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MATTERS RELATING TO COMMITMENTS

METHODOLOGICAL ISSUES

Addendum

METHODOLOGIES TO CALCULATE THE CONTRIBUTIONS OF DIFFERENT GASES TO CLIMATE CHANGE: GLOBAL WARMING POTENTIALS

Note by the interim secretariat

CONTENTS

Annexes

I. INTRODUCTION

A. Committee mandate and Convention provisions

1. At its eighth session, on the basis of the recommendations of Working Group I, the Committee adopted a number of conclusions on matters related to methodologies, drawn from the Convention, the debate and background documents (notably document A/AC.237/34, "Matters relating to commitments: methodologies for calculations/inventories of emissions and removals of greenhouse gases"). In particular, the Committee considered the issue of how to calculate the contributions of different gases to climate change taking into consideration the concept of global warming potentials. It was pointed out that the methodologies for this latter purpose, as far as they deal with calculations of emissions by sources and removals by sinks, are not identical to those used for the preparation of inventories as referred to in Article 12.1 of the Convention.

2. Interest in the comparison of the relative effects of the different greenhouse gases stems from Article 4, paragraph 2 (c), of the Convention: "Calculations of emissions by sources and removals by sinks of greenhouse gases for the purposes of subparagraph (b) ... [communicating information on policies and measures], should take into account the best available scientific knowledge, including of the effective capacity of the sinks and the respective contributions of such gases to climate change" (emphasis added).

B. Scope of the note

3. The interim secretariat was requested to prepare a compendium of relevant existing studies (see A/AC.237/41, para. 43). The present note responds to this request while at the same time reviewing the current state of knowledge of the global warming potentials of the various greenhouse gases. The note also highlights some of the issues surrounding the global warming potential concept with a view to stimulating discussion in the Committee.

II. THE GLOBAL WARMING POTENTIAL (GWP) CONCEPT

4. In preparing this note extensive recourse has been made to the findings of the Intergovernmental Panel on Climate Change (IPCC). In its first Scientific Assessment of Climate Change (1990), the IPCC observed that the climate of the Earth has the potential to be changed on all time-scales by the way in which shortwave radiation from the Sun is scattered and absorbed by the Earth and its atmosphere as well as by the way thermal infrared radiation is absorbed and emitted by the Earth-atmosphere system. If the climate system is in equilibrium then the absorbed solar energy is exactly balanced by the radiation emitted to space by the Earth and the atmosphere. Any factor that is able to disturb this balance, and thus potentially alter the climate is called a radiative forcing agent. The greenhouse gases covered by the Convention are among the most significant radiative forcing agents. Other radiative forcing agents not covered by the Convention include, for example, stratospheric ozone, ozone depleters (chlorofluorocarbons (CFCs)), aerosols, solar radiation and albedo change. Water vapour which is also a powerful, naturally occurring greenhouse gas, is not usually taken into account in the context of the Convention.

5. The major contributor to increases in radiative forcing due to increased concentrations of greenhouse gases (covered by the Convention) since pre-industrial times is carbon dioxide (CO_2) (more than 50 per cent), with substantial contributions from methane (CH_4) and nitrous oxide (N_2O). Stratospheric water vapour increases, which are expected to result from methane emissions, also contribute. Thus, increased concentrations of greenhouse gases increase radiative forcing, and the total radiative forcing, at any time, is the sum of those from the individual gases. It should also be noted that gases can exert forcing both directly and indirectly: direct forcing occurs when a gas itself is a greenhouse gas; indirect forcing occurs when chemical transformation of the original gas produces a gas or gases which are themselves greenhouse gases or which affect other greenhouse gases. The sign of the indirect forcing can be positive or negative (see para. 6 below, for example). In the former case, the indirect forcing reinforces the direct effect; in the latter, it reduces the direct effect.

6. The concept of the global warming potential (GWP) has been developed for policy makers as a measure of the possible warming effect on the surface to the troposphere layer of the atmosphere (that is, to an altitude of approximately 10 km. from the surface), arising from the emission of each gas relative to CO_2. It defines the warming effect of 1kg of each gas relative to that of CO_2 for a specified period of time subsequent to the emission. Numerical estimates (IPCC, 1992) of the direct GWPs and the sign of the indirect effects of several greenhouse gases for a 100-year time horizon are given the table below.

DIRECT GLOBAL WARMING POTENTIALS (GWPs) FOR 100-YEAR TIME HORIZON

Gas	Direct GWP	Sign of the indirect component of the GWP
Carbon dioxide	1	none
Methane	11	positive
Nitrous oxide	270	uncertain
CFC-11	3400	negative
CFC-12	7100	negative
HCFC-22	1600	negative
HFC-134a	1200	none

7. In the 1992 Supplement, the IPCC took into account significant advances in understanding of the impact of ozone depletion and sulphate aerosols (particulate matter in the atmosphere) and of the concept of GWPs. The IPCC concept of GWPs, as well as its views on its limitations, as extracted from the 1992 Supplementary Report to the IPCC Scientific Assessment, is reproduced in annex I to this note.

