The status of integrated assessment in climatic policy making
An overview of inconsistencies underlying response functions

Pierre Courtois*

Abstract
What climatic lessons can be derived from cost and benefit integrated assessment models? This paper presents state of the art methods to assess climate change impacts and build corresponding response functions. These last constitute one of the keystone of cost and benefit integrated assessment approaches to climate change. It focuses on the many shortcomings and inconsistencies underlying these functions and highlights how they can act as an invisible hand driving modelling results. The paper deduces lessons over the status of cost and benefit integrated assessment models to guide decision makers on climatic policy design, and closes on some relevant methodological insights over the treatment of these issues.

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1. Introduction
As defined by the Intergovernmental Panel on Climate Change, integrated assessment models (IAMs) are “convenient frameworks for combining knowledge from a wide range of disciplines in order to conduct co-ordinated exploration of possible future trajectories of human and natural systems, development of insights into key questions of policy formation, and prioritisation of research needs in order to enhance our ability to identify robust policy options” (IPCC, 1996). The IPCC team adds that “Assessment is distinguished from disciplinary research by its purpose: to inform policy and decision making, rather than advance knowledge for its intrinsic value”. This paper argues that while IAMs can be a valuable aid to decision making as an heuristic tool, some unresolved methodological limits should prevent their use from portraying reality.

IAMs can provide policy makers with a useful framework to think about the issues involved in climate change. In particular, it can highlight courses of actions and pros and cons of when and where to abate emissions. On the other hand, given the current state of the art, its utilisation becomes problematic when used to legitimise emission abatement targets or to fix specific timing of actions. Yet, despite an increasing awareness of the sea of uncertainties characterising the issue (e.g. Carter et al., 1994; Rotmans and Dowlatabadi, 1998; Mahlman, 1997; Jaeger et al., 1998; Myles et al., 2000; Katz, 2001), a few scientists act sometimes as if IAMs could picture reality. This holds particularly for macroeconomics-oriented IAMs, which focus specifically on economic aspects of the issue. One striking example is supplied by a letter submitted by Robert Mendelsohn, a recognised expert working on monetary impact assessment, to Senator McCain (Mendelsohn, 2000). This letter quotes materials published in 1999 which claim that in the next century, the United States will likely enjoy benefits of between US$ 14 and 23 billion a year and damages in the neighbourhood of $13 billion if warming reaches 5°C. Far from guiding policy makers, I believe that claiming to portray reality on the basis of the current state of the art IAMs can only earn discredit of the scientific community.

This paper focuses on some inconsistencies related to macroeconomics-oriented IAMs. In particular, I scrutinise limits related to the representation of impacts of climate change, their assessments and functional forms. I bring up successively drawbacks inherent to the formal representation of monetary impacts and show that IAMs are no truth machines but heuristic tools characterised by unavoidable caveats.

The remainder is organised as follows. In Section 2, I present cost and benefit IAMs and the role played by impacts in these modelling frameworks. In Section 3, I focus on methods to build response functions. I define what is an
impact and discuss generic functional forms. In the following section, I derive a range of inconsistencies which justify that IAM as a policy design tool, face credibility problems within the scientific and policy communities, and draw conclusions in Section 6.

2. Representing climate change impacts in IAMs

Most macroeconomics-oriented IAMs are neoclassical models based on an equilibrium framework, using traditional economic concepts regarding optimisation and capital accumulation. These models represent relatively simple parameterised formulations of complex problems. They commonly try to optimise key policy variables such as carbon emission control rates and carbon taxes, given certain policy goals.

IAMs architecture is rather simple. Countries are considered as optimising their economic welfare given that to emit greenhouse gases allows to produce GDP but involves impacts due to geophysics transformations. A first range of equations represents the economics sphere while a second range represents geophysics. In order to better understand the dual role played by impacts in IAMs, a simplified version of the RICE model developed by Nordhaus and Boyer (2000) is presented in Fig. 1.

