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Jean-Charles Hourcade [a], Minh Ha-Duong [a], Arnulf Grübler [b] and Richard S.J. Tol [c]

[a] *Centre International de Recherche sur l'Environnement et le Développement, CNRS. Mail to CIRED, campus du Jardin Tropical, 45bis avenue de la Belle Gabrielle, 94736 Nogent sur Marne CEDEX, FRANCE.*

E-mail: haduong@centre-cired.fr

[b] *International Institute for Applied System Analysis, Laxenburg.*

[c] *Institute for Environmental Studies, Vrije Universiteit, Amsterdam.*

This communication summarizes the main findings of INASUD, an European-wide research project on integrated assessment of climate policies. The project aimed at improving the framing of climate policy analysis through the parallel use of various existing integrated assessment models. It provides a comprehensive examination of the link between uncertainty regarding damages and inertia in economic systems. Results show that the Kyoto targets and timing are consistent with the precautionary principle but offers little insurance for longer-term climate protection. Flexibility mechanisms offer potentials for cooperation with developing countries, and are necessary to tap the environmental and economic benefits of joint carbon and sulfur emissions abatement.

Keywords: integrated assessment modeling, climate policy, Kyoto protocol, dynamic consistency, double dividend, cooperation

1. Introduction

This article has a somewhat unusual tone for a scientific paper, as it tries to convey modeling results to a broader policy-oriented readership. It summarizes the findings of a project carried out by a multidisciplinary European network: INASUD. We acknowledge that most of the material is not new and that most of these results have been already published in various journals with more technical details, confirming results from other studies outside this project.

This paper is motivated by the feeling that the main findings of modeling efforts are insufficiently used by decision-makers. As noticed by IPCC, stakeholders have a somewhat paradoxical attitude towards models mixing great expectations with real distrusts. This is especially true for integrated assessment models. This is legitimate given the novelty and intrinsic weaknesses of these tools, but also reflects a lack of communication from the modeling community itself. Model findings are widespread in plenty of specialized journals and the scientific discussion tends to focus on the most interesting, i.e. controversial, points. Yet these ongoing debates about the implementation of the Kyoto protocol and its evolution beyond 2012 in models should not hide a core of agreed upon robust insights useful to put some rationale into discussions.

To this respect the INASUD project on Integrated Assessment Modeling of Global Environment Policies and Decision Patterns has the specific interest of relying on a set of parallel and complementary numerical experiments carried out by various integrated assessment models. We will try hereafter to demonstrate that, beyond their differences in approaches, these models are apt to provide a consistent results which aim at framing better the decision-making in the face of controversial risks.

The first group of results examine how to implement globally the precautionary principle through an appropriate timing of actions. The second discusses Kyoto targets and dynamic consistency problems raised by quantity based coordination of climate policies. Lastly, some insights about policy design are drawn including the consideration of environmental double dividend and flexibility mechanism.

2. On the Rio objective, precaution and impacts

The target of two times the pre-industrial CO_2 concentration level retained by the EU before Kyoto to support its position, and which governed at least implicitly many though-experiments, refers to a CO_2-equivalent level of 550 ppm. Experts generally agree that *the target 550 ppm does not qualify adequately the ultimate policy objective* for various reasons:

- Ambiguity: accounting for other greenhouse gases, the target could be interpreted as referring to about 450 ppm for the level of CO_2 alone. It is also unclear whether 550 is more related to radiative forcing, which matter for climate dynamics, or to a two degrees warming, temperature being a proxy for damages.

- Atemporality: there is no serious policy targets without timetables. This is all the more important that the speed of climate change commands the variability of climate, and that increased intra-annual and regional climatic instability is directly related to the occurrence of extreme events in local ecosystems and economies.
- Uncertainty: surprises are still possible regarding the concentration level and the pace at which global climatic non-linearities occur, leading to revision of the ultimate objective.

Modeling exercises suggests that the idea of a long run GHG concentration target apt to prevent dangerous interference with the climate system, as phrased by the Climate Convention, should be taken *cum grano salis*. This is the reason why the IPCC Second Assessment Report strongly advocated that climate policies must be framed as a sequential process: one should not look forward to optimize the response over the long run, but one should try to find a flexible strategy apt to be modified in the light of new information regarding climate and technology.