8. The IPCC study of radiative forcing and GWPs continues and will form part of the Second IPCC Scientific Assessment scheduled for 1995. Preliminary results will be available in late 1994. If the state of scientific knowledge allows, these might include quantitative estimates of GWPs.

9. A summary of major research topics associated with GWPs, for which there is substantial work in progress, is given in annex II to this note.

III. ADVANTAGES AND LIMITATIONS OF GWPs

Advantages of GWPs

10. GWPs are useful in several policy contexts, including the following:

(a) They can assist in assessing the total effect on climate of measures taken to limit emissions of different gases, as well as in comparing individual national efforts;

(b) They could function as a quantitative signal to industries and policy makers, thereby encouraging some activities and discouraging others. They can also contribute to assessment of trade-offs between technologies, for example, weighting with GWPs in comparing methane vis-à-vis gasoline (carbon dioxide) as a transportation fuel;

(c) They can be the quantitative basis to a "basket" approach to greenhouse gas emission reductions. For example, the product of a gas's GWP and the amount by which the emissions of that gas are reduced (or its removal increased) would yield the equivalent reduction in global radiative forcing achieved. With an internationally agreed-upon index and related application guidelines, a country could reduce its contribution to global radiative forcing by reducing the emissions (or increasing the removal) of a particular gas by "x equivalent units", with a view to achieving the greatest benefit at the least cost.

11. Given the above utility, GWPs could be used in implementation of the Convention, in the development of international and national policy tools, and in refinements of the IPCC process, thereby providing an opportunity for science to support the decision-making process.

Limitations of GWPs

12. The GWP concept as developed by the IPCC is a useful first step in the direction of the comparison of the contributions of the different greenhouse gases to climate change. However, in addition to the difficulties associated with estimating the indirect effects for some gases, it is important to recognize that it is unlikely to be possible to develop indicators which, through a single number, will allow for the comparison of all the effects of the different greenhouse gases upon the climate itself. It is possible, however, to compute a table reflecting the contribution of unit (1kg) emissions by source and removals by sinks of a given gas, relative to a reference gas, normally taken as CO_2. Time horizons used in such calculations could include 20, 50, 100 and 500 years.

13. Currently, scientists view the work on GWPs as preliminary, but policy makers, notably in the Conference of the Parties (COP), will soon need agreed reference values that are simple to use.

14. Because GWPs will be involved at the policy/science interface, it will be important for those scientists involved in formulating agreed reference values to be aware and take account of the questions from the policy perspective that are associated with the reference values and their application.

15. Human-influenced trace gases are also associated with other global issues (for example, acidification). When applying the GWP concept, these other properties should also be kept in mind.

16. The limitations of GWPs are further discussed at length in the extract from the IPCC 1992 Supplementary Report given in annex I.

IV. QUESTIONS FOR CONSIDERATION BY THE COMMITTEE

17. There are clearly many questions to be answered, not all of which are purely scientific; policy decisions will also be required. Such questions, which the Committee may wish to discuss, include the following:

(a) What gases should be included in an agreed reference values scale?

(b) Can guidelines be agreed upon to facilitate the use and comparability of GWPs, for example, base year and concentrations?

(c) What time horizon(s) might be the most appropriate (20, 50, 100, 500 years or other), given the varying residence times of the individual greenhouse gases in the atmosphere?

(d) Should GWPs be used in national communications?

18. Answers to the above questions are particularly important for the development of guidelines on the preparation of first communications by Annex I Parties. As noted in document A/AC.235/45, decisions on such guidelines will be required at the ninth session if the guidelines are to be available to Annex I Parties in time to be useful. In this context, it will be recalled that document A/AC.235/45, while proposing that any use of GWPs in national communications be based on a fully disaggregated and detailed inventory (including a summary table with original emissions and removals data), also invites the Committee to provide further guidance pursuant to its consideration of the present document.

Annex I

EXTRACT FROM THE 1992 SUPPLEMENTARY REPORT TO THE IPCC SCIENTIFIC ASSESSMENT

A2.3 THE GLOBAL WARMING POTENTIAL (GWP) CONCEPT

The aim of the GWP index is to offer a simple characterization of the relative radiative effects of the well-mixed species. It was created in order to enable policy makers to evaluate options that affect the emissions of various greenhouse gases, by avoiding the need to make repeated, complex calculations. IPCC (1990) discussed the GWP concept in considerable detail and only the salient features are addressed here. However, as noted below, there are serious limitations associated with the calculation of GWPs that constrain their practical utility.

