EXTENDING INTEGRATED CLIMATE ASSESSMENT MODELS TO INCLUDE ANCILLARY BENEFITS: PROBLEMS AND PROSPECTS

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Abstract

This paper describes the ancillary benefits problem in its broad context, and discusses critical elements that need to be added to conventional climate modeling tools to adequately describe three major areas, local air pollution, land use and water quality and supply, where climate policy may either affect or be affected by other environmental concerns. It also reviews some of the methodological issues raised by addressing these three areas, and suggests some strategies for addressing these problems. The paper concludes with some cautionary notes about the difficulties involved in integrating ancillary benefits into quantitative global climate impact models and the importance of providing for the consideration of factors which cannot currently be quantified.

1. Introduction

The climate change problem arises because human-activities produce a wide variety of emissions of greenhouse gases (GHG) that are anticipated to change atmospheric behavior in ways that will increase temperature and affect precipitation and climate variability. While the bulk of the relevant emissions come from energy use, agriculture and industrial activity also emit significant emissions. Many of the activities leading to greenhouse gas emissions also emit other environmental pollutants of concern. Thus we can expect that policies to control greenhouse gases may reduce (or expand) a variety of other impacts of societal concern. It is these other changes that constitute ancillary benefits (or dis-benefits). Therefore, as we consider the development of sets of strategies to manage the climate issue, it is important to have a full understanding of the results of implementing such policies. In this regard, the tools that are used to assess quantitatively the policy alternatives for reducing GHGs need to include the ability to simulate the full range of effects, not just those that are related to climate change.

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This paper explores the development of interest in ancillary benefits by the general climate modelling community and others, discusses 3 types of ancillary benefits that can be incorporated into these quantitative models, and notes some methodological difficulties and challenges of providing for integration of ancillary benefits into the policy discussion. This is followed by a discussion of some of the kinds of strategies that could be expected to be useful in resolving these issues. The paper concludes with a discussion of the ways these kinds of tools can be used, of the resources required to develop them, and a suggested path forward.

The full range of effects of climate policies is potentially quite broad, since the two major sources of greenhouse gases, energy production and agriculture/land use, affect almost all aspects of human activity. Included in the policies under consideration to manage the climate problem are such diverse strategies as increasing energy efficiency, decreasing energy demand, increasing the efficiency of non-carbon sources of primary energy such as solar, providing alternative motive power for vehicles, changing agricultural management practices to increase storage of carbon in the land, as well as managing the way in which diets change as incomes increase in the developing countries.

The dominant focus for work on ancillary benefits has been local air pollution. This focus arises because energy production and use is a major source for both problems. But the two problems are not identical, having very patterns of emissions and policy impact profiles. In addition to local air pollution, there are two other major areas it is useful to consider. The first, land use, arises because some policies to reduce or offset carbon emissions assume large scale changes in land use, for example, biomass, or in land management to increase carbon in land. The second is water, whose supply is likely to be changed significantly by climate change, and whose availability and quality may also be compromised by various proposed energy policies. These three areas do not exhaust the topics of interest, but they will illustrate the range of geographic scale issues and time step issues that need to be resolved to construct integrated programs to manage a wide variety of environmental issues.

In addition to climate policy impacts on other environmental issues, it is essential to consider the impact of other policy on climate results. For example, reducing fine particulates by limiting sulfur emissions from electricity generation is anticipated to increase temperature change, although the magnitude of this effect remains uncertain. Limiting emissions of local air pollutants by introducing a new generation of internal combustion engines could foreclose an alternative source of motive power, fuel cells, considered to be an important tool to reduce carbon emissions.

The analytic systems used for examining ancillary benefits have to be useful in a variety of communities. Initially, the issues have to be examined and tested within the science and research communities. After these communities have considered the tools and results, the policy community uses the tools to determine what alternatives might be appropriate. Finally, the political process, which necessarily includes the public at large, has to consider and decide on appropriate responses. In the light of the diverse groups that can be expected to use results from the modeling exercises, the modeling tools must not only be scientifically defensible, they also must be transparent, flexible, and reliable.

