Background Note

The relevance of climate change integrated assessment models in policy design

By Nicola Cantore

A growing body of literature examines the use of integrated assessment models (IAMs) in informing climate policy. Economists and researchers suggest that such sophisticated models can provide useful insights for policy-makers. IAMs represent stylised mechanisms and processes underlying world economic activity and the environment, and provide information on policy choices through appropriate data from simulations. While the building of new models to address specific research questions can be time-consuming, the pay-off is the availability of tools to evaluate how specific policies can affect growth and the environment. In the climate change debate, long-running simulations are vital to presenting ideas that stick.

There are various types of models (policy evaluation, policy optimisation) and model specifications to address policy questions related to climate change and development. Examples of these questions include: what are the best emissions reduction policies in terms of economic development, international equality and environment? How can the vulnerability of developing countries to climate change damage be decreased? Is the promotion of economic growth the best policy option to deal with environmental challenges?

This Background Note highlights an example of the benefits of IAMs for climate change policy analyses and examines the environmental and welfare effects of different mitigation policies. Scenarios are organised to reflect different hypotheses around the participation of developing countries in international agreements to stabilise emissions. Tight constraints on emissions for developing countries are more likely to curb the world emissions per capita path but the cost in terms of welfare could be dramatic. The paper provides a definition of IAMs, describes the different categories of IAMs and the policy questions they can address. It also explains the advantages and disadvantages of these tools for research analysis. Finally, we provide an example of the type of policies that can be investigated using IAMs.

What are integrated assessment models?

A flourishing literature is emerging about the use of integrated assessment models to inform academics and policy-makers about the most cost effective and equitable measures to tackle global warming. As outlined by Parson (1994), an integrated assessment driven by modelling:

- seeks to provide and order information for use by relevant decision-makers rather than merely advance understanding for its own sake;
- brings together a wide set of areas, methods, styles of study, or degrees of confidence than would typically characterise a study of the same issue within the bounds of a single research discipline.

According to Kolstad (1998: 265) an IAM is: 'a model that includes both human activity and some key aspects of the physical relationships driving climate change'.

Kolstad goes on to identify three purposes for integrated assessment:

- to assess climate change control policies;
- to force constructively multiple dimensions of a climate change problem into the same framework;
- to quantify the relative importance of climate change in the context of other environmental and non-environmental problems.

Table 1: Models' description and their suitability to answer policy questions

Model	Category	Regional aggregation	Main features	Some relevant research questions for each model
DICE	Policy optimisation model. Cost-benefit model. Nordhaus (1994).	Analysis at global level (1 world region).	In DICE a representative world utility function is maximised, subject to economic and environmental constraints. No trade.	What is the cost of policies to tackle global warming? What is the effect of intertemporal preferences? What is the timing of abatement?
MARKAL – TIMES	Policy optimisation model. Cost-effectiveness model. Fishbone and Abilock (1981).	Analysis at local, national, regional and global level (15 regions for the TIMES model).	MARKAL depicts both the energy supply and demand side of the energy system. The optimisation routine used in the model's solution selects from each of the sources, energy carriers and transformation technologies to produce the least-cost solution subject to a variety of constraints.	How to reach carbon dioxide reduction? What is the effect of market-based instruments? What is the impact of endogenous technological change?
IMAGE	Policy evaluation model. Alcamo (1994).	Analysis at global level (26 regions in IMAGE 2.4).	IMAGE consists of three linked clusters of modules: the Energy-Industry System (EIS), the Terrestrial Environment System (TES) and the Atmosphere-Ocean System (AOS). The collective emissions from EIS and TES are then fed into AOS, which subsequently computes the build-up of greenhouse gases in the atmosphere.	What are the economic and social consequences of alternative climate change abatement goals? What is the impact in terms of sustainability, energy and land use from different scenarios?

Both Parson's and Kolstad's definitions emphasise the interdisciplinarity of the IAMs framework and policy relevance.