A2.3.1 Definition

The Global Warming Potential is a measure of the relative, globally-averaged warming effect arising from the emissions of a particular greenhouse gas.

- It is a **relative** measure in that it expresses the warming effect compared to that of a reference gas (or ‘molecule’).
- It is a **global** measure in that it is derived from the globally- and annually- averaged net radiative fluxes at the tropopause, and thus describes the effects on the whole surface-troposphere system.
- It is a **time-integrated** measure of warming over a specified time horizon, taking account of the change with time of the species concentration.

The GWP of a well-mixed gas was defined in IPCC (1990) as the time-integrated change in radiative forcing due to the instantaneous release of 1kg of a trace gas expressed relative to that from the release of 1kg of CO_2. Calculation of the GWP for a particular species requires specification of the following:

(i) the radiative forcing both of the reference gas and of the species, per unit mass or concentration change;

(ii) the time horizon over which the forcings have to be integrated;

(iii) the atmospheric lifetime both of the species and of the reference gas;

(iv) the pathway of chemical breakdown of the species and the extent to which it gives rise to other greenhouse species, e.g., O_3 production from CH_4, NO_x, CO and NMHCs;

(v) the present and future chemical state of the atmosphere, i.e., levels of the background concentrations of various species throughout the troposphere;

(vi) the present and future physical state of the atmosphere, i.e., values of meteorological variables throughout the troposphere (e.g., temperature profile, cloud properties).

Factors (iii) and (iv) are intimately related to (v) and (vi) and are the sources of greatest uncertainty in the calculation GWPs - see section A2.3.4 below.

It is possible to offer alternative definitions of GWP, for example based on sustained rather than pulse emissions (Wigley et al., 1990). Such alternatives can lead to numerical values of GWP which are different from those under the present definition, but in general not so different as to alter the relative ranking of the important species.

A2.3.2 Reference Molecule

Given the conceptual framework of the GWP and its implications for policy-making, the choice of a reference molecule is dictated by the need to evaluate the results in terms of the dominant contributor in the greenhouse gas problem. IPCC (1990) therefore chose CO_2 as the reference gas for the determination of GWPs. Although another gas or surrogate would have a simpler atmospheric decay behaviour compared to CO_2 (e.g., CFCs, see Fisher et al., 1990), the evaluation of GWPs presented here continues, after extensive review, to use CO_2 as the reference gas.

To avoid the need to use a single lifetime for CO_2, IPCC (1990) used a carbon cycle model to calculate the integrated radiative forcing for CO_2, specifically the ocean-atmosphere box diffusion model of Siegenthaler and Oeschger (1987; see also Siegenthaler, 1983) which assumed a net neutral biosphere.

A2.3.3 Time Horizons for GWPs

Because greenhouse gases have a variety of removal mechanisms they have different residence times, or lifetimes, in the atmosphere. The calculated value of GWP thus depends on the integration period chosen. There is no single value of integration time for determining GWPs that is ideal over the range of uses of this concept, though the choice of a time-scale for integration in the GWP calculation need not be totally arbitrary (see IPCC (1990) and WMO (1992) for a discussion on the choice of time horizons). In this [i.e. 1992 Supplementary Report to the IPCC Scientific Assessment] report GWPs are calculated over time horizons of 20, 100 and 500 years (as employed in IPCC, 1990). It is believed these three time horizons provide a practical range for policy applications.

A2.3.4 Limitations of Present GWPs

While the GWP, as defined in IPCC (1990), is a convenient and reasonably practical index for ranking the relative and cumulative impact of greenhouse gas emissions, it has the following limitations, some of which are very serious:

(a) the modelling of radiative transfer within the atmosphere contains uncertainties, as was pointed out in IPCC (1990);

(b) since the direct GWP is a measure of the global effect of a given greenhouse gas emission, it is most appropriate for well-mixed gases in the troposphere (e.g., CO_2, CH_4, nitrous oxide (N_2O)

and halocarbons). The radiative forcing employed in the determination of GWPs does not purport to characterize the latitudinal and seasonal dependence of the change in the surface-troposphere radiative fluxes. Different well-mixed gases can yield different spatial patterns of radiative forcings (Wang et al., 1991);

(c) the GWP definition used here considers only the surface-troposphere radiative forcing rather than a particular response (e.g., surface temperature) of the climate system. While the surface-troposphere radiative flux perturbations can be related to temperature changes at the surface in the context of one-dimensional radiative-convective models (WMO, 1986), such a general interpretation for the temperature response either in three-dimensional General Circulation Models or in the actual surface-atmosphere system must be approached with caution. Further, although the GWP of a well-mixed gas can be regarded as a first-order indicator of the potential global mean temperature change due to that gas relative to CO_2, it is inappropriate for predicting or interpreting regional climate responses;