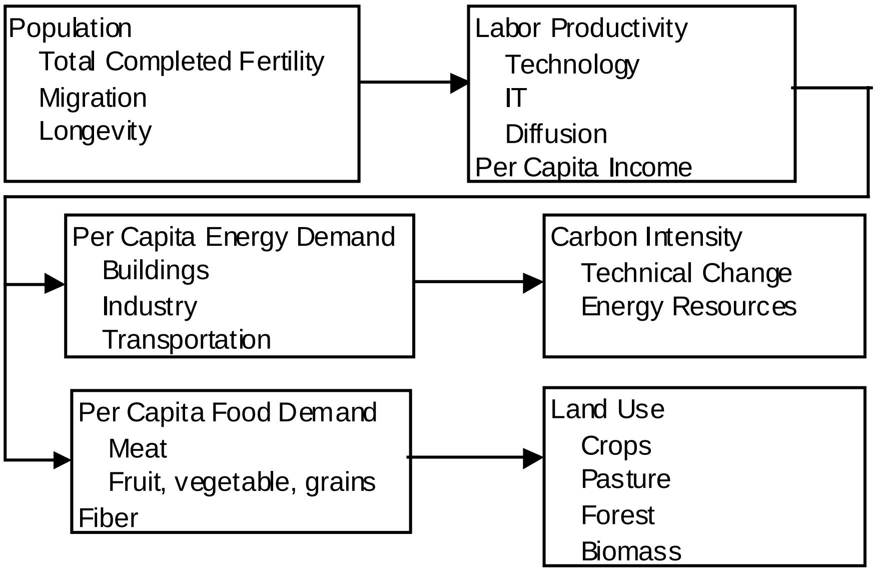
The existing tools for analyzing the climate problem have begun to explore the wider set of issues that are raised by the ancillary benefits problem, making the theme of this paper, how to model such changes, clearly appropriate and important. Major systems presently under development include IMAGE (Alcamo, et al, 1998), AIM(Jiang et al, 2000), EXTERNEE (Barker, 2000) and PCAM(Edmonds et al, 1993).

The considerations discussed above imply that introducing ancillary benefits into the decision making process for climate change significantly increases the complexity of the policy environment. One cannot simply add the benefits of the non-climate related changes due to controlling greenhouse gases to the benefits of the climate changes and compare these to the costs of the climate policies. Because resources to manage the environment are limited, introducing ancillary benefits requires adding consideration of alternative policies to achieve the ancillary changes, such as alternative ways to control local air pollution. The policy problem is then one of allocating the available resources so as to most effectively solve a wide variety of environmental problems, which in addition to the climate problem will commonly include public health, air and water pollution, as well as solid waste and land use management. While it is clearly appropriate to consider this wider set of problems, effectively doing this remains one of the major challenges to environmental management.

Three kinds of ancillary benefits: air pollution, land use changes, and water quality and supply

The introductory section suggested that there were three major areas in which ancillary benefits could be expected to be important. In addition, it was suggested that these three areas would introduce systematic problems with geographic scale and time steps. To understand why this is the case we begin by introducing the following simple framework for the sources of greenhouse gases. As shown in Figure 1, the first important determinant is the scale of economic/human activity which is driven by population and worker productivity. Figure 1 suppresses important issues with respect to the geographic allocation of this activity and the inequality of income. Figure 1 also shows the two important processes which generate economic activity, the demand for and production of energy, and the demand for and production of food and fiber. The green house gases produced by these two systems are well mixed in the atmosphere, and therefore it is not important where they are produced. Thus the energy and land uses sources for these gases need only be modeled at a convenient scale in terms of the economic activity involved, which typically represents the entire world with a breakdown of from ten to twenty regions. In addition, very aggregate time steps, which range from five to fifteen years, are typically used, because these are sufficient to understand the long term trends in population, economic activity, and technological characteristics which is all that is necessary to understand how greenhouse gases are changing. These long time scales are also sufficient to understand the long terms changes in global temperature change, and in sea level, the two indicators most often used to measure climate change.

