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Information on Global Warming Potentials

Technical Paper

Summary

Global Warming Potentials (GWPs) are used to estimate, compare and aggregate the relative climate effects of various greenhouse gases (GHGs). They are a measure of the relative radiative effect of a given substance compared to another, integrated over a chosen time horizon. This note provides basic information on GWPs and their use under the Convention and the Kyoto Protocol, in particular their use in guidelines for reporting GHG inventories and for preparation of national communications by Parties.

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I. Introduction

1. Decisions 2/CP.3, 17/CP.8 and 18/CP.8, as well as Article 5.3 of the Kyoto Protocol, state how Global Warming Potentials (GWPs) should be used in the context of the Convention and the Kyoto Protocol.

2. This document gives information on the definition, characteristics and use of GWPs in the work under of the Convention. It draws primarily on information in the Second Assessment Report (SAR) and the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), and on emission data from the GHG inventories of Parties reported to the UNFCCC.

II. What are Global Warming Potentials?

A. Definition

3. The TAR describes GWPs as "a measure of the relative radiative effect of a given substance compared to another, integrated over a chosen time horizon" (TAR, chapter 6.12.1). In the glossary of the TAR, GWPs are defined in more detail as "an index, describing the radiative characteristics of well mixed GHGs, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide (CO_2)." Carbon dioxide, the so-called reference gas, is assigned a GWP value of 1, independent on the time horizon used or other parameters that can influence GWPs of other GHGs. Annex I to this note contains the mathematical definition of GWPs.

B. Characteristics

1. Basic concept

4. The formulation of GWPs is based on the forcing concept, which relies on the relationship between radiative forcing and climate response. Recent studies have supported the view that various GHGs yield similar globally averaged climate responses per unit of forcing. Forcing values (with units of W/m^2) can therefore be added and compared, which is not the case for emissions (with units of mass) of different GHGs. For example, the emission of 1 kg CO_2 causes a different effect on climate to the emission of 1 kg CH_4, but a forcing of 1 W/m^2 is assumed to cause the same effect on climate, whichever gas is responsible for the forcing. Based on the forcing concept, GWPs are a metric that allows the climate effects of different GHGs to be compared and aggregated.

5. The greater the GWP of a GHG, the greater its ability to cause global warming. A GWP for CH_4 of 21, for instance, means that 1 kg of CH_4 causes 21 times more effect on global warming than 1 kg of CO_2 (which has a GWP of 1).

2. Parameters

6. A GWP value depends on two parameters:

(a) The ability of the GHG to trap heat in the atmosphere (described via its radiative forcing, or more explicitly its radiative efficiency

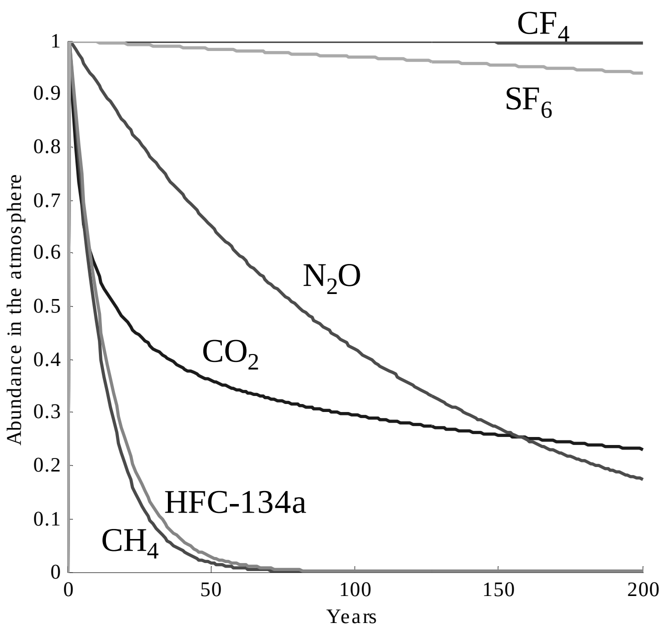
(b) The lifetime of the GHG (described via its decay in the atmosphere).

7. Annex I describes these parameters mathematically and lists values for some key GHGs.

8. The radiative efficiency of a gas in the atmosphere is not constant. For CO_2, in particular, it depends on the atmospheric concentration of the gas itself; the higher its atmospheric concentration the lower its radiative efficiency. Therefore, changes of the concentration of the reference gas CO_2 impact on the GWPs of all other GHGs.[1] This means that GWPs are not constant over time and can only be calculated for given concentrations of GHGs. These natural changes of GWPs over time, as well as constantly improved and up-dated scientific knowledge, are the main reasons for the differences among GWP values given in various IPCC reports. GWP values published by the IPCC are listed in annex II.

9. The decay of key GHGs is illustrated in figure 1. Some gases, such as SF_6 and CF_4, decay slowly and remain in the atmosphere for thousands of years (see also table 1 in annex I).

