Greenhouse Gas Indices
Milind Kandlikar

Abatement of greenhouse gases is a key element of policy responses to climate change. Comprehensive strategies view the greenhouse abatement issue as one involving multiple gases and not CO₂ alone. Each gas has a different potency in affecting the Earth's radiative balance and poses different challenges for control. These strategies require the formulation of greenhouse gas indices to facilitate an evaluation of the tradeoffs involved. Greenhouse gas indices compare the impacts of other greenhouse gases, such as methane, relative to CO₂. However, scientific and socio-economic uncertainties make it hard to justify the use of a single comparative scale. This makes comprehensive abatement policies difficult to implement. Beyond this technical problem, comprehensive abatement is politically contentious because it brings the divisions between rich and poor countries into sharp focus.

WHY DO WE NEED GREENHOUSE GAS INDICES?
In the past decade the greenhouse effect has emerged as a key long term issue for energy modeling and policy. Abatement of greenhouse gas emissions is an important policy response to mitigating the effects of climate change. While most abatement alternatives focus on reducing long term atmospheric carbon dioxide concentrations, there has been some interest in viewing the emissions abatement problem as one that also involves gases beyond CO₂, such as methane and nitrous oxide. Comprehensive abatement strategies are based on the rationale that all greenhouse gases contribute to climate change, hence abatement should target all gases. For example, abatement could be carried out for each gas at a level where the net costs of climate change are minimized.

It has been argued that such comprehensive abatement strategies require the formulation of summary tradeoff measures called greenhouse gas indices. Greenhouse gas indices attempt to capture the relative effect of the emissions of different greenhouse gases on the environment. Such indices would allow for an evaluation of the tradeoffs between greenhouse gases in a number of possible abatement contexts including:

- The evaluation of tradeoffs between gases in a comprehensive abatement strategy.
- Comparing investments in abatement made towards mitigating the effects of climate change.
- Comparing the current and future emissions responsibility of nations.

The use of a single greenhouse gas index in each of the above policy contexts is not without pitfalls. Although a greenhouse gas index is useful for analyzing the trade-offs between different gases, its relevance for policy is confounded by uncertainty. As we will observe later, a single number for any particular gas is difficult to pin down and uncertainties create problems in each of the abatement contexts described above.

THE GLOBAL SETTING
The most controversial element of greenhouse gas indices is their possible use as a means to allocate greenhouse warming responsibilities across nations. Carbon dioxide is primarily released from the burning of fossil fuels for energy use. Hence, a majority of carbon dioxide emissions are released by industrialized nations. Emissions of the other major greenhouse gases, particularly methane, are biogenic in nature. Hence, emissions of these gases are distributed more evenly between less and more industrialized countries. Rice paddies, for example, are responsible for about 15% of global methane emissions, with 90% of these emissions coming from East and South Asia. As a result, many developing countries see comprehensive abatement as a western ploy to burden them with an unfair share of responsibility for changing climate. To be sure, comprehensive abatement was brought to the fore to give credit to the U.S. and other industrialized countries for CFC reductions undertaken...
under the Montreal protocol. It was first championed by the Bush administration in the U.S. prior to the time of the Rio summit in 1992. The scientific understanding at that time suggested that CFCs were a major contributor (≈15%) to radiative forcing of the atmosphere. In the follow-up to Rio, the Bush administration stated that they considered climate change important but the science too uncertain to warrant carbon abatement policies. Consequently, the United States was portrayed in the international media as resistant to agreements on curbing greenhouse gas emissions. At the same time, U.S. economists were championing “no regrets” policies for global climate change. These were policies that were already in place or could be justified on the basis of considerations other than climate change. Analysts in the administration sensed a good opportunity to spruce up the embattled U.S. image and pushed to include radiative forcing offsets of CFC reductions as proof that the U.S. was actively pursuing “no regrets” approaches.

Scientific uncertainty has an important effect on the development of comprehensive abatement strategies and plagues many of the schemes prescribed for greenhouse gas indices. In addition to scientific uncertainty, new research indicates that index calculations should also include socio-economic factors such as climate change impacts, the expected changes in welfare, and future patterns of emissions.