Figure 1. **Simple framwork for sources of GHG**

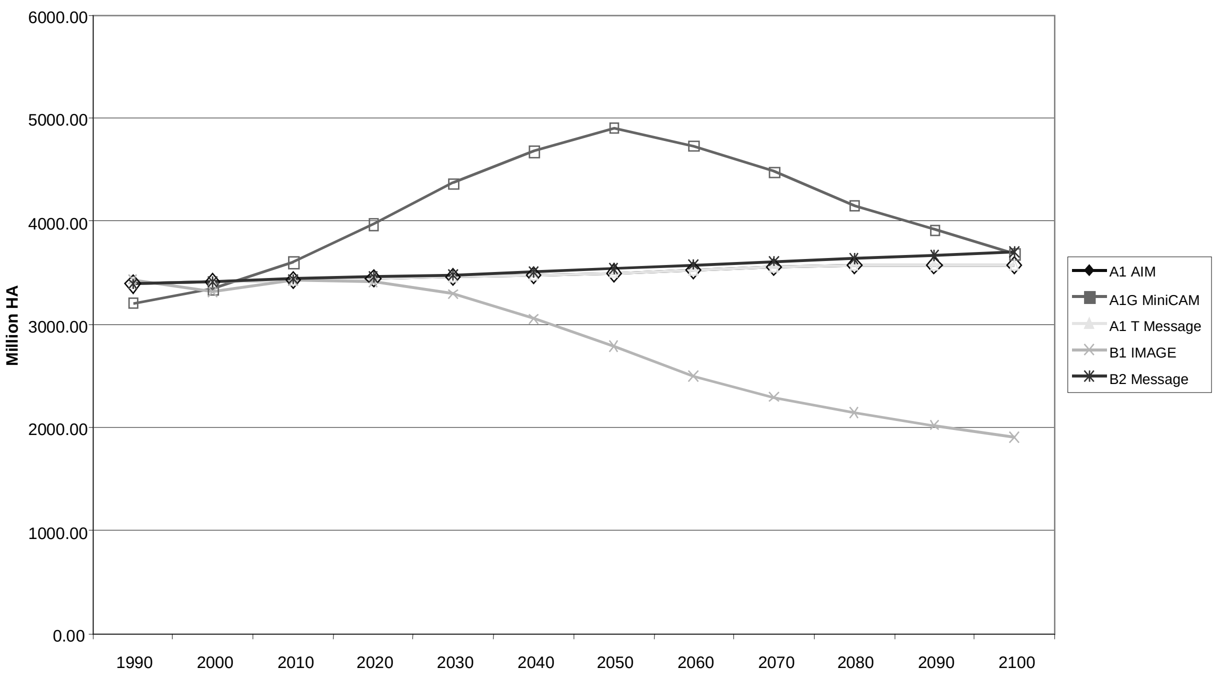


Understanding local air pollution, land use and water issues requires very different geographic breakdowns and time scales from those used in typical climate tools. Local air pollution is driven by emissions on the one hand, and by the pattern of local weather on the other. Understanding this issue requires both an understanding of where economic activity is occurring and how the weather is changing on a much a much finer scale than is needed for modeling climate effects. Not only that, most of the severe air pollution problems are of a very short term duration and a function of particularly unfavorable stable air masses, implying we need a rather fine time step for our models, and the need to have climate models provide information about changes weather patterns, a capability well beyond what any of the current climate models can provide. As referred to earlier, on the societal front, it is almost certain that many sources of local air pollution will be controlled as developing countries become richer, leading to reductions in sulfur emissions and other fine particulate sources, which in turn will cause significant increases in observed temperature change.

Analyzing local air pollution risks involves understanding the sources of and extent of pollutant emissions, the process by which these are transformed into concentrations, the patterns of behavior that lead to human exposure, the set of factors such as prior disease and genetic susceptibility that lead from exposure to health risk, and the societal benefits that accrue from a reduction in risk. The health risks associated with exposure are complex, since there risks are interactive in nature. Thus, reducing the health risk may be more effectively achieved by improving nutrition status than by reducing local air pollution. Different kinds of health risk respond very differently to reductions in pollutants, with acute respiratory infections responding quite rapidly, while chronic obstructive pulmonary disease responds only very slowly.