2.1. Formalizing precaution

Models used in INASUD formalized this precautionary policy approach by balancing explicitly the environmental irreversibility, increasing today the stock of pollutant imply more effort tomorrow, and the investment irreversibility, the opportunity cost of over-cautious policies. The first and most robust insight of the analysis is that *the critical factor is adjustment costs under the worst-case hypothesis*. Figure 1 shows that if the target is 550 ppm, then differing action until 2010 has only a modest effect upon the optimal cost profile, but if the target is 450 ppm there is an very high supplementary cost to waiting.

This is why postponing greenhouse gases abatement and simply waiting for cheaper carbon saving technologies or new information would not represent a precautionary policy strategy. Our numerical experiments demonstrate that *in most cases, costs of acting too late dominate costs of early action.* They are set in a stochastic cost-efficiency framework where a 550 is treated as the mean value of targets ranging from 450 ppm to 650 ppm with equal probability.

The level of the optimal abatement over the short and medium term is all the more important that technical systems' inertia is high, capital stock turnover and diffusion rates of carbon-saving technologies are slow. This inertia enhances

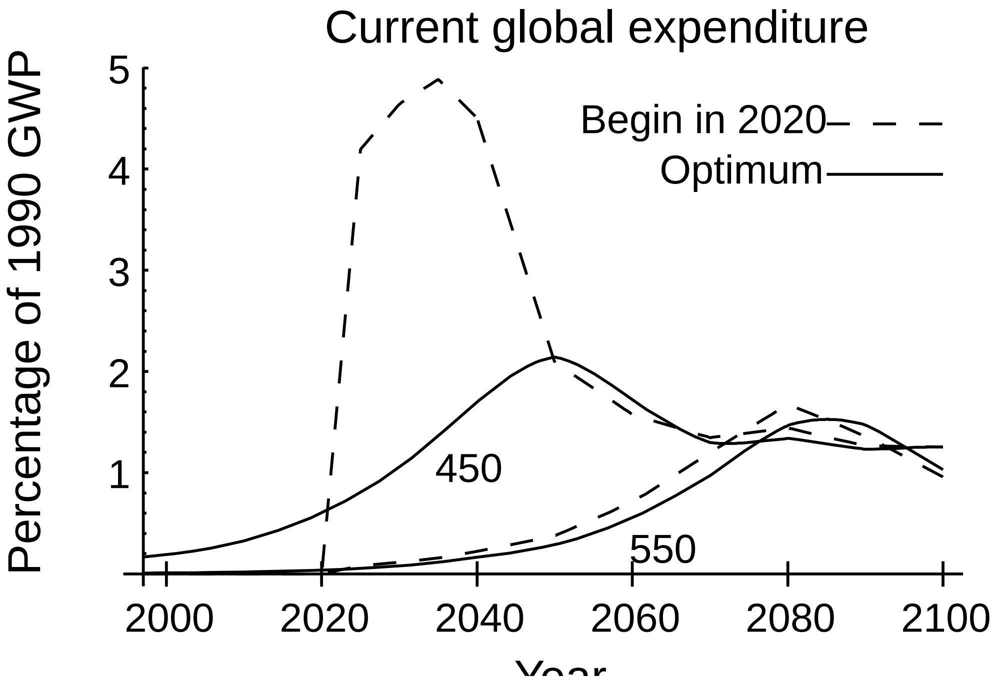

Figure 1. Optimal cost profiles for CO_2 stabilization at 450 and 550 ppm, starting in 1990 and 2010. Computed with DIAM at CIRED.

the costs of shifting from an initial 550 ppm concentration target towards a 450 ppm target which may be required in case of bad news about climate change damages.

