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Viewpoint

Representing global climate change, adaptation and mitigation

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Abstract

The diagrammatic representation of climate change, adaptation and mitigation is important in conceptualizing the problem, identifying important feedbacks, and communicating between disciplines. The Synthesis Report of the IPCC's Third Assessment Report, 2001, uses a "cause and effect" approach developed in the integrated assessment literature. This viewpoint reviews this approach and suggests an alternative, based on stocks and flows. The alternative gives a much richer representation of the problem so that it includes the enhanced greenhouse effect, ancillary benefits of mitigation, the distinction between climate-change and other stresses on natural systems, and a more refined distinction between adaptation and mitigation.

Keywords: Integrated assessment; Climate change; Energy–environment–economy modelling; Driving force; Presssure; State; Impact; Response

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) has confirmed in its Third Assessment Report (Watson et al., 2001) that greenhouse gas emissions from human activity are threatening the stability of the global climate. Various governments and international bodies have initiated substantial research programmes to construct, develop and use coupled climate–ocean, climate change models in order to understand the extremely complex physical processes involved (e.g. the UK Hadley Centre's model). The same bodies have also, often independently, initiated research in the area of impacts of climate change on the natural environment involving complex geographical and ecosystems modelling. Finally, the driving forces leading to climate change have been also been investigated in other research programmes, involving integrated energy–environment–economy (E3) models, intended to help the formulation of equitable, efficient and effective policies to abate the greenhouse gas emissions (e.g. the European E3ME model http://www.camecon.co.uk/e3me/index.htm). In addition to these three separate areas of research, reported respectively in the three Working Groups of the IPCCs Third Assessment Report, many integrated assessment models have been developed, often with simplified versions of the large models (EEA, 2000; IPCC, 2001).

The *integration* of the knowledge embodied in these large-scale modelling programmes is a major problem in developing understanding of the adaptation to climate change and its mitigation. There are many important feedbacks in the whole system, some of which can have major effects on the costs of mitigation. For example, mitigation of greenhouse gases (GHGs), particularly CO_2, can often have favourable impacts by reducing emissions of other pollutants and by reducing other damaging side-effects, mainly because the burning of fossil fuels is lower. When the overall benefits and costs of climate policies are assessed, such benefits should be included, e.g. those from reduced local and regional air pollution, because under some circumstances they can be comparable in size to the direct costs of mitigation. As the main benefit of climate policies is to reduce climate change, these benefits are usually referred to in the literature as ancillary benefits (or secondary benefits).

It is important to represent these process and interactions in a diagram, to make understanding easier, to set them in context, to conceptualize the problem, to help identify gaps in knowledge, and to make communication between disciplines easier. The pressure–state–response (PSR) framework, adopted and developed by the OECD (1993) and the EEA (1998), among others, has been used by the IPCC (Watson et al., 2001) as a framework for the integrated assessment of climate

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change. This viewpoint reviews that framework, characterized as a ‘‘cause and effect’’ representation, and suggests an alternative ‘‘stock and flow’’ representation to emphasis the physical flows, accumulation of gases and effects, and complex interactions associated with climate change.

2. ‘‘Cause and effect’’ representation of global climate change

2.1. What is to be represented?

The integrated assessment framework is intended to represent climate change, its causes and effects, how the human and natural systems will adapt to climate change and how it might be mitigated. The issue is the effectiveness of the ‘‘cause and effect’’ versus the ‘‘stocks and flows’’ approaches to the representation of the system.

2.2. ‘‘Cause and effect’’ approach

The simple PSR framework was developed by the OECD (1993), based on an approach to organizing environmental statistics by Statistics Canada (Rapport and Friend, 1979) and has appeared in many publications of international organizations. A clear account of the framework is available in www.fao.org/lead/toolbox/Index.htm. The framework starts with the idea that human activities impose *pressures* (such as pollution or land use change) on the natural environment, which can induce changes in the *state* of the environment (such as, raised concentrations of atmospheric pollutants or reduced habitat diversity). These changes in state may then lead to a socio-economic response to mitigate or remove the original pressures and reduce the environmental damage or prevent further damage. The framework was further developed by the EEA (2000) to become the driving force–pressure–state–impact–response framework (DPSIR) so as to provide a more comprehensive approach to analyzing environmental problems. The framework, when applied to the climate change issue can be stated as follows.