Let us describe briefly this simplified presentation of RICE. Each region maximises his welfare, \( W \), which is assumed to be the sum of his discounted utilities, \( U \). The discount rate, \( \rho \), is assumed uniform in all regions and decreases over time. Utility is exclusively driven by the consumption, \( C \). In other words, the environment is not considered as a source of amenity but only as a mean to produce and thereof, to consume. As in any classical growth model, optimal consumption path is derived, requiring relation (7) to be fulfilled. The net output, \( Q \), is balanced by the sum of the consumption and the investment, \( I \), and the production function, \( f \), is a Cobb-Douglas with the labour, \( L \), the capital, \( K \), and the carbon-energy, ES, as production factors. Dynamics of capital accumulation is described in relation (8). Investment is assumed to devalue over time and world economies are supposed to converge in the long run.

Note that the main difference between this economic module and a traditional growth model relies in the consideration of GHG emission both as a production factor and as an environmental impact, imp.\(^2\) The carbon-energy factor corresponds to the energy intensity produced by GHG emissions,\(^1\)

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\(^1\) Note that considering the environment in the production function is a specificity of the RICE model.

\(^2\) Impact expresses the monetary variation of populations welfare due to climate change retroactions on natural systems and human activities.
To use carbon-energy involves however a cost, denoted \( \Delta E \). This cost relies on the extraction cost of industrial emissions, \( q \), and on a regional service mark up, \( mkp \), which includes the distributional cost of the energy tax. Environmental impacts are also taken into account. Their monetary amount is the difference between the net and the gross output, \( Y \). This difference depends on the specification of the response function and is described in relation (3). As in most IAMs, this function, represented by relation (4), is assumed to be a first or second order polynomial of the temperature, \( T \). Impact parameters, \( \theta_1 \), \( \theta_2 \), determine therefore whether climate change begets a benefit or a damage.

Temperature change is driven by geophysics transformations. The geophysical module is made of three groups of equations describing the causal chain: emission-concentration-global change. The first group of equations captures the relationship between emission volumes and gas accumulation in the atmosphere, \( \text{Cum}C \). Accumulation dynamics of GHG concentration represented by relation (9), depends on the emission level which varies according to the regional specifications of the carbon-energy supply (relation 10). This supply is defined as a function of both, the GHG stock in the atmosphere, the level, \( \text{Cum}C \), from which carbon-energy extraction has decreasing return to scale, and the \( \xi \) parameters qualifying industrial emission technologies. The second group of equations defines the carbon cycle. Although very simplified in the specification provided here, relations (11) and (12) represent respectively the dynamics of carbon absorption by the atmosphere, the biosphere and the oceanic tanks and, the process which alters the energy balance of the earth-atmosphere system known as radiative forcing. Finally, the third group links GHG concentration and temperature and is embedded here in relation 13.3

It is straightforward to deduce that response functions pinpoint the outcomes of the model. According to the functional form chosen and its calibration based on impact assessments, IAMs recommendations can range over opposite policy advices. I present in the next section methods followed to build these functions.

3. Response function: two steps

Response to climate change is region specific, it varies over time (i.e. the monetary impact of a 1 °C temperature change is not the same in 2010 and in 2100) and it is not monotonic (i.e. impacts can be positive up to a certain temperature rise to become negative afterward; there are temperature thresholds after which natural catastrophes occur) (IPCC, 1996, 2001).

Representing impacts in IAMs should consist in encompassing the three categories of alterations drawn in Table 1. Unfortunately, as shown in the following, only the two first categories of alterations are considered and moreover, not exhaustively neither accurately.

To build response functions, we follow a two step analysis. Each step is characterised by approximations which are due to complexities and uncertainties related to the problem at stake. The first step consists of evaluating monetary impacts of discrete variations of the temperature on physical sectors threatened by climate change (e.g. agriculture, forest, health, sea level rise, water, etc.). The idea is to evaluate as many discrete couple (monetary impact, \( \Delta T \) temperature) as possible for extrapolating a response function. Unfortunately, few of these evaluations are made available due to the little information promoted by geophysicists who claim that knowledge is not sufficient to estimate rigorously physical impacts associated to temperatures rises. Therefore, we concentrate mostly on impacts that would result from a doubling of the \( \text{CO}_2 \) concentration in the atmosphere (i.e. which corresponds on average to an expected 2.5 °C temperature rise in 2060).