The other factor increasing the level of optimal precautionary action is the importance of induced technical change. This was illustrated in INASUD through a quantified retrospective analysis of the Montreal Protocol history. Indeed this is the set of expectations formed after the first debates about ozone depletion and the regulation of CFCs which triggered a learning-by-doing process which reduced drastically the cost of phasing out ozone depleting substances and make acceptable ambitious abatement targets. In the case of GHG reduction the set of technology to be changed is so wide that it requires early initial action such as up-front investments into R&D but also early abatement to deploy niche market and experiment low- and zero-carbon technological options.

2.2. Capturing impacts of climate change

The policy outcomes of cost-benefit modeling exercises is less straightforward. Until intergenerational equity issues and the different aspects of ignorance are formalized much better, it is safer for the policymaker not to believe the numbers. That is why we focused on methodological issues associated with impacts of climate change, uncertainty and ultra long period economic analysis. Simulations confirms that the level of discounting matters but that the impact of various forms of discounting is dominated by other parameters such as the shape of the damage function and the preference for equity.

We analyzed the representation of damages in integrated assessment models. It appeared that most of those structurally exclude any significant subjective probability attached to the occurrence of highly non-linear damages such as a slowing down of North Atlantic thermohaline circulation. Exploring the sensitivity of our models with respect to the shape of the damage curve, results shows that optimal climate policies depends critically on where and when non-linearities are expected. More specifically, optimal concentration trajectories imply early departures from current emission trends which are substantial only if significant damages occur for a +3 degrees temperature increase or a 500 ppm CO_2 concentration. Early drastic emission reductions can be justified if at least a low probability is attached to damages increasing very rapidly with warming, at a rate greater than discounting, at some point in the future.

INASUD compared optimal emission policies using different intertemporal criteria in dynastic models. The result is that to focus on alternative discounting methods does not add much to more conventional approaches. We found that Heal and Rabl discounting for example have the same numerical effect on optimal control as a lower pure time preference in classic discounting. Optimization using the Chichilniski criteria did not change significantly the emissions targets over the following two or three decades, which is the relevant time horizon for most of today decisions. Comparative experiments confirms that the level of discounting matters but that the impact of various forms of discounting is dominated by other parameters such as the shape of the damage function, risk-aversion and the preference for equity.

Given the uneven distribution of climate damages, one have to account for the preference for equity when aggregating welfare in global optimization models. This is a way to translate in a tractable manner real political concerns behind