This paper discusses the use of IAMs in general and their importance for understanding the policy facets of climate change, in particular.

Different types of IAMs

Different types of IAMs have been analysed in the literature. A simple classification that is widely affected by economists (Weyant et al., 1996) is between policy evaluation and policy optimisation models. The former takes a small set of policies and proposals and examines the consequences of these in a 'what-if' exercise. The latter includes a strictly formal, uni-dimensional assessment of 'better' and 'worse' outcomes, and uses these to select the 'optimal' policy from a large number of what-if exercises (Tol, 2002).

Policy optimisation models can further be classified in cost-benefit and cost-effectiveness analyses. In a cost-benefit analysis, the costs of a policy intervention are weighed against its benefits so as to determine the optimal intensity of an intervention. A cost-effectiveness analysis assesses the cheapest way to reach a goal.

In Table 1 a reference for each different category mentioned above is provided. The selection of models is not exhaustive as these can differ according to several assumptions concerning technology, sector, consumer, uncertainty (stochastic versus deterministic). By providing valuable quantitative information about future economic, social and environmental indicators in different scenarios, these models are useful to understanding the consequences of decision-makers' actions.

IAMs and policy questions on climate change and development

The world is currently facing one of the biggest challenges to development. The vast environmental and socio-economic problems deriving from global warming have never been experienced to such an extent. A large majority of scientists and policy-makers agree that without appropriate policies implemented in a reasonable timeframe, the world could experience extreme events that pose serious risks to the living standards of future generations (Stern Review, 2006). If we consider the Brundtland Report definition (WCED, 1987: 43) of sustainability, (according to which sustainable development is intended as a

form of development that satisfies 'the needs of the present generation without compromising the ability of future generations to meet their own needs'), we can understand why weak and fragmented actions against global warming can lead to undesirable growth paths. From this perspective the priority is to set up the most effective policies to curb increasing emissions over time (Holtz-Eakin and Selden, 1995).

Interesting research questions related to hot policy issues can be investigated through IAMs, most notably:

Is the promotion of economic growth the best policy tool to deal with environmental policies? Researchers have tried to examine the trajectory of future emissions for developed and developing countries and verify the existence of a turning point in the relationship between the level of income per capita and emissions. They test if richer countries with more resources and capabilities follow an emissions reducing growth path, or if they need specific policies to induce environmentally friendly behaviours.

What are the best emissions reduction policies in terms of economic development, international equality and the environment? Several contributions focus on different scenarios that assume different evolutions of international environmental negotiations for environmental agreements. They examine the consequences of each policy scenario in terms of growth rates, levels of emissions, and distribution of income among countries. Other important studies provide support to decision-makers by implementing methodologies to choose the 'best' policy scenarios on the basis of different criteria.

How to reach a consensus over desirable emissions reduction policies? Recent modelling papers focus on identifying modalities that can induce a positive outcome in international negotiations to tackle global warming. For example, policies oriented at reaching an equal division of responsibility in generating emissions or an equal distribution of benefits may facilitate a widespread consensus towards global agreements. Interesting contributions investigate the level of emissions per capita and the distribution of avoided climate change damages that could derive from different future scenarios of international environmental constraints.

How should emissions reduction policies be implemented? Modellers examine when to abate emissions (timing of abatement) and where to abate (which countries should bear the highest percentage of emissions reduction burden?) on the basis of economic considerations.

Does technological development enhance a green growth path? Many economists focus on indentifying the most promising technology options that can be useful to abate the level of emissions by preserving

growth rate. Studies examine opportunities provided by technologies such as carbon capture and storage activities, transition to fossil-free sources of energy and energy savings.

How can the vulnerability of developing countries to climate change damage be decreased? Researchers use IAMs to examine which countries are most vulnerable to climate change and the most appropriate adaptation policies that can preserve developing countries' growth.