Land use raises a different set of issues. First, as the recent IPCC exercise to develop a new set of emissions scenarios discovered, there is wide variation in the potential future development of dietary preferences as incomes rise in the developing countries. As shown in Figure 2, there one scenario in which demand for pasture land grows rapidly, while all the others remain flat. This difference can be traced back to different projections for the demand for beef and other forms of ruminant livestock, which are typically range fed for a large portion of their life. There is already great concern about the destruction of forest and the loss of land due to desertification, erosion, waterlogging, and accumulation of salts due to improper irrigation. There is also much interest in land based activities that might play a major role in reducing carbon emissions through the production of biomass, or sequestration of carbon in soils through changes in management practices. What seems clear is that we do not yet have a sufficient understanding of the demands for land that are likely to emerge in the future to be able to assess what the potential negative results of large scale biomass might be. We also cannot assess whether it is feasible to reforest large areas as permanent stores. Nor, can we determine whether we can expect to keep large amounts of carbon in the ground through permanent changes to such management practices as no-till agriculture.

Figure 2. **Pasture land in the SRES marker scenarios**



The second major issue about land is that there is some evidence that there is a major flow of carbon into the land. However, we do not yet know in what geographic area this land based sequestration is occurring, nor do we understand the biological processes which are responsible for it. Thus, to understand the climatic impacts on land use issues, we need a much better understanding of the basic drivers for land use, the potential for improvements in management practices which are destroying the productivity of significant amounts of land, as well as a deeper understanding of the land based carbon cycle.

Finally, water poses a still different set of issues. For a large part of the earths surface water is the factor which limits the productivity of the land. The productivity benefits of water have been understood for thousands of years and are the basis for the very extensive set of irrigations facilities found in all areas of the world. The geographic basis for understanding water issues is the river basin, still another geographic scale which needs to be considered in the models. There is good reason to believe that climate change will affect stream flow in two important ways. First, in those regions where snow pack is an important source of water storage, there may well be less snow and more rain, resulting in a smaller snowpack, which is expected to melt earlier, thus changing the annual runoff patterns. In order to maintain the same annual yield, or sustainable flow, this will require more storage, and more storage is increasingly difficult to implement, because of human, ecosystem and recreational changes created by large dams. The second problem is that while climate change is expected to increase the speed of the hydrological cycle, the increased precipitation this implies may be more than counteracted by the increased rate at which evaporation and transpiration will occur in a warmer climate. The result may well be decreased stream flow. Finally, there is a concern that the location of precipitation may change, with some models showing a decline in rainfall in many of the central continental areas, such as the Great Plains in the United States.

2. Methodological Issues

The challenge posed in the previous section, to develop a set of tools which let us understand the much wider set of issues posed as we extend the climate models to consider a fuller set of environmental objectives and policy tools, is truly daunting. Typical climate based tools, commonly referred to as integrated assessment models, are already large and complex tools. As discussed, adding a capacity to manipulate air, land and water issues requires a major increase in the complexity of these programs. This poses major problems for the development, reliability, execution time, and transparency of the resulting expanded tools. In this section we discuss each of the major issues that experience suggests will arise as the tools are developed.

Complexity: Complexity is a function of the number of elements contained in the modeling system, and it typically will rise in an exponential fashion. In order to maintain transparency and efficiency, it becomes crucial to be very disciplined in reducing the complexity of each of the elements of the problem. Otherwise, the system becomes so complex and difficult to manage that effective policy analysis and response is not possible. An example of the issues which arise when the full complexity of the issues are considered is the Intergovernmental Panel on Climate Change (IPCC) paradigm for analyzing climate issues. This paradigm, which includes the following steps: develop emissions scenarios, analyze these emissions with global scale atmospheric chemistry and coupled atmospheric/ocean models, and consider the impacts of the resulting climate changes with a variety of tools, takes on the order to three to five years to complete with costs on the order of five to ten million dollars per scenario. Even as a research tool, the process is cumbersome and expensive. Because models of climate impacts are being devised as tools for the policy process, the pace and cost of scenario development heretofore is unworkable.