(1) Driving forces, such as economic growth, produce
(2) Pressures on the environment, such as greenhouse gas and other emissions, which then change the
(3) State of the environment by inducing climate change, which then
(4) Impacts on the human and natural systems, causing society to
(5) Respond with various policy measures, such as regulations, information and taxes, which can be directed at any other part of the system.

This way of representing an integrated assessment framework can be called ‘‘cause and effect’’, because it is essentially a cycle describing a sequence of causes and effects, applicable to a wide range of environmental issues.

The framework adopted by the IPCC's Synthesis Report (2001, Figure SPM-1, p. 3) is shown in Fig. 1. The ovals and box in the four quadrants represent changes in four domains: starting with the box, there is the socio-economic system, then the atmosphere, then the climate, then human and natural systems. The arrows show the direction of causes from one domain to effects in another in a clockwise cycle; one reverse arrow is shown to represent the non-climate stresses, such as changes in land use leading to deforestation, on the natural system.

Fig. 1 shows the linkages between changes in human society and climate change as a set of ‘‘causes and effects’’ in a driver–pressure–state–response methodology. More formally, it provides a schematic and simplified representation of an integrated assessment framework for considering anthropogenic climate change. The figure shows changes in four *domains* in the quadrants, i.e. (1) *human society*, i.e. the socio-economic system with development paths described in the SRES (this is shown in a box to indicate that it is different in that choices and options are available that may change the whole system); (2) *atmospheric gases* with concentrations of greenhouse gases, aerosols and precursors (3) *the climate system* undergoing Climate Change as a result of higher concentrations and radiative forcing, and (4) *human and natural systems* including all plants and animals. The arrows show a full clockwise cycle of *cause and effect* between the domains.

Each socio-economic development path explored in the SRES, including development of the industrialized countries, has driving forces that can be grouped into the areas of population, economic growth, technology and governance. These driving forces give rise to emissions of greenhouse gases, aerosols and precursors, with CO_2 being the most important. The emissions accumulate and interact in the atmosphere as concentrations and disturb the natural balances, depending on physical processes such as solar radiation, cloud formation and rainfall. The aerosols also give rise to air pollution, e.g. acid rain, that damage human and the natural systems (not shown). The long-term effect is to change the global climate system (higher radiative forcing i.e. the enhanced greenhouse effect) with temperature rise leading to sea level rise and more global precipitation change. These climate changes, in turn, have impacts on natural systems through more storms, floods, droughts, thawing of permafrost, avalanches, landslides, reduced snow cover affecting food and water security, ecosystems and biodiversity, and human health and settlements. There is a possibility of

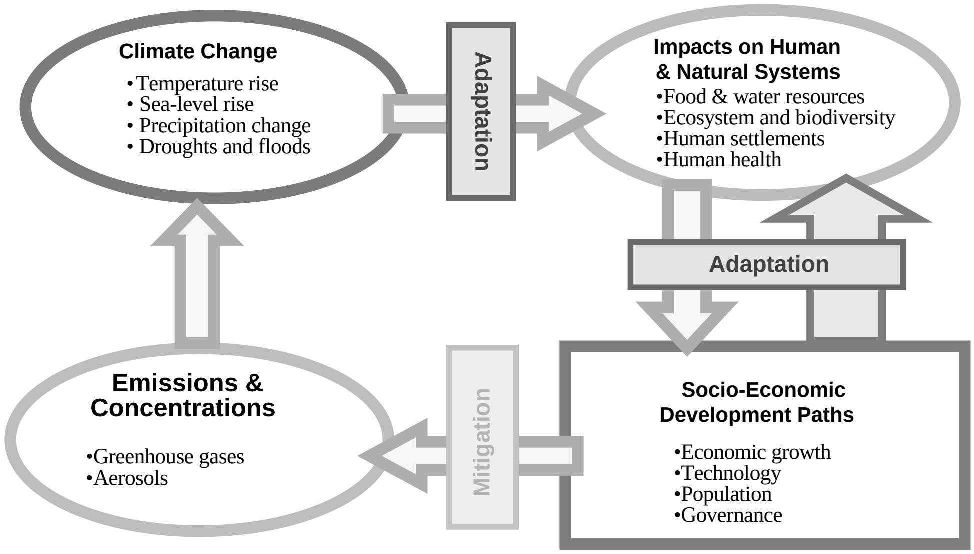

Fig. 1. A "Cause and Effect" integrated assessment framework for climate change with adaptation and migration.

some feedback between the changes in these systems and the climate (not shown), such as albedo effects from changing land use, and other, perhaps larger interactions between the systems and atmospheric emissions, e.g. effects of changes in land use (again not shown). These changes will ultimately have effects on human society in the form of different socio-economic development paths e.g. by weakening food and water security. The reverse arrow indicates the societal response to climate change impacts. The effects of development of emissions can be modified by mitigation as shown in the box superimposed on the arrow. The effects of climate change on natural and human systems and therefore on the impacts on socio-economic development can be modified by adaptation, also shown in the figure.