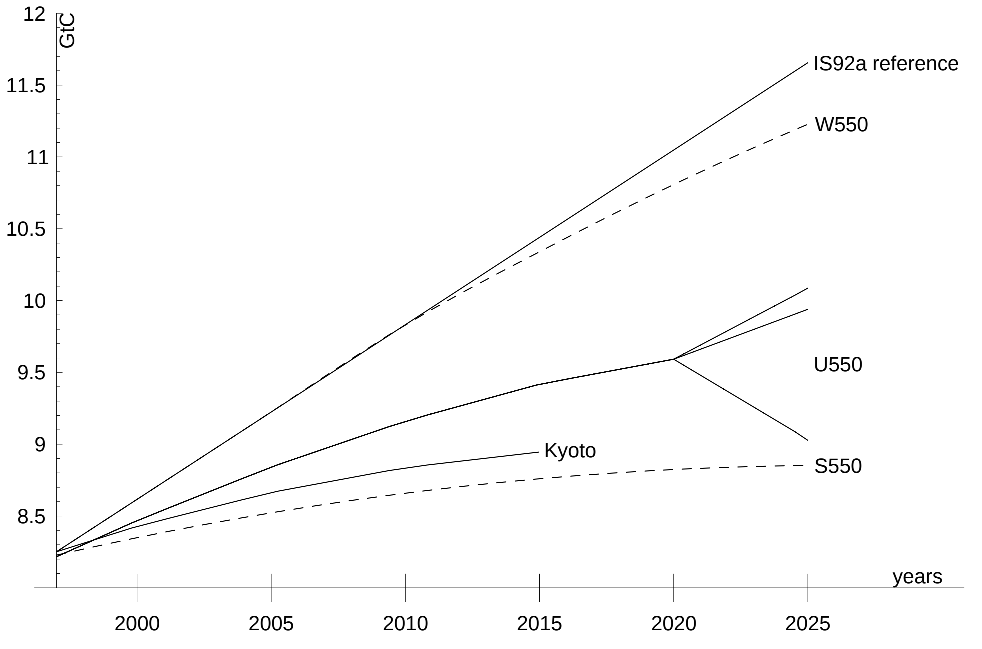

Figure 2. Global CO_2 emissions pathways consistent with long-term stabilization. The S550 and W550 trajectories illustrate two extreme attitudes with respect to early action. The U550 curve illustrates a sequential decision-making strategy. It assumes that the 550ppm target is only an expected value, to be revised to 450, 550 or 650 ppm in 2020. The displayed U550 strategy minimizes reduction costs using the DIAM model. [1, p. 707]

climate policies. The introduction of the "inequity aversion" provided an unambiguous result. Since climate change affects more poorest regions and since developed regions emit more GHGs, emission abatement implies a transfer of wealth (in utility terms) from the rich to the poor and this is valued more positively as inequity aversion increases. In a cost-benefit framework, substantial emission reductions only occur if countries co-operate and heed to each other's well-being.

3. On Kyoto targets and dynamic inconsistencies

3.1. Kyoto targets allow for precautionary strategy

The concern emerges from many quarters that globally, *the Kyoto targets may not be ambitious enough to significantly mitigate climate change*. Quantitatively, exercises carried out in INASUD illustrated figure 2 tend to demonstrate the contrary. Kyoto targets are consistent with the option of staying below two degrees Celsius global warming, and do not preclude the possibility of shifting from an intermediate 550 ppm target towards a more ambitious 450 ppm target with reasonable costs if future scientific information demonstrate that such a shift is required.

But the diagnosis on the Kyoto targets has to consider the heterogeneity across industrial systems, gases and countries. INASUD explored the role of technical inertia, inter greenhouses gases substitution, and development in non Annex B countries on the distribution of efforts.

3.2. *Differential inertia across sectors*

Uncertainties about the baseline socio-economic future are as large as uncertainties about the climate system, and this is all the more dangerous that the underlying technical systems are rigid. The INASUD project tried and emphasized the trends in transportation sector as one of the most critical uncertainty, which is totally related to the role of inertia. In transportation sector the loops between demand and supply patterns is so high that is inertia may lead to a lock in carbon intensive development patterns.

Experience demonstrates that progress in the efficiency of oil-based motors have been largely offset by rebound effects such as higher driven distances; bigger cars and increased competitiveness of road compared to rail and waterways transportation. This can significantly delay the market penetration of low- and zero-carbon transport technologies. Moreover, the dynamics of transport-related emissions are driven by feedbacks between infrastructure policy, urban forms and life styles. *In case of a lack of early control of the transportation sector's dynamics, an over-proportional burden will ultimately fall on the industry sector.*

3.3. *Multi-gases*

The inertia parameters are also important to discuss the role of other gases in the system. Including methane in the emission basket reduces dramatically the overall cost of meeting Kyoto targets, but does not contribute to long run stabilization of the greenhouse effect. Assuming a five percent discount rate, it was found that including methane divided the stabilization cost by three to five (see table 1). In principle, the optimal use of the CH_4 abatement potential would be to preserve it as safety reserve, to use in case of unexpected rapid climate change or difficulties to control CO_2 emissions. Because of its short residence

No international cooperation		Full international cooperation	
CO_2 only	CO_2 and CH_4	CO_2 only	CO_2 and CH_4
27	9.5	6.7	5.7

Table 1

Net present income losses of a 550 ppm stabilization scenario (losses relative to business as usual scenario) with and without international cooperation, and with and without methane emission reduction. Computed with FUND, discount rate 5%. [1, p. 466]

S550 reducing:		W550 reducing:	
CO_2 only	CO_2 and SO_2	CO_2 only	CO_2 and SO_2
11^{3}_{27}	10^{3}_{26}	13^{4}_{31}	11^{3}_{28}

Table 2

Climate change global impact with and without sulfur reduction. See figure 2 for CO_2 550 ppm stabilization trajectories. Computed with PAGE, trillions US$, discount rate 3%. Results show central value and the value corresponding to the first and the last quintile. [1, p. 430]

time in the atmosphere of about twelve years, reductions on CH_4 could be used to lower the apex of costs of long-term climate policies, rather than as a substitute for initial efforts on CO_2.