PITFALLS OF GLOBAL WARMING POTENTIALS

The most widely discussed greenhouse gas index is the Global Warming Potential (GWP). GWPs integrate radiative forcing from a unit emission of a non CO₂ gas over a prescribed time horizon and compare it with the similar effect for a unit emission of CO₂. The scientific issues associated with GWP calculations such as the uncertainties of greenhouse gas lifetimes and the choice of a time horizon for integration have been extensively discussed. However, little attention has been paid to the socio-economic issues implicit in the calculation of GWPs. GWPs do not explicitly include the potential damages linked to climate change and future patterns of emissions. Climate change damages and costs of abatement both vary with time. Both need to be explicitly included in the calculation of a measure that determines the relative roles of greenhouse gases in abatement policies. This is particularly important due to the long time horizon of climate change and the possibility of non-linear impacts. Most decision makers are principally concerned about the impacts of climate change. In order to develop reliable greenhouse equivalence schemes that inform policy decisions one needs to compare the relative impacts of unit emissions of greenhouse gases. Damages from climate change are expected to arise from changes in a variety of climatic variables such as global mean temperature. If greenhouse gas damages are a function of global mean temperature change, then the net impact of a current unit of emission will depend upon future emissions of greenhouse gases. Future emissions of greenhouse gases are intrinsically linked to economic growth and abatement policies, which in turn are governed by expectations of greenhouse damages. Measures that only focus on radiative forcing are wholly inadequate for addressing these complex issues.

The impact of an incremental unit of a greenhouse gas emitted into the atmosphere now can be described by calculating the total (present and future) impacts that arise from the emission of that unit. These impacts depend on mean global temperature change, future greenhouse gas emissions, and the social discount rate. Additionally, the index depends on a number of scientific factors such as greenhouse gas lifetimes, radiative forcing functions for the greenhouse gases, interactions with other pollutants, and the response of the climate system to the excess radiative forcing. Researchers at CMU have developed such an index in order to emphasize the nature of these indices. They have been termed Scenario Based Indices (SBIs).

SCENARIO BASED INDICES

We calculated Scenario Based Indices by specifying emissions scenarios such as those devised by the IPCC. The resulting global temperature change and the indices were then calculated. Index evaluations were carried for methane, nitrous oxide, and HCFCs for a time horizon of 100 years. Greenhouse gas cycles were represented by simple reduced form models. A simple climate model with climate sensitivity of (ΔT for CO₂ doubling) of 3°C, and an ocean response time of 30 years was used. The calculations were carried out for damages that rise: with temperature, with the square of temperature, and with the cube of temperature change, and for discount rates of 0%, 2%, and 6%. Note that for Scenario Based Indices (SBIs) only the functional form of the relationship, i.e., the level of non-linearity in the relationship between the impacts of global warming and temperature change is important. The SBIs are independent of the
scale factor that converts the relationship into economic units.

SBIs were calculated using two emissions scenarios: A (high emissions) & D (low emissions) from IPCC (1990). In Table 1 we provide SBIs derived from this analysis for each of the emissions (methane, nitrous oxide and HCFC-11) and damage scenarios (linear, quadratic and cubic) with an assumed discount rate of 2%. In Table 2, we capture the effect of discount rates on the SBIs for methane. From these calculations we derive a number of qualitative insights regarding greenhouse gas indices which are detailed below.

**INSIGHTS ABOUT SCENARIO BASED INDICES:**

The numbers in Table 1 indicate that for gases that are short lived relative to CO₂, i.e., Methane and HCFC-22, the trace gas index decreases as damages grow more severe. Note that when damages are linear (proportional) to temperature, the index is almost insensitive to divergence in the future pattern of emissions. From Table 1 it is also seen that trace gas indices are more sensitive to the level of non-linearity in the damage function than they are to familiar scenarios of future patterns of emissions. Scenarios A & D capture very different views of the expected future energy mix: a coal intensive energy supply for scenario A; a renewable and nuclear intensive energy supply for scenario D. This suggests that index calculations are reasonably robust over a wide range of possible outcomes of energy supply futures.

From Table 2 it is also apparent that trace gas indices depend critically on the discount rate. A higher discount rate reduces the impact of future damages from trace gases with longer lifetimes, and leads to an increase in the value of the index for species that are short lived relative to CO₂. Conversely, for a species that is long lived relative to CO₂, higher discount rates lead to a decrease in its greenhouse gas index.

Much of the early discussion on trace gas indices, particularly GWPs centered around the choice of an appropriate time horizon for integration. This was particularly problematic because there is no clear way to choose an integration time. When the problem is cast into an economic framing the choice of time horizon is converted into a choice of an appropriate discount rate, which is a well defined problem area in economic literature. However, the choice of a single social discount rate for all the impacts is fraught with problems. There is little agreement regarding the appropriate value for discount rates for market based damages.