2.3. Advantages and disadvantages of the cause and effect approach

The advantages of the approach are mainly its simplicity and the message it gives as to the direction of causation. The costs of this simplicity is however substantial. It has no treatment of feedbacks. It mixes stocks and flows (emissions and concentrations) in one of the quadrants. It mixes two different symbols for societal responses: the (blue) arrow and the white boxes marked "mitigation" and "adaptation", so that it is not clear why both are included. It introduces a boundary between "impacts on human and natural systems" and "socio-economic development paths" which is not obvious. For example, changes in food and water resources are also partly a component of socio-economic development. It emphasizes adaptation over mitigation (adaptation is shown as modifying two causal links) although it could be argued that mitigation in fact modifies the whole chain of cause and effect. And finally it gives the impression that adaptation can manage all the impacts, e.g. on biodiversity, when adaptation can only be limited and partial and will not prevent all damage.

The confusion between stocks and flows is the most telling criticism of this conceptualization of the climate change problem. The distinction between stocks, i.e. what exists at a moment of time, and flows, i.e. change over a period of time, is basic in the understanding of the systems and their behaviour. The DPSIR framework treats variables that seem to relate to stocks ("pressure" and "state") as conceptually on a par with variables that seem to relate to flows ("driving forces", "impacts" and "responses"). This can be particularly confusing in representing the climate change issue because a critical concept is the flow of emissions of greenhouse gases (a flow) into the atmosphere, accumulating as concentrations (a stock). Fig. 1 has both emissions and concentrations in one of the quadrants. This may be confusing because it looks as though anthropogenic emissions may be causing climate change, when the science tells us that it is concentrations that are important in the long term. The links between emissions and concentrations are in fact much more complicated than at first sight because of the different atmospheric lives of the different greenhouse gases and the possibilities of their interactions with other components of the atmosphere, e.g. water vapour.

3. "Stocks and flows" representation of global climate change

3.1. The "stocks and flows" approach

An alternative approach can be developed that focuses on stocks and flows in representing the interacting systems, with the quadrants representing different systems as stocks, "states of the world" or bodies of knowledge and the arrows in the figure representing flows from one system affecting another. The direction of the arrows can then represent the direction of cause and effect.

Fig. 2 shows the integrated system in a stocks and flows approach, with adaptation and mitigation measures affecting certain flows. In contrast with Fig. 1 the ovals and box represent domains as systems rather than as changes in key variables and the arrows represent flows and effects between the systems rather than simple cause and effect directions. Several of the arrows represent measurable flows, such as emissions of greenhouse gases and aerosols into the atmosphere. The positioning of the ovals and the box has been changed to reflect the fact that two of them are mainly concerned with the atmosphere and so are better placed above the other two, which are mainly concerned with the surface of the earth.

Fig. 2 provides an integrated assessment framework for considering climate change using the "stocks and flows" approach, although it is a simplified and schematic representation that omits several interactions and feedbacks. The figure shows four domains in each corner: (1) *society and the economy* with their socio-economic development paths, with the main driving forces of economic growth, technology, population and governance, (2) the anthropogenic emissions leading to *atmospheric concentrations*, (3) *the climate system* affected by the concentrations, and (4) *the natural systems* stressed by climate change and socio-economic development. Each system contains complex interactions and feedbacks, with the possibilities of extreme events, critical threshholds and shocks. The arrows show the main ways in which the systems affect one another as a clockwise series of flows.

The economy gives rise to *anthopogenic emissions* that accumulate in the atmosphere. The concentrations give rise to the *enhanced greenhouse effect*, which affects the behaviour of the climate system. *Climate changes* take the form of higher average temperatures, sea level rise and more extreme events, such as floods and droughts. These impact on natural systems with *environmental impacts* on human society and the economy.