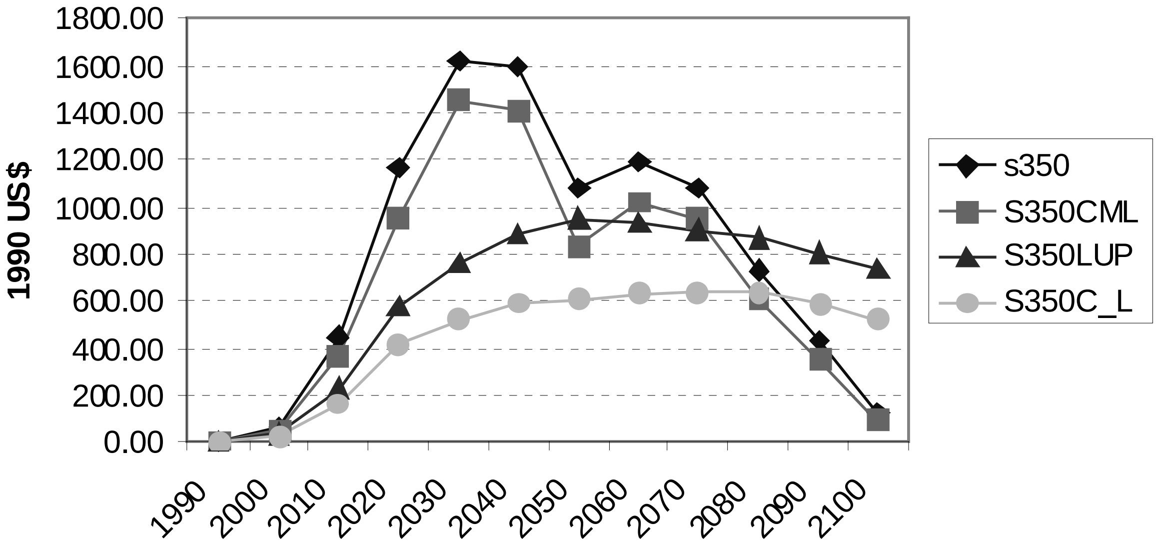
In order to provide useful information for those charged with making decisions in the near term about GHG policies, it is important to reduce the scale of the components, and to simplify the information moved between the elements of the model. There is no right answer to how to do this: the tradeoff is one of execution time and transparency against the potential cost of missing important interactions. In addition, because most decisions are made at the local or national level, it is important to generate information that has direct relevance to regional or local decision makers.

Interactions: The essence of modeling ancillary benefits is joining models with substantially different subjects and normally different styles, scales, and time steps. Beyond the human and practical issues which arise in these kinds of collaborative effort, the act of specifying the interfaces between the models often generates new questions, and the pursuit of these questions often leads to new insights about how the system behaves. These in turn can lead to modifications of either or both of the systems, so that the process of integrating the models leads to new scientific or policy understanding.

In a practical sense, in order to understand system behavior it is necessary to be very clear about what is happening in the interface between the models. This will often necessitate aggregating or disaggregating across physical scales, as when adding land use to an economic model, or across time scales, when integrating climate and economic models. Experience suggests that the values of variables as they pass through the interface should be readily accessible to the modeler—otherwise the process of understanding why the models behave as they do is nearly impossible.

An example from the work done for the Working Group III chapter on mitigation illustrates the kind of issues that might be expected to arise (Pitcher, 2000). As a device to test model behavior, a scenario was run whose goal was to stabilize CO_2 concentrations at 350 ppm. Then a subsequent scenarios was examined in which carbon sequestration from energy production was added. As seen in Figure 3, this made only a very small difference in the very high carbon tax necessary to achieve the 350 target. Investigation showed that even though carbon was being taxed very aggressively, land was being rapidly converted to pasture in order to supply meat as diets changed in response to rapid income growth. The carbon emissions from the land conversion used up more than three quarters of the allowable carbon emissions budget, leaving no space for even the small emissions remaining after sequestration. Assuming that it would be possible to reduce the large scale land conversion resulted in the carbon tax trajectory labeled land use in Figure 3, while the combination of a carbon sequestration and a land use policy (the CLU trajectory) resulted in a two thirds reduction in the carbon taxes needed to achieve the target. The important lesson this test revealed was that it was important to modify the agriculture and land use model so that behavior in this sector reflected the overall policy towards carbon.