Can agriculture provide a contribution to tackle global warming? Land use was already mentioned in the Kyoto Protocol as a policy option to reduce emissions. However, the research frontier has only recently begun to understand the contribution the agriculture sector can make to reduce global emissions; this, as well as the most efficient and effective policies that can induce farmers, especially in developing countries, to revise management and production methods.

IAMs are suitable to examine in-depth the effects of specific policy measures. Each model tends to describe a specific set of transmission channels. For this reason, results from comparison of IAMs is crucial for policy-makers to gain the most reliable insights. Though they are often very different, they well describe economic and environmental mechanisms but no model can capture the whole complexity of reality. A comparison is necessary to provide a wide and exhaustive overview of the best policies for global warming.

Advantages and disadvantages of using IAMs to address climate change policy issues

Compared to other less sophisticated complex scientific tools, IAMs offer a number of benefits when designing policy:

1. They allow the setting up of simulations based on scenarios for the future;
2. They incorporate mechanisms governing the complex link between economy and environment;
3. They can deal with uncertainty about the future evolution of economic and environmental parameters (e.g. technology, degree of absorption of pollution from the atmosphere);
4. They can be used to isolate the effects of a particular parameter on other mechanisms governing economic and environmental processes (e.g. the effect of China's population growth on the rest of the world economy);
5. They provide a large amount of information about the path of significant policy variables over time.

On the other hand, IAMs are also associated with possible disadvantages:

1. They do not provide forecasts, but only simulations and as such can only provide 'hypothetical data' based on model assumptions and calibration;

2. They sometimes offer contrasting results depending on different assumptions about transmission channels from policies to relevant variables and on data;

3. The implementation of IAMs and their use can be time-consuming for practitioners, and research centres therefore tend to use their own models and do not attempt to compare different results from other models;

4. IAM codes are not always available for the scientific community and results may at times appear quite cryptic;

5. There is a trade-off between complexity of models and comprehension of results. Very detailed models incorporating a wide set of transmission channels can appear unfit to answer specific research questions because of being highly complex.

In other words, IAMs represent powerful tools to explain how economic activity can affect environment but setting up a model or adopting a new model to answer research questions can be time-consuming.

The pay-off is the availability of more sophisticated tools to evaluate the effect of specific policies as well as the future evolution of 'exogenous' variables not controlled by the policy-maker on growth and environment.

Using IAMs in policy design: models and scenarios

To understand the potential of IAMs in shaping policy we will focus on the role that developing countries could play in policies to stabilise emissions to tackle global warming. The forthcoming Copenhagen Conference at the end of 2009 will be crucial for the design of future post-Kyoto agreements. The main difficulty concerning the negotiations for mitigation policies regards the role that developing countries will play over time. On the one hand, industrialised countries argue that the involvement of developing countries is a necessary pre-condition for the implementation of effective global environmental policies. On the other, developing countries are reluctant to accept constraints to the levels of emissions production, as they could force them to reduce growth rates in order to accomplish environmental policies.

These opposing views lead to some complicated political scenarios. The Bush Administration refused to sign the Kyoto Protocol and rather focused its attention on regional agreements such as the Asia-Pacific Partnership Programme aimed at reducing emissions' intensity and creating opportunities for environmen-

tally friendly technological improvements instead. Countries such as India refuse to join global emissions agreements and have not yet finalised their policies for the Copenhagen negotiations. Meanwhile, the current Obama Administration appears more open to involvement of the US in mitigation policies.

IAMs are useful tools that allow us to answer two crucial questions arising from the current debate about international global warming policies:

• How can international policies be most effective if developing countries are not involved in emissions stabilising policies?

• What would be the consequences for global and developing country welfare if developing countries were also subject to emissions stabilising policies?

Cantore and Canavari (forthcoming) recently provided answers to these questions with a paper containing results from simulations in the projected timescale 1995-2085 using the policy optimisation model RICE99 (Nordhaus and Boyer, 1999). Given the huge uncertainty about the evolution of relevant variables and design of future policy agreements, the paper assumes four hypothetical scenarios. These are:

• 'Business as usual' (BAU) in which no country implements new policies.