The physical impact associated to each sector concerned is then translated into a monetary impact. Methods used for this monetary valuation differ from one sector to another. It is, however, always based on assumptions one could qualify of being sometimes hazardous. For instance, monetary impact on ecosystem is often derived from a proportionality law between ecosystem protection and GDP. It is alternatively evaluated by assigning a willingness to pay for preservation of vulnerable systems. Similarly, sea level rise is at best evaluated as a sum of costs incurred by coastal protection, losses of humid and dry lands and population migration (Tol, 2002a,b). Since future coastal protection is undetermined, protection level is derived from a cost benefit valuation of protection cost considering damages caused by sea level rise in a business as usual scenario. Costs of land losses are calculated for a one meter sea level rise. Damages are evaluated on an average basis, and are multiplied by an estimation of the coast surface. Other studies such as Nordhaus (1999) derive from literature reviews, a coastal protection value according to an index of regions vulnerability. In all cases, one can doubt on the accuracy of the sectorial impact price incurred by a given temperature variation at a given moment in the future. This statement is confirmed by the gap between monetary impact assessments of discrete variations of the temperature in the three studies available in the literature (cf. Table 2).

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1 I do not explain exhaustively the carbon module for readability purpose. The aim of this paper is indeed to focus on inconsistencies related to the economic module. Further details on geophysics module are available in Nordhaus and Boyer (2000).

2 Note that both the proportionality law and willingness to pay methods are based on contingent theory.
Table 1
A typology of impacts

<table>
<thead>
<tr>
<th>Allocations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Natural capital</td>
<td>The product of economic activities derived from agriculture, sylviculture, water resources, tourism or human health is directly dependent on the environmental quality which is used as a natural capital. In particular, temperature rise would modify production geography with dramatic consequences for vulnerable zones, abundance of water would be threatened for several regions, tourism geography would be modified and human health consequences would involve mortality increases and region disaffection.</td>
</tr>
<tr>
<td>(2) Productive capital</td>
<td>Climate change threatens infrastructures and human settlements and affects economic productivity. Storms, hurricanes, floods and other natural risks could oblige increase both equipment robustness, frequency of infrastructure renewal and even lead to obsolescence of human settlements.</td>
</tr>
<tr>
<td>(3) Amenities</td>
<td>Beside environmental impacts on the economic apparel, climate change alters the environment which is also to be considered as carrying amenities. Among satisfactions given by the environment one can distinguish hedonist preoccupation (i.e. well being from practicing leisure in a protected environment) and existence values (i.e. biodiversity loss, bequest value, patrimonial value, etc.)</td>
</tr>
</tbody>
</table>

The accuracy of the second step of the analysis is also questionable. It consists of extrapolating response functions on the basis of discrete impact valuations. The goal of these functions is to provide with the sectorial monetary impact of any temperature variation occurring at any time. The two studies which propose sectorial monetary response functions based on regional valuations, i.e. Nordhaus (1999) and Tol (2002a,b), extrapolate it on the basis of a unique calibration point. For that reason, functional forms presented are either simple non linear functions of the form \( \text{imp}_{i,s,t} = \alpha_i s T_{n_i} t \) or second order polynomial functions of the form \( \text{imp}_{i,s,t} = \alpha_i s T_{n_i} t^2 \), with imp the monetary impact (% of GDP), \( T \) the temperature variation, \( \alpha, \beta, n \) parameters, and indexes \( s, i \) and \( t \) denoting respectively sectors, regions, and time periods. In the first case, the extrapolation is straightforward. The second case is more problematic since extrapolation of a second order polynomial necessitates two calibration points. However, this last functional form is far more attractive for several sectors such as agriculture or tourism which in some areas should benefit from higher temperature in the first periods (i.e. second order polynomial allows to represent impacts which are first positive to then become negative). To extrapolate such functional form, two methods were introduced. The first method implemented by Tol (2002a,b) is to consider a second order polynomial form for agriculture only. For that specific sector, a second calibration functional form is employed where \( \text{imp}_{i,s,t} = \alpha_i s T_{n_i} t^2 \), with imp the monetary impact (% of GDP), \( T \) the temperature variation, \( \alpha, \beta, n \) parameters, and indexes \( s, i \) and \( t \) denoting respectively sectors, regions, and time periods. In the first case, the extrapolation is straightforward. The second case is more problematic since extrapolation of a second order polynomial necessitates two calibration points. However, this last functional form is far more attractive for several sectors such as agriculture or tourism which in some areas should benefit from higher temperature in the first periods (i.e. second order polynomial allows to represent impacts which are first positive to then become negative). To extrapolate such functional form, two methods were introduced. The first method implemented by Tol (2002a,b) is to consider a second order polynomial form for agriculture only. For that specific sector, a second calibration