Figure 3. **Impact of sequestration and land use on carbon taxes necessary to reach 350 ppmv**



Stochastic Processes*:* Important elements of the impacts of climate change may arise from events where current theory and practice suggests there is no reasonable likelihood of being able to improve model performance to the point of making long term forecasts. For example, current weather forecasting technology has no ability to improve upon seasonal means more than 15 days into the future. Even the variation is weather patterns produced by the climate models is often only the current long term pattern adjusted by the estimated change in temperature and average rainfall. Thus it is unlikely that weather related causes for high air pollution events can be reliably estimated, except perhaps for the impact of changes in ambient temperature. Likewise, the observation that for much of the United States there has been an increase in large rainfall events is going to be difficult to substantiate within the current framework. The same lack of precision must be attached to the likelihood of major droughts. It looks likely that projecting certain major impacts will be beyond the capability of our tools for the foreseeable future.

Multiple Baselines*:* As indicated in several parts of the discussion so far, the baseline evolution of economic and human systems is a critical component of understanding how climate policy may affect and be affected by other important environmental objectives. As the recent SRES made clear, there is no reliable way to develop a best long-term projection of the future. The unknowns are simply too large, and the evolution of critical systems too sensitive to small changes in such things as the rate of technical change in different sources for primary energy to allow such a forecast to ever be achieved. The SRES recommendation is that all analysis should use multiple baselines, as a way of being sure that the uncertainties about the future are explicitly incorporated into the analysis. Since relatively few studies and tools have routinely used multiple baselines, the methodologies for doing this and presenting the results in a coherent transparent way have not yet been made explicit or solved. In contrast, for some of the impacts of major interest for ancillary benefits, such as public health and land use, shorter time frames can be assessed with some precision.

Some Tricks to Reduce Dimensionality: So far the discussion has focused on the things that need to be added, and some of the areas where it is going to be difficult or impossible to produce reliable results. But there is some hope that the system can be made to work. For many questions, making the results and the reasons for the results clear will require analysis for only a small subset of the total set and for more limited periods of time. The analysis of the impacts of climate policy is apt to be well understood with an analysis of ten exemplary cities, rather than all of the world's major cities. Once the tools are demonstrated in this way, then particular problems can be addressed with relative ease, should additional analyses be deemed important. A second approach utilizes a sample from the set of available scenarios, advocating a strategy which is used today by the large scale climate modelers of analyzing only a few of the many scenarios, and then capturing this information in much smaller models such as MAGICC, so that the essential results of the large process oriented models are available in a computationally very cheap form.

2.1 Discussion

Including ancillary benefits in integrated assessment tools results is problematic. Managing these problems is essential to obtain useful, understandable results. Perhaps the most difficult problem arises from what is known as the 'curse of dimensionality'. Incorporating more detail and more subject matter areas results in tools which are difficult to operate, difficult to debug, difficult to run and difficult to explain. It is essential to use judgement at many points in the process of developing the extended models to require that the additional material be germane and contribute to the overall system behavior in some qualitatively important way. If there are six potential arguments, but only the first three matter much to the behavior of the component, use only the first three. The constant temptation is to add more detail, the price of this temptation is the creation of tools which cannot operate within reasonable time frames and lose the important aspects of their behavior in a welter of detail. Another advantage of being parsimonious is that the results become easier to understand and interpret. It is then more likely that major elements which are not included in the analysis can be perceived and corrected for, even if by a process exogenous to the model. Being able to make such adjustments is crucial to the overall sense of reliability of the model.

The crux of the ancillary benefits issue is that policies to control greenhouse gas emissions have joint products; they also end up reducing emissions of other gases, or have impacts that are germane to other major areas of concern, such as land use patterns. Joint products have the unfortunate characteristic that it is no longer possible to assign unique costs to the various outputs. In this regard, the costs and benefits that may be compared are not developed with the same methodologies, rendering the comparison of limited value.