• 'Kyoto forever' in which Annex I regions are committed to a 'Kyoto forever' constraint with the possibility to exchange emissions permits in a pollution permits market as a flexible mechanism to reduce compliance costs. If we consider the current policy debate the 'Kyoto forever' scenario may be unrealistic because the US refused to sign the Kyoto Protocol. However, this scenario is useful to understanding what the consequences of climate change agreements could be if all ratifying Annex I countries were involved and committed to maintaining the same level of emissions over time.

• 'Global Kyoto' where, beyond the assumptions concerning Annex I countries in the 'Kyoto forever' scenario, developing regions (which includes poor and middle-income countries) are obliged to maintain their level of emissions at 2015 levels. In this case there is a global emissions permits market in which all world countries can freely exchange permits to reduce policy compliance costs.

• 'Global Kyoto 2' where developing regions are obliged to maintain 80% of the previous period BAU emissions from 2025. A market of pollution will also be implemented for all countries. 'Global Kyoto' therefore is a tight emissions constraint for developing countries as they are obliged to

stabilise emissions over time at 2015 levels. 'Global Kyoto 2' represents a 'soft' emissions constraint. Developing countries in 'Global Kyoto 2' are supposed to produce an increasing emissions path as according to the model, a 20% proportional reduction in each period does not stabilise their level of emissions over time.

Cantore and Canavari calculate the path of world Gross Domestic Product (GDP) per capita – the emissions per capita relationship over time. Moreover they use appropriate indices to evaluate the world welfare impact in each scenario.

Using IAMs in policy design: results

Results from this exercise can be summarised as follows:

First, the 'BAU', 'Kyoto forever' and 'Global Kyoto 2' scenarios do not show a turning point in the relationship between per capita GDP and emissions. This is consistent with many earlier empirical studies that cannot confirm the existence of the Environmental Kuznets Curve (EKC) generating a bell-shaped income-pollution path for global pollutants. The only scenario that provides evidence of a turning point is 'Global Kyoto', where all countries are committed to stabilise emissions at a fixed level.

Second, by using global welfare indices, the authors find the scenarios showing the lowest welfare levels are those that involve developing countries ('Global Kyoto' and 'Global Kyoto 2'), in particular 'Global Kyoto' with the tightest emissions constraint for poor and middle-income countries.

This is explained by the fact that the IAM assumes a growing path of GDP for developing countries. The assumption is that the commitment to cut emissions induces developing regions to reduce the consumption of carbon sources of energy and, consequently, their output levels.

Third, welfare measure results are different when they incorporate equality issues. The authors use different measures of welfare to examine the distributional consequences of each scenario. One index is based on the discounted sum of world consumption per capita. It captures the idea that global welfare increases (decreases) as world consumption per capita increases (decreases). Other indices include equality concerns from different strands of welfare economics research (Atkinson, 1970; Sen, 1974). These are based on the idea that world welfare increases (decreases) when both world consumption per capita and equality in the distribution of consumption increase (decreases).

These indices are useful to manage trade-offs, if policy-makers face scenarios that are not 'win-win'

because they do not include improvements for economic and equality targets.

When considering indices that include equality issues, Cantore and Canavari find the 'Global Kyoto' and 'Global Kyoto 2' assuming binding emissions constraints for developing countries are the worst. This is because these scenarios decrease world consumption per capita and equality in the distribution of consumption, as developing countries are heavily penalised by assumed mitigation policies.

An interesting result is that when welfare indices excluding equity are considered, 'BAU' is the best scenario. This is because no country suffers a loss of consumption per capita. But when dealing with welfare measures which incorporate equality issues, 'Kyoto forever' is the best. This is because the loss of consumption of developed countries from their environmental commitment is more than compensated for by the welfare gains from a more egalitarian distribution of consumption per capita. Table 2 summarises the results.