(d) GWP values are sensitive to uncertainties regarding atmospheric residence times. Thus, revisions to GWP values should be expected as scientific understanding improves. Because CO_2 is used as the reference gas, any revision to the calculation of its integrated radiative forcing over time will change all GWP values. GWP results are also sensitive to the choice of carbon cycle model used to calculate the time-integrated radiative forcing for CO_2. In particular, because the Siegenthaler-Oeschger model has only an ocean CO_2 sink, it is likely to overestimate the concentration changes and to lead to an underestimate of both the direct and the indirect GWPs. The magnitude of this bias depends on the atmospheric lifetime of the gas, and the time horizon:

(e) as defined here, GWPs assume constant concentration backgrounds at current levels. The calculated GWPs depend on the assumed background level(s). The indices are calculated for the contemporary atmosphere and do not take into account possible changes in the chemical composition of the atmosphere. Changes in radiative forcing due to CO_2 , CH_4 and N_2O concentration changes are non-linear with respect to these changes. The net effect of these non-linearities is such that, as CO_2 gases increase from present values, the GWPs of all non-CO_2 gases would become higher than those evaluated here (see WMO, 1992);

(f) for the GWP concept to be most useful, both the direct and the indirect components need to be quantified. However, accurate estimates of the indirect effects are more difficult to obtain than those for the direct effects for the following reasons:

  (i) there are uncertainties in the details of the chemical processes as well as in the spatial and temporal variations of species involved in such transformations. As shown later, there is fair confidence in the sign of some of the indirect effects; however, precise estimates are lacking. Because of our incomplete understanding of chemical processes, it is now recognized that the uncertainties in the indirect components of GWPs reported in IPCC (1990) are so large that their use can no longer be recommended;

  (ii) for gases that are not well-mixed (e.g., tropospheric ozone precursors), the GWP concept may not be meaningful;

(iii) further, while the GWP concept thus far has been applied to gases with perturbations only in the longwave spectra, it may not adequately account for the seasonally and latitudinally varying radiative effects due to inhomogeneously distributed species with a significant interaction in the solar spectrum (e.g., aerosols).

In conclusion, given the above limitations, great care must be exercised in applying GWPs in the policy arena.

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Annex II

SUMMARY OF MAJOR RESEARCH TOPICS ASSOCIATED WITH GLOBAL WARMING POTENTIALS FOR WHICH THERE IS SUBSTANTIAL WORK IN PROGRESS

Substantial research is under way regarding several scientific aspects of the global warming potential concept and calculations, which include the following:

1. Indirect components. Numerous chemical species have substantial indirect contributions to radiative forcing. IPCC (1992) pointed out that the difficulties in meaningful calculations of these components were more challenging than had been originally thought. Subsequently, research has focused on trying to improve such calculations. The investigations include:

   ° An emphasis on a better characterization of the multiple indirect effects associated with methane.

   ° A comparison of lower-atmospheric models to examine the status of the current understanding of the chemical and other processes that influence the indirect components of methane’s GWP. Such results will provide critical insight into how well these indirect components of the methane GWP can be reliably specified at present.

   ° Testing how well the GWP concept can be applied to carbon monoxide, whose atmospheric processes are similar to those of methane.

2. Net GWP for the ozone-depleting substances. WMO (1992) and IPCC (1992) pointed out that the lower-stratospheric ozone depletion introduced a cooling (i.e., negative) component to the GWP of chemical species that deplete stratospheric ozone. Since that finding, several researchers have begun to work on a quantitative estimate of the sum of the positive and negative components for each of the major ozone-depleting substances (e.g., chlorofluorocarbons and halons).

3. Exploration of alternate forms of specifying GWPs. Traditionally, GWPs have been expressed in terms of the radiative forcing of a given chemical species relative to that of carbon dioxide. Since the knowledge of the removal mechanisms for carbon dioxide are still being improved quantitatively, the use of it as the basis of the GWP scale has implied that the GWPs of all other species change when the knowledge of carbon dioxide improves. Researchers are exploring options for different ways of specifying a GWP, e.g., (i) expression of radiative forcing in absolute, not relative, units and (ii) the use of a standard, carbon-dioxide-like molecule as the reference.

4. Other improvements in concepts and calculations. Investigators are examining the sensitivity of GWP calculations to several assumptions made in calculations of these global-averaged quantities, e.g., (i) the potentially different latitudinal and vertical radiative forcings of the various greenhouse gases, (ii) changing atmospheric concentrations of other greenhouse gases, and (iii) variation in atmospheric properties (e.g., clouds and water vapour) due to climate change.

The time-scales for which results on these and other topics will be forthcoming in the peer-reviewed scientific literature will vary considerably for the various topics, since the degree of complexity and difficulty is quite different for the separate areas of endeavour. This pace, as well as unforeseen future discoveries, will influence the conclusions of future assessments of the state of understanding of this topic.

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