3.4. Potential carbon-intensive lock-in by developing countries

Beyond 2012, all simulations confirm the interest of *embarking developing countries to climate policies as soon as possible.* Without their participation no safe long-term stabilization of climate can be achieved. Model simulations highlight the difficulty of setting emissions targets for these countries that meet equity concerns and avoid repeated excess assignments because of the uncertainty on emissions baselines and long-term targets. North/South discussions should be conducted in order to support domestic policies and measures enhancing sustainable development patterns in developing countries.

The environmental double dividend related to sulfur emissions is large. Developing countries emit a growing share of the global CO_2 and SO_2, the latter leading to unacceptable acidification impacts, particularly threatening in Asia (see figure 3). Under an illustrative 550 ppm concentration scenario, the secondary benefit of an early CO_2 abatement in developing countries is that: cumulative sulfur emissions are reduced by sixty percent, methane emissions by sixty-five percent. Aggregate cost savings up to forty percent can be realized by

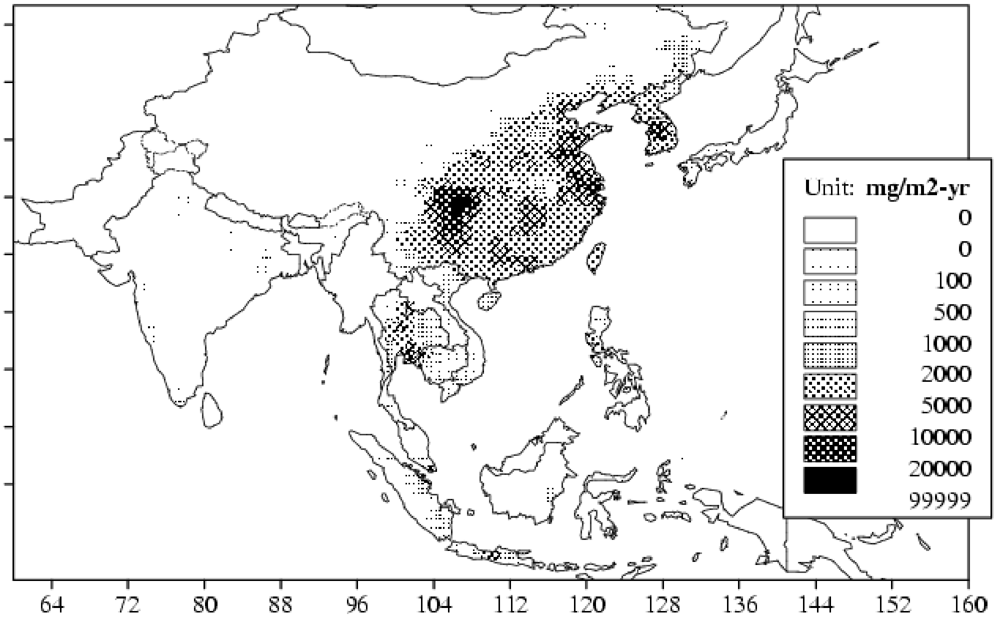

Figure 3. Excess sulfur deposition above critical loads for ASIA in 2050, uncontrolled scenario F, computed with IIASA MESSAGE and RAINS models. [1, p. 411]

simultaneous reduction of SO_2 and CO_2 emissions, most notably in Asia, when compared to pursuing these two environmental objectives separately, reducing SO_2 emissions only in Asia and CO_2 in the OECD.

This environmental double dividend can be achieved only if carbon and sulfur reduction occur in the same region, which implies *the need for interregional transfers of funds through emission trading systems or extended clean development mechanisms.* An indirect double-dividend would be to avoid the lock-in of countries as China or India in a coal-based economy. Those are indeed likely to focus on add-on policy measures to lower SO_2 emissions, for example flue gas desulfurization from coal fired power plants, reinforcing the dominance of existing energy use and supply patterns, making future carbon reduction more difficult and costly to achieve.