How should the results from these modelling exercises be interpreted?

Results should be considered not as forecasts but as specific storylines. They suggest that in a world where carbon energy reduction is the main policy option to reduce emissions, developing countries would suffer the highest growth reductions by mitigation policies. They are of course dependent on model assumptions. In a world where transboundary technological spillovers are widespread and the substitution of carbon for carbon-free sources of energy is inexpensive, the consequences of mitigation policies for developing countries could be less costly.

Each paper in the literature uses a single model for policy analyses and gives valuable insights into the effects of actions to tackle global warming. But a comparison of models would provide more in-depth analysis of the consequences for developing countries of global environmental policies based on different storylines.

The paper by Cantore and Canavari outlines the potential loss for developing countries participating in emissions stabilising policies if optimistic hypotheses are unrealistic. Uncertainty about the future evolution of crucial parameters and variables, the identification of the causal relationships amongst these, and the evolution of the political international scenario, are all obstacles for analysts attempting to provide sound policy messages.

This implies that it is important to use a wide comparison of IAMs, an interdisciplinary research approach, and a mixed set of research methodologies to examine the consequences of climate change and the policies to tackle market failures from global warming.

Table 2: Impact of different scenarios about future climate change policy agreements according to the RICE99 IAM. Synthesis of the quantitative results from simulations, 1995–2085.

	BAU	KYOTO FOREVER	GLOBAL KYOTO	GLOBAL KYOTO 2
Scenario description	'Business as usual' ('BAU').	'Kyoto forever' emissions constraint for Annex I countries. Emissions permits market among Annex I regions.	'Kyoto forever ' emissions constraint for Annex I countries. Developing regions (poor and middle-income countries) are obliged to maintain the level of emissions as in 2015. Global emissions permits market.	'Kyoto forever' emissions constraint for Annex I countries. Since 2025 developing regions (poor and middle-income countries) are obliged to maintain 80% of the previous period BAU emissions. Global emissions permits market.
Consequences for Annex I countries	Benchmark level of consumption per capita.	The 'Kyoto forever' emissions reduction commitment reduces carbon sources of energy consumption and output levels.	The 'Kyoto forever' emissions reduction commitment reduces carbon sources of energy consumption and output levels.	The 'Kyoto forever' emissions reduction commitment reduces carbon sources of energy consumption and output levels.
Consequences for non Annex I countries	Benchmark level of consumption per capita.	Benchmark level of consumption per capita.	The 'strong' emissions constraint for developing countries reduces their carbon sources of energy and consumption per capita.	The 'soft' emissions constraint for developing countries reduces their carbon sources of energy and consumption per capita.
World GDP per capita – emissions per capita path	Benchmark U-shaped path.	Reduction of world GDP per capita and emission per capita but U-shaped path.	Decreasing path in the pollution-income relationship.	Reduction of world GDP per capita and emission per capita but U-shaped path.
World welfare indices ranking (1 = best to 4 = worst)	**1** when equality issues are not incorporated; **2** when equality issues are incorporated.	**2** when equality issues are not incorporated, **1** when equality issues are incorporated.	**4** according to all welfare indices.	**3** according to all welfare indices.

Source: Canavari and Cantore (in press)

Conclusions

By the description of a simple scenario analysis through the RICE99 model we have explained the potential of IAMs for research analyses oriented towards policy issues. IAMs cannot address all questions at the same time. Each IAM emphasises specific transmission channels by which environmental policies impact on the economy. It is therefore important to contextualise results. This is within a framework of modelling assumptions that condition results; data used to calibrate models; other results in the IAM literature; and the findings from other disciplines and research methodologies.

IAMs are precious evaluation tools to understand how developing countries may tackle climate. They use a multi-dimensional set of economic, environmental and inequality criteria. They may inform decision-makers about the future path of relevant variables, and help our understanding of the transmission channels linking climate change policies to emissions and growth.