Table 2
Regional estimates of climate change impacts (% of regional GDP)

<table>
<thead>
<tr>
<th>Region</th>
<th>+1.5°C</th>
<th>+2°C</th>
<th>+2.5°C</th>
<th>+2.5°C</th>
<th>+1°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>0.3</td>
<td>0.3</td>
<td>-0.5</td>
<td>3.4 [1.2]</td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>0.4</td>
<td>0.5</td>
<td>-2.8</td>
<td>3.7 [2.2]</td>
<td></td>
</tr>
<tr>
<td>OECD Europe</td>
<td>-0.1</td>
<td>-0.5</td>
<td>-0.1</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>EU</td>
<td>1.1</td>
<td>11.1</td>
<td>-0.7</td>
<td>2.0 [1.8]</td>
<td></td>
</tr>
<tr>
<td>OECD Pacific</td>
<td>-2.0</td>
<td>1.1</td>
<td>-0.7</td>
<td>2.0 [1.8]</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>-1.3</td>
<td>-1.4</td>
<td>-0.1</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Eastern Europe/FSU</td>
<td>-0.8</td>
<td>-1.7</td>
<td>-4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern Europe, Russia</td>
<td>0.4</td>
<td>0.1</td>
<td>1.8</td>
<td>-0.2</td>
<td>2.1 [5.0]</td>
</tr>
<tr>
<td>Middle East</td>
<td>-4.7</td>
<td>-3.9</td>
<td>-4.1 [2.2]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latin America</td>
<td>0.12</td>
<td>0.03</td>
<td>-0.8</td>
<td>-0.17</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>0.09</td>
<td>0.1</td>
<td>-0.3</td>
<td>-1.5</td>
<td>2.3 [1.0]</td>
</tr>
<tr>
<td>South, South East Asia</td>
<td>-0.8</td>
<td>-2.0</td>
<td>-4.9</td>
<td>-1.7</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>0.05</td>
<td>0.1</td>
<td>0.03</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>0.09</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Negative figures (respectively positive) are loss (respectively gains); figures in brackets are standard deviations.

1 Mendelsohn et al. (2000).
2 Mendelsohn and Neumann (1999).
3 Nordhaus (1999).
4 Tol (2002b).
point can be derived from studies which evaluate for each region the optimal temperature allowing for the highest agriculture productivity, i.e. Darwin et al. (1995), Reilly et al. (1994), Rosenzweig and Parry (1994). Such temperature corresponds to the maximum of the second order polynomial function giving therefore a second calibration point to perform the extrapolation. Other sectors considered are represented with simple functional form which can be extrapolated on a unique calibration point without any loss of generality. The second method implemented by Nordhaus (1999) allows to consider second order polynomial for each of the sector considered. It consists of evaluating current expenses related to each sector affected by temperature changes in a range of regions of the world (e.g. health or water expenses in the United States, Europe, Eastern Europe, etc.). To each regions corresponds an average temperature. The computation of a weighted average by population and GDP allows to deduce a functional form associating temperature and sectorial impact. The calibration point evaluated in the first step is then sufficient for the response function to be extrapolated.

Finally, the timing of climate change is to be taken into account, i.e. an average 2°C temperature rise does not involve the same monetary impact in 2010 and in 2100 due to income growth and technological change. To perform so, the idea is to make sectorial response function dynamical by multiplying it by \( (Y_{i,t}/Y_{i,0})^{\eta_i} \), with \( Y \) denoting regional incomes, \( \eta \) denoting income elasticity and indices \( i, t, b \), de-noting regions, time period, and time baseline, respectively.