3.5. Risks of intergenerational inconsistencies: the role of induced technical change

Beyond the technicalities of the Kyoto system, a specific risk of dynamic inconsistency stems from the fact that abatement efforts of our generations may be annulled by decisions of the forthcoming generations. We have demonstrated that incorporating this risk leads to higher abatement efforts today to anticipate the careless behavior of our children.

It seems unlikely and probably un-equitable that current generations support such an extra burden. A great deal of empirical work has to be still done to assess to what extend modeling technical change as an autonomous process or as induced by the actions changes the magnitude of the burden imposed on the current generation to prevent later generations to defect.

From a qualitative point of view, the most efficient way to prevent this risk and to upgrade the effectiveness of climate policies is to induce carbon saving technical change so as to reduce abatement cost and the attractiveness of later slackening mitigation endeavors.

4. Policy relevant insights

In conclusion, *the distinction between* action *and* abatement *is critical* to clarify policy debates. Abatement corresponds to quantitative emission reduction targets over a given time period, but a quantitative target is not a good indicator of the relevance of policies over the long run. Immediate action corresponds to enhanced R&D and infra-structural efforts. They contribute little to greenhouse gases emissions abatement over the short to medium term. But these efforts are required in order to be able to abate more, faster and cheaper in the future.

The INASUD project shows that in the absence of certainty about climate damages and future socio-economic trends, the interplay between inertia of technical systems and uncertainty legitimates early action. Recognizing the importance of inertia in energy systems and adopting the perspective of induced technical change makes technology policy the critical determinant for creating synergies between various environmental targets and for lowering future costs of complying with uncertain environmental limits.

At the aggregate level the Kyoto targets are compatible with precautionary strategies against a two degrees global warming. They trigger a shift towards lower levels of greenhouse gases emissions which is apt to avoid passing a too heavy burden to future generations. But quantitative targets over the short and medium run are not a good indicator of the sustainability over the long run: the short-term Kyoto targets do not assure any long-term climate stabilization. Even if technically, Kyoto targets could then be met without investments into low- and zero-carbon technology R&D and in sustainable transportation infrastructure development, *differing these actions could be unacceptable from future generations' point of view as it narrows their future response options by increasing technological and infra-structural inertia.*

The Kyoto framework also is also open to dynamic inconsistencies intrinsic to any quota approach. This legitimates the supplementarity condition to trading systems, although not necessarily in the form of quantitative limits to trade. However *arbitrary limits to trade will not resolve the problem*: the burden may indeed fall more on the European countries and Japan than on the US. This will reduce the acceptability of ambitious targets for the second budget period, and penalize countries which initiate long-term structural changes in the transport sector, because these have a small short term effect. Despite the Kyoto framework's current weaknesses, models confirmed that carbon trading and the Clean Development Mechanism are necessary to face uncertainties regarding abatement costs and to capture joint environmental benefits of climate policies.

Kyoto mechanisms are important but limited because minimizing costs of meeting the short-term Kyoto targets is not necessarily consistent with minimizing costs of long-term emissions control strategies. The INASUD experiments demonstrate that *there is indeed a risk of dynamic inconsistency if cap and trade policies are not supplemented* by domestic measures apt to curb down trends in rigid and low price sensitive domestic sectors. Excess emissions assignments in Russia and Ukraine will contribute to depress the international price of carbon. Over the first budget period: opportunity for CH_4 abatement; negative costs options in the energy sector and hot air result in lower incentives for longer-term initiatives in the transportation, infrastructure and R&D sectors. There is no guarantee for the large scale involvement of developing countries.

Developing countries emit a growing share of the global CO_2 and SO_2, potentially leading to high acidification impacts in Asia. These represents an opportunity to use the Kyoto mechanism. Models show that an early CO_2 abatement in developing countries would also induce a very significant reduction in sulfur and methane emissions as well as large aggregate cost savings. This environmental double dividend is however contingent on that carbon and sulfur reductions occur in the same region, which requires interregional transfers of funds through trading systems or the Clean Development Mechanism.

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