IAMs give insights that no other research tool can provide. They are interdisciplinary and highlight specific relationships between variables that are relevant

for policy. However, decision-makers and analysts should treat results with caution and place them in a wider context of climate change economics literature.

The paper we summarise gives just one example of the role IAMs could play to select the most suitable climate change policies for developing countries. It points out that the participation of developing countries in global emissions stabilising policies through a binding commitment is essential to curb the level of global emissions. However results coming from a model that does not incorporate optimistic assumptions about a rapid and cheap transition towards renewable sources of energy, technology diffusion and mitigation costs suggest that welfare consequences for the poorest regions would be dramatic. IAMs are currently under-exploited as a tool to inform decisions. The recent declaration of the Chinese leader Hu Jintao about China's possible commitment to reduce emissions is the most immediate opportunity for modellers to investigate, using IAMs, the impact of a wider coalition of countries signing up to international environmental agreements on the economy of poor regions.

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References

Agrawala S., Raksakulthai, V., Aalst, M.V., Larsen, P., Smith, J. and Reynolds, J. (2003) *Develpoment and Climate Change in Nepal: Focus on Water Resources and Hydropower*. Paris: OECD.

Alcamo, J. (ed.) (1994) *IMAGE 2.0: Integrated modeling of global change*. Dordrecht: Kluwer Academic Publishers.

Atkinson, A. (1970) 'On the measurement of inequality', *Journal of Economic Theory*, 2: 244-63.

Cantore, N. and Canavari, M. (forthcoming) 'Reconsidering the Environmental Kuznets Curve Hypothesis: the trade off between environment and welfare', forthcoming in A. Montini and M. Mazzanti (eds), *Environmental efficiency, innovation and economic performance*. Routledge.

Fishbone, L.G. and Abilock, H. (1981) 'MARKAL, a linear-programming model for energy system analysis: Technical description of the BNL version', *Int Journal of Energy Research* 5 (4): 353-75.

Holtz-Eakin, D. and Selden T. (1995) 'Stoking the fires? CO2 emissions and economic growth', *Journal of Public Economics* 57: 85-101.

Kolstad, C. (1998) 'Integrated Assessment Modelling of climate change', in W. Nordhaus (ed.), *Economics and Policy issues in climate change, Resources for the future*. Washington, DC: RFF Press.

Nordhaus, W. (1994) *Managing the global commons: the economics of climate change*. Cambridge, MA: MIT Press.

Nordhaus, W. and Boyer, J. (1999) *Rolling the DICE again: economic models of global warming*. Cambridge, MA: MIT Press.

Parson, E. (1994) 'Searching for integrated assessment: a preliminary investigation of methods and projects in the integrated assessment of global climatic change'. Paper presented at the 3rd Meeting of the CIESIN Harvard Commission on Global Environmental Change Information Policy, NASA Headquarters, 17-18 February, Washington, DC.

Sen, A. (1974) 'Information Bases of Alternative Welfare Approaches: Aggregation and Income Distribution', *Journal of Public Economics* 3: 387-403.

Stern, N. (2007) *Stern Review on The Economics of Climate Change*. London: HM Treasury (www.hm-treasury.gov.uk/sternreview_index.htm).

Tol, R. (2002) 'Integrated assessment modelling' (www.fnu.zmaw.de/fileadmin/fnu-files/publication/working-papers/efieaiamwp.pdf).

Weyant, J. P., Davidson, O., Dowlatabadi, H., Edmonds, J. A., Grubb, M. J., Parson, E. A., Richels, R. G., Rotmans, J., Shukla, P. R., Tol, R. S. J., Cline, W. R., and Fankhauser, S. (1996) 'Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results, in Climate Change 1995: Economic and Social Dimensions – Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change', J. P. Bruce, H. Lee, and E. F. Haites (eds). Cambridge: Cambridge University Press.

WCED (1987) *Our common future*. New York: Oxford University Press and United Nations.

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