r,\ r=1,\ldots,N, \end{cases}$$

where for each country r: c_r is the cost vector of the energy system activities of r, whose level vector is x_r; E_r is the emission coefficients matrix of CO_2 by the activities of r; e is the vector of overall targets for CO_2 emissions; P_r is the constraints matrix for the national MARKAL model r and p_r its associated right-hand side. The objective function of the model corresponds to minimizing the total system cost for the N countries. The first constraint links up the N countries and insures that the total CO_2 emissions are reduced down to the level e. The dual variable associated with this constraint yields the marginal cost of CO_2 reduction, which corresponds to the uniform carbon tax. The second set of constraints describes the N national MARKAL models without CO_2 emissions constraints.

REFERENCES

Bahn, O. (1994) Techniques de Décomposition dans l'Analyse des Choix Energétiques et Environnementaux, Ph.D. thesis, University of Geneva.

Bahn, O., Haurie, A., Kypreos, S. and Vial, J.-P. (1996) A decomposition approach to multiregional environmental planning: a numerical study, in: Carraro, C. and Haurie, A. (eds), Operations Research and Environmental Management, Kluwer, Dordrecht, pp 119–132.

Bahn, O., Haurie, A., Kypreos, S. and Vial, J.-P. (1997) Advanced Mathematical Programming Modeling to Assess the Benefits from International CO_2 Abatement Cooperation, HEC working paper 97.10, University of Geneva.

Baumol, W. J. and Oates, W. E. (1971) The use of standards and prices for protection of the environment, Swedish Journal of Economics, 73, (42–54).

Berger, C., Dubois, R., Haurie, A., Lessard, E., Loulou, R. and Waaub, J.-P. (1992) Canadian MARKAL: an advanced linear programming system for energy and environmental modelling, INFOR, 30, (222–239).

Fishbone, L. G. and Abilock, H. (1981) MARKAL, a linear-programming model for energy systems analysis: technical description of the BNL version, International Journal of Energy Research, 5, (353–375).

Fragnière, E. (1995) Choix Energétiques et Environnementaux pour le Canton de Genève, Ph.D. Thesis, University of Geneva.

Fragnière, E. and Haurie, A. (1996) A stochastic programming model for energy/environment choices under uncertainty, International Journal of Environment and Pollution, 6, (587–603).

International Energy Agency/Energy Technology Systems Analysis Programme (IEA/ETSAP) (1997) New Directions in Energy Modeling: Summary of Annex V (1993–1995), ETSAP-97-1.

Kram, T. and Hill D. (1996) A multinational model for CO_2 reduction, Energy Policy, 24, (39–51).

Kypreos, S. (1992) CO_2 emission control in Switzerland using mathematical programming, INFOR, 30, (194–206).

Kypreos, S. (1995) Economic implications of environmental policy for Switzerland, in: 16th Congress of the World Energy Council, 4.3.04, Tokyo, pp 65–83.

Manne, A. and Richels, R. (1992) Buying Greenhouse Insurance: the Economic Costs of Carbon Dioxide Emission Limits, MIT Press, Cambridge, MA.

Shapley, L. S. (1953) A value for n-person games, in: Contributions to the Theory of Games (Annals of Mathematical Studies 28), Vol. 2, Kuhn, H. W. and Tucker, A. W. (eds), Princeton University Press, Princeton, NJ, pp 307–317.

BIOGRAPHY

Dr. Olivier Bahn and Socrates Kypreos are researchers at the Paul Scherrer Institute. Dr. Emmanuel Fragnière is an assistant professor at HEC – Lausanne (University of Lausanne). They can be contacted at the following addresses.
Paul Scherrer Institute
Energy Economics
CH-5232 Villigen PSI
Switzerland.
Tel.: +41 (0)56 310 2111.
Fax.: +41 (0)56 310 2199.
E-mail address: Bahn@psi.ch and Kypreos@psi.ch
University of Lausanne
Ecole des Hautes Etudes Commerciales
CH-1015 Lausanne-Dorigny
Switzerland.
Tel.: +41 (0)21 692 3448.
Fax.: +41 (0)21 692 3305.
E-mail address: Emmanuel.Fragniere@hec.unil.ch