The discussion so far has suggested that there will be a lot of work required in order to enable the careful analysis of the impacts of climate policy on ancillary benefits and other crucial economic and environmental outcomes. Likewise, a careful understanding of how some of these other policies might work out is crucial to understanding the milieu within which climate policy will be carried out. What does seem evident is that by applying careful judgement and using simplified tools rather than the full scale process based models, it will be possible to improve the understanding of how ancillary benefits are affected by proposed GHG policies..

However, it is also important to understand that there are aspects of the problems raised by considering ancillary benefits that we are unlikely to be able to analyze quantitatively. These limits flow out of the many aspects of the models that reflect either very poorly understood but quantitatively important variable such as the average number of children born to mothers in each generation or a level of information which is simply not feasible to attain, such as detailed measurements of atmospheric conditions over the worlds oceans.

Because of the complexity of the tools involved in climate modeling, it is essential to use the results with care. Admittedly pithy phrases like ‘common sense’ and ‘grain of salt’ spring to mind. It is especially important to ask if assumptions abut fixed inputs such as energy supplies are driving results and are unlikely to be fixed in the real world. To make modeling results more useful, it is essential to produce lots of graphical outputs, especially ones which show the historical and the forecast period in the same graph Graphic displays allow inspection for the possibility of major trend breaks at the start of the forecast period, one of the sure clues that something may be amiss in the forecast period. Failure to perform these kinds of analyses can lead to major mistakes.

A particularly troublesome element in developing and understanding climate impact models is the presence of many critical areas which simply cannot be well quantified. One type of problem is that we don’t understand long term demands very well, whether it is for babies, for energy or for food. These are critical for understanding the long term levels of the economic activity. The best way to handle the uncertainty is to use multiple scenarios which reflect the plausible range of outcomes. Plausibility is a tricky concept in the phrase. As Granger Morgan and colleagues have shown, experts normally overestimate the reliability with which they can estimate effects. Because of this expert ‘hubris’, it is essential to push the boundaries a bit, especially if there is any suspicion that there may be non-linearities in the system. Another aspect of poor ability to quantify modeling results is the presence of many elements in the system which are noisy or chaotic in nature. Weather patterns, for example, are critical to predicting local air pollution, and changes in the patterns cannot be projected with any skill. Again, the solution is to use scenarios which cover a range of outcomes.

Resources: The additions required to effectively model and understand the issues raised by ancillary benefits are considerable. The existing integrated assessment tools are the product of extensive efforts by teams of researchers over what is approaching a decade. The process of model development, calibration, validation and data development is resource intensive. It requires a multi-disciplinary approach with considerable collaboration between those who develop specific models for such areas as local air pollution and the members of the integrated assessment group. Because of the distinct possibility that there will be unforeseen and important feedbacks, it is essential that the tools actually be integrated.

Use of the best possible tools to manage model development, input and output will reduce the difficulty of the task at hand, so that the tools are easier to develop, debug, evaluate, and mange. This will increase the reliability and value of the tools.

***Priorities**:* There are many aspects of the climate problem, especially those having to do with understanding impacts, which in turn will help us to understand what constitutes ‘dangerous anthropogenic interference with the climate system’, the FCC touchstone for determining the level of effort required to reduce climate emissions, which are simply not well understood today. The issue has to be raised about the level of effort which should go into the study of ancillary benefits when the direct impacts of climate are not yet well enough understood to allow us to determine how urgent the task of reducing greenhouse gas emissions is. Some have suggested that the potential ancillary benefits of proposed GHG mitigation policies may well be greater than the direct benefits of these same policies, in regions such as Santiago (Cifuentes *et al.*, in press, JAPCA) It would seem preferable to focus on such areas as public health, food production, sea level rise, and the potential to adapt before spending large amounts of resources on the issue of ancillary benefits.

However, because control of local air pollution and the base case evolution of land use will be such important determinants of the environment within which climate policy must be conducted, a balanced approach is required that highlights clear and evident local and regional impacts.

It is essential to begin work on modeling ancillary benefits with simplified regional models, so that the major elements of the problem can be understood, and areas where further elaboration is required can be identified. As tools are generated for use in these models, it is essential that experts in the relevant science be involved who can identify those elements in the system which contribute least to the performance and can therefore be eliminated.

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