Adaptation will take place by human society in response to the environmental impacts of climate change on human and natural systems. The adaptation will be both autonomous, such as households protecting their

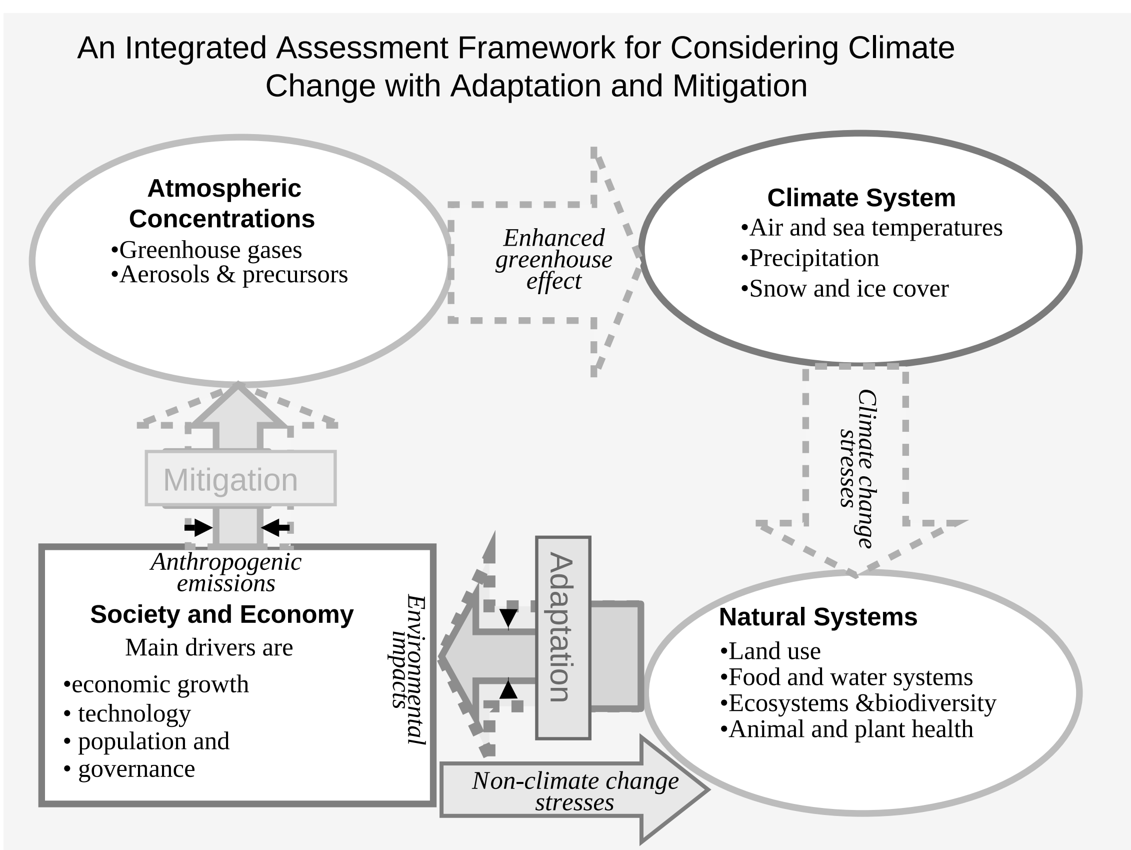

Fig. 2. An integrated assessment framework for considering climate change with adaptation and mitigation.

dwellings from local flooding, and via government initiatives, such as more flood defences in areas threatened by higher sea levels. These adaptation actions will also help to reduce (but not entirely avoid) some of the impacts of climate change. *These actions provide benefits but also entail costs. Net climate change costs are the adaptation benefits less adaptation costs, plus the costs of the unavoided impacts.*

The figure also shows that *mitigation* of GHG emissions is unlike adaptation in that it reduces emissions at the start of the cycle and through the cycle. This is important because there are many unknowns and uncertainties in the effects and feedbacks; in consequence, mitigation reduces risks of dangerous outcomes much more than adaptation. Mitigation reduces anthropogenic emissions at source and this explains the narrowing of the mitigation arrow and other arrows throughout the flow chart, including that for adaptation, compared to the figure without adaptation and mitigation. Mitigation reduces concentrations, then the climate change, then the impacts of climate change and finally the required adaptation. *The primary benefit of mitigation is avoided climate change, but it also has costs* (e.g. higher energy costs) *and ancillary benefits* (not shown) (e.g. in the form of reduced air pollution such as improvements in human health from reductions in airborne fine particles (smog and dust), or more rural employment in biomass projects).