4. Theoretical inconsistencies

Five main theoretical inconsistencies characterise the manner we deal with impacts. The first two were mentioned above. They are related to the method followed to build response functions. The last three are inherent to the manner impacts are conceived. In particular, they regards the shape of the response functions, the exhaustiveness of the impacts considered and their modes of implementation into models.

First, monetary translation of physical impacts is based on dubious assumptions: Prices are indeed to be associated with ecosystem degradations, sea level rise, or health diseases, which by nature cannot be monetised accurately.

Second, physical impact valuation is so complex and uncertain that geophysics does not provide extensive analysis. Solely the physical impact of a doubling of CO2 concentration is evaluated. It follows that the monetary impacts valuation of discrete temperature rise is only evaluated for that value which corresponds to a 2.5 °C temperature rise. Therefore, extrapolation of response functions is to be based on a unique calibration point making it highly uncertain.

Third, functional forms used cannot claim to represent impact satisfactorily. Climate analysts highlight that a given variation of CO2 concentration in the atmosphere leads region specific temperature rise. Unfortunately, this distribution of the temperature change is still rather unknown. Impact valuations are therefore based on an average temperature variation. Moreover, as highlighted by Parry et al. (1996), rhythm of climate change is of prime importance. There exists, a priori, temperature rise thresholds beyond which, frequency of climatic events would increase dramatically. Hence, besides technical considerations, one can question the accuracy of using simple non linear or second order polynomial form. In this respect, Garry Yohe at the publication of the American science academies report on climate change non linearity (National Academies, 2002) declared: “my biggest fear is that international policy is being made based on smooth climate change”. However, Peck and Teskeberg (1993) had already highlighted that climate policies were more sensitive to uncertainties on functional form of response functions than on the level of impact for a given temperature rise. As shown by Hourcade and Chapuis (1995), given response function forms and costs of carbon free technologies assumed, these model can only recommend low emission abatement in the first periods. To illustrate the idea of these authors, it suffices to understand that it is always advisable to postpone emission reduction as long as the growth rate of marginal damage is lower than the product of discount rate by the rate of decrease of the marginal cost.

Next, impacts represented are not exhaustive since amenities are mostly omitted (cf. Table 1). As in many macroeconomics studies, welfare is assumed to be related only to consumption. Emission is considered as a production factor. It follows that as long as the payoff derived from pollution is higher than its associated damage, countries should keep polluting. Considering amenities would involve assuming low climate change as an argument of the welfare function. In this respect, Tol (1994) estimated that considering the climate change degradations in the welfare function could involve a doubling of the mitigating efforts in the short run (up to 2020) and a tripling in the long run (up to 2100).

Finally, impacts implemented as such, propagation on socio-economic systems is not considered. As highlighted by Funkhauser (1994), this enumerative approach of climate change impacts only takes into account of direct impacts. This inconsistency finds an explanation in the way IAMs are built. They are partial equilibrium models. A general equilibrium model would allow to take into account retroactions on production volume, on prices, on investment levels, on implications of these direct impact on behaviours and on production processes. In other words, a general equilibrium model would allow to take indirect costs of climate change.

5. Conclusion

Different impact assessments and associated response functions can lead to profoundly different policy
recommendations. Taking estimations of monetary impacts of discrete temperature rises from Mendelsohn et al. (2000) or Nordhaus (1999) would lead to contradictory interpretations of climate change (cf. Table 2). While the first would call for relativism since climate change would be mostly beneficial, the second would give a darker picture of a warmer future. Likewise, the extrapolation method and particularly the shape of the response function chosen can drive IAMs to opposite recommendations. For instance, the profile of impacts under a cubic response function would imply low near term impacts which rapidly increase in the future, while a linear form would imply a smooth climate change. In other words, emissions under a cubic response function would cause less damage over the atmospheric lifetime compared with linear responses.