The situation is further complicated by the fact that non-market damages may play a key role in climate change policy decisions. Traditional approaches used by economists for the valuation of non-market environmental goods such as contingent evaluation are plagued by conceptual and operational shortcomings.

If damages from climate change are highly non-linear the current emphasis on GWPs may result in an overestimate of the benefits of greenhouse abatement projects involving non CO₂ trace gases relative to CO₂ abatement. The larger question, however, is the applicability of greenhouse gas indices in climate change policy.

<table>
<thead>
<tr>
<th>Trace gas</th>
<th>D(1)</th>
<th>D(2)</th>
<th>D(3)</th>
<th>GWP*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>19</td>
<td>12.9</td>
<td>8.5</td>
<td>11</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>269</td>
<td>282</td>
<td>289</td>
<td>290</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>2445</td>
<td>1706</td>
<td>1284</td>
<td>1500</td>
</tr>
</tbody>
</table>

Table 1: Scenario based trace gas indices for a discount rate of 2%. D(1), D(2), and D(3) refers to linear, quadratic and cubic dependence of damages on temperature.

*GWP Integration time is 100 years.

<table>
<thead>
<tr>
<th>Discount rate</th>
<th>D(1)</th>
<th>D(2)</th>
<th>D(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>r = 0%</td>
<td>13.3</td>
<td>8.5</td>
<td>6.4</td>
</tr>
<tr>
<td>r = 2%</td>
<td>19</td>
<td>12</td>
<td>8.5</td>
</tr>
<tr>
<td>r = 6%</td>
<td>27.7</td>
<td>20.6</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 2: The effect of discount rate on trace gas index for methane. As in much of global climate change policy, the choice of a discount rate makes a big difference to the conclusions.

As can be seen from tables 1 & 2, the index for methane can range from about 6 to 28. Such differences have enormous implications for investment decisions for abatement, as well as for international negotiations. For example, in switching from coal to natural gas, the benefits of reduced carbon emissions need to be compared with potential leakage of natural gas from coal mines and gas extraction, during transmission and use. Therefore, the value of indices...
used for methane may affect decisions about whether or not to invest in projects that use natural gas and determine the amount of leakage allowable if natural gas projects are to be implemented.

Large uncertainties in the indices also make them very difficult to use in international negotiations. This is a politically contentious issue, where the uncertainty is paramount because it leads to enormous differences in current and future emissions responsibility of nations. Therefore, it seems prudent to avoid the use of a single greenhouse gas index in a global accounting framework. In addition, the emissions of different greenhouse gases on a country by country basis are also very uncertain.

In conclusion, greenhouse gas equivalence schemes seem destined to fail. Instead, focusing on strategies to reduce emissions in a cooperative manner without the need for the accounting of responsibility between nations seems to offer a better solution. There have been several other interesting suggestions in the literature. One suggestion is to divide emissions into "luxury" and "subsistence" categories, and target the luxury emissions. A second suggestion is to divide categories on the basis of the level of uncertainty and to target sources with the least uncertainty for abatement. Whatever the details of the eventual arrangements may be, it is clear that comprehensive abatement encapsulates all the nuances and difficulties of implementing climate change policies. Scientific uncertainty, uncertainty in impacts, and the global geopolitical context are all important determinants in making sound policy choices. The challenge is to find mutually acceptable common ground for all the concerned parties.

**FURTHER READING**


**GLOSSARY OF TERMS**

**Non linear impacts**: Impacts of climate change will be non-linear with respect to climate if they accelerate with increasing levels of climate change. For example, impacts that are a quadratic function of mean global temperature increase much faster than increases in mean global temperature. Similarly, cubic impacts increase much faster than mean global temperature change.

**Discount rate**: Long term strategies may require the aggregation of costs and benefits accrued over time to a common comparative basis. In the case of climate change, one may want to compare the costs of reducing emissions with the future benefits of these reductions. Discount rates provide a mechanism to translate future costs and benefits to a current basis, typically by comparing the utility of a monetary unit (e.g., a dollar) at the present time to the expected future value of the same amount. Since economists expect richer future generations to value a dollar less than do present generations, they tend to "discount" the utility of a future dollar.

**Radiative Forcing**: Radiative forcing refers to the ability of greenhouse gases and aerosols to change the balance of incoming radiation from the sun and outgoing radiation from the earth. These balances determine earth's climate. A change in the balance leads to climate change.

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