3.2. *The advantages of the stocks and flows approach*

The advantage of the approach is mainly that it maintains a clear distinction between stocks and flows, necessary for understanding the science. In addition, there is a one-to-one representation of two key flows between systems, i.e. (1) anthropogenic emissions between the socio-economic system and the atmosphere and (2) the enhanced greenhouse effect (higher radiative forcing) between the atmosphere and natural systems based on land and water. There is the possibility of a logical depiction of adaptation and mitigation as the narrowing of flow arrows. This leads to a clearer depiction of mitigation at the start of the cycle, reducing uncertainties and risks throughout the cycle worldwide, in contrast with adaptation at the end of the cycle, mainly affecting the eventual outcome of climate change impacts at a local level. It also allows (at the expense of complication) the possible depiction of the key concept of ancillary benefits, shown as reduced damages of air pollution. The problem of putting such benefits into the "cause and effect" figure is that ancillary benefits are not a "smaller" cause of damages, but simply lower damages.

The stocks and flows approach also allows a closer identification of the systems represented by the domains with the underlying scientific disciplines and modelling systems. For example the coupled atmosphere–ocean (AO) models are of the climate system and project changes in air temperature and sea level rise, and the energy–environment–economy (E3) models are of human behaviour and project emissions of greenhouse gases and aerosols. Finally the approach explicitly includes the effects of socio-economic development on natural systems that is not a direct consequence of climate change, e.g. changes in land use leading to loss of biodiversity, as represented by the "non-climate-change stresses" arrow.

However, the full diagram with feedbacks becomes too complex to be understood easily as a stand-alone figure. There is also a difficulty in separating "natural systems" from "human society" in that humans are also part of the natural system. The last point is serious and worth a discussion. Humans are part of the natural system, but they have changed it intensively and extensively through burning, changes in land use away from forestry and prairie towards agriculture and urban use, and more recently through atmospheric emissions. If a natural system is juxtaposed with human society, the contrast suggests that the natural system is somehow one without such human interference. However, the distinction is useful and clearly underlies much of the analysis of the impacts of climate change and other human interventions on the natural system, e.g. as described in (IPCC, 2001, WGII Report). The natural system is seen as the uncontrolled and unregulated part of the natural environment, e.g. the natural conditions that lead to the spread of tropical diseases, such as higher winter temperatures.

The complexity of the full "stocks and flows" figure can be reduced to give a much more comprehensive picture of the climate change issues, by dividing it into a series of 10 figures, which builds up the various systems and their main interactions. These figures are available in a separate presentation, with the explanation of each figure given in the notes. See the web page http://www.tyndall.ac.uk/publications/working-papers/working-papers.shtml under the heading TWPII.

4. Conclusions on representing climate change and human responses

Both approaches have their advantages, but the "cause and effect" framework seems more appropriate as a description of human interference with natural systems rather than as a description of the non-human system interactions also covered in the figures. The driver–pressure–state–response causal chain works well when the driver is a social group, but not when the driver is an outcome of a complex physical system, such as the radiative forcing of greenhouse gas concentrations, with multiple interactions and time-scales. The physical systems do not respond with choice and motivation; and the pressure–state relationships are complex and intrinsic parts of all the systems being represented. The ''stocks and flows'' figure has the advantage that it is conceptually more logical. Several of the complexities inherent in the climate change problem can be explained by developing the figure into a series of component figures, as described above.

5. The state of the art in integrated assessment models of climate change, adaptation and mitigation

Figs. 1 and 2 representing the integrated assessment of climate change as discussed above are more conceptual aids for thinking about the issues rather than a description of an actual modelling system, including ''state of the art'' models reviewed in the IPCC Report (2001).

The main way in which consistency have been achieved in the results reported in (IPCC, 2001) is by running the different modelling systems on a set of common scenarios based on the six illustrative marker scenarios in SRES (Nakicenovic et al., 2000). This has been done for versions of the coupled atmosphere–ocean models and for the energy–environment–economy (E3) models, but not for most of the modelling of climate change impacts. None of the potential feedbacks between the systems in Fig. 2 has been formally modelled in the large systems, with the exception of the link back from the higher temperatures of sea water to atmospheric concentrations of GHGs (sea water absorbs less CO_2 at higher temperatures). The current state of science as represented in the IPCC reports does not yet allow the quantification of such a fully integrated assessment.

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