This paper highlights that both the evaluation of monetary impacts of discrete temperature rise and the extrapolation method to derive response functions are highly speculative. Gaps among impact estimates and among impact profiles are the results of estimation methods and assumptions that can often be questioned. In other words, uncertainties and methodological limitations pervade all levels of a climate impact assessment and one should be aware that IAMs based on response functions are no truth machines but heuristic tools characterised by unresolved and sometimes unavoidable caveats. This tends to discredit the ability of current cost and benefit IAMs to legitimise emission abatement targets or prices incurred by a given policy strategy. On the other hand, they can provide insights on signs, orders of magnitude, or patterns of alterations. They can also highlight the pros and cons of when and where to abate emissions or help to conceive and compare courses of actions, modes of adaptations, of regulation and so on. IAMs have therefore a lot to say on an heuristic ground.

Given the limitations underlying cost and benefit IAMs, characterisation and analysis of uncertainty should be the central focus of the assessment. Indeed, without thorough and systematic modelling and analysis of uncertainty, significance of results should be questioned. However, although climate experts acknowledge the uncertainty in the global climate system, IAMs are still predominantly deterministic in their orientation. Explicit treatment of uncertainty in each model component and stochastic analysis is therefore needed to keep pace with the growing complexity of IAMs dealing with climate change.

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Appendix A

List of variables and parameters.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_{i,t} )</td>
<td>Welfare</td>
<td>( \rho_t )</td>
<td>Discount rate</td>
</tr>
<tr>
<td>( U_{i,t} )</td>
<td>Utility</td>
<td>( \theta_{1,j} )</td>
<td>Response function parameter</td>
</tr>
<tr>
<td>( C_{i,t} )</td>
<td>Consumption</td>
<td>( \theta_{2,j} )</td>
<td>Response function parameter</td>
</tr>
<tr>
<td>( Y_{i,t} )</td>
<td>Gross output</td>
<td>( V_{i,t} )</td>
<td>Carbon-energy intensity parameter</td>
</tr>
<tr>
<td>( Q_{i,t} )</td>
<td>Net output</td>
<td>( M_{E} )</td>
<td>Energy service markup</td>
</tr>
<tr>
<td>( K_{i,t} )</td>
<td>Capital stock</td>
<td>( \delta )</td>
<td>Capital depreciation rate</td>
</tr>
<tr>
<td>( E_{E_{i,t}} )</td>
<td>Carbon-energy factor</td>
<td>( C_{E} )</td>
<td>Point of decreasing returns in carbon extraction</td>
</tr>
<tr>
<td>( E_{i,t} )</td>
<td>Cost of carbon-energy</td>
<td>( C_{E} )</td>
<td>Parameters of long run industrial emission supply curve</td>
</tr>
<tr>
<td>( E_{i,t} )</td>
<td>Industrial GHG emissions</td>
<td>( i_1, i_2, i_3 )</td>
<td>Investments</td>
</tr>
<tr>
<td>( \text{imp}_{i,t} )</td>
<td>Impacts of climate change</td>
<td>( i_4 )</td>
<td>Cost of extraction of industrial emissions</td>
</tr>
<tr>
<td>( T_{i,t} )</td>
<td>Atmospheric temperature</td>
<td>( C_{E} )</td>
<td>Cumulative carbon emissions</td>
</tr>
<tr>
<td>( C_{E} )</td>
<td>Upper ocean and biosphere GHG concentration</td>
<td>( M_{E} )</td>
<td>Atmospheric GHG concentration</td>
</tr>
<tr>
<td>( M_{E} )</td>
<td>Lower ocean and biosphere OHO concentration</td>
<td>( M_{E} )</td>
<td>Upper ocean and biosphere GHG concentration</td>
</tr>
<tr>
<td>( M_{E} )</td>
<td>Land use carbon emission</td>
<td>( F_{E} )</td>
<td>Radiative forcing</td>
</tr>
</tbody>
</table>

Indices \( i, t \) denote respectively regions and time period.
References


Pierre Courtois is a research scientist at the Centre for Organizations and Decisions in Economics, Universitat Autònoma de Barcelona. His research interests are related to the economics of global environmental changes. His works focus on applications of economic theory to policy making and include game theoretic and integrated assessment analyses of global environmental issues. He is currently involved in an OECD project aiming at incorporating multi-gas treatments in computable general equilibrium models.


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