Figure 1: Decay of some greenhouse gases in the atmosphere



3. <u>Time horizon</u>

10. A GWP can be calculated only for specified time horizons. The IPCC provides GWPs for time horizons of 20, 100 and 500 years (see table 1). The GWPs of GHGs with a lifetime longer than that of CO_2 (e.g. CF_4, SF_6) increase with increasing time horizon; GHGs with a lifetime shorter than that of CO_2 (e.g. CH_4) show a decreasing GWP when the time horizon increases.[2]

11. Therefore, the choice of the time horizon has implications on the relative weight of different gases when applying the GWP metric. Short-lived gases get more weight when a short time horizon is chosen, long-lived gases when the choice is a long time horizon.

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[1] This does not influence a relative comparison, based on the GWP metric, among non-CO_2 gases.

[2] The lifetime of CO_2 is nominally about 150 years, but no single number can be given because of the various processes involved in the removal of CO_2 from the atmosphere.

Table 1: Global Warming Potentials of some key GHGs for time horizons of 20, 100 and 500 years

Gas	GWP for time horizons of		
	20 years	100 years	500 years
CO_2 (reference gas)	1	1	1
CH_4	62	23	7
N_2O	275	296	156
HFC-134a	3 300	1 300	400
CF_4	3 900	5 700	8 900
SF_6	15 100	22 200	32 400

Source: Third Assessment Report of the IPCC.

III. Global Warming Potentials in the work under the Convention

A. Greenhouse gas inventories

12. The UNFCCC guidelines on reporting and review of GHG inventories[3] state that Annex I Parties should report aggregated emissions and removals of GHGs using GWP values provided by the IPCC in its SAR based on the effects of GHGs over a 100-year time horizon. Decision 17/CP.8 states that the same GWP values should be used by non-Annex I Parties wishing to report.

13. For reporting purposes, emission values in mass units are multiplied by the GWP of the relevant gas to yield emissions in CO_2 equivalents. Hence, an emission of 1 gigagram (Gg) CH_4, multiplied by its GWP of 21 gives a CO_2 equivalent of 21 Gg. This indicates that the emission of 1 Gg CH_4 has the same effect on climate as the emission of 21 Gg CO_2.

14. A practical example, using data from the UNFCCC Greenhouse Gas Inventory Database, is given in table 2. The table contains, for the years 1990 and 2000, emissions of some important GHGs, reported by the European Community,[4] and corresponding CO_2 equivalents calculated by using the GWP values from the SAR over a 100-year time horizon.

[3] "Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC guidelines on annual inventories" (FCCC/CP/2002/8).

[4] The European Community was chosen as one possible example to compare data of the years 1990 and 2000. For more detailed information on the reporting by individual Member States of the European Community, please refer to documents FCCC/SBSTA/2003/14 and FCCC/WEB/2003/3. The database contains comprehensive information on all reported data from Annex I and non-Annex I countries, currently for all years from 1990 to 2000. Therefore, comparable aggregations/comparisons can be made for other countries or groups of countries, and also for specific sources.

Table 2: Example for the aggregation and comparison of different GHG emissions via the calculation of CO_2 equivalents using GWPs

	1990			2000		
Gas	Emissions (Gg)	CO_2 equivalents (Gg)	Relative contribution (%)	Emissions (Gg)	CO_2 equivalents (Gg)	Relative contribution (%)
CO_2	3 341 804	3 341 804	79.27	3 324 800	3 324 800	81.74
CH_4	20 310	426 506	10.12	16 275	341 771	8.40
N_2O	1 293	400 948	9.51	1 091	338 111	8.31
HFCs		24 426	0.58		47 285	1.16
PFCs		13 545	0.32		6 846	0.17
SF_6		8 440	0.20		8 955	0.22
Total		**4 215 668**	**100**		**4 067 767**	**100**

Source: UNFCCC Greenhouse Gas Inventory Database, accessible via <http://ghg.unfccc.int>. Shown are data reported to UNFCCC by the European Community for the years 1990 and 2000.

15. Conversions of GHG emissions into CO_2 equivalents are used in many ways within the inventory work under the Convention. Some examples are included in document FCCC/SBSTA/2003/14, such as trends in aggregated GHG emissions for groups of Parties since 1990, total aggregated GHG emissions of individual Parties for certain time periods, and GHG emissions by sector.

16. Currently, emissions are converted into CO_2 equivalents using GWP values from the SAR for a time horizon of 100 years. Table 3 contains an example showing the differences that occur when TAR values are used instead of SAR values. The CO_2 equivalents change considerably.

Table 3: Differences when applying TAR vs. SAR GWPs. The example is for three important GHGs using data reported by the European Community for the year 2000

		GWP (100-year time horizon)		CO_2 equivalents (Gg)		
Gas	Emissions (Gg)	SAR	TAR	SAR	TAR	Change SAR→TAR %
CO_2	3 324 800	1	1	3 324 800	3 324 800	0.0
CH_4	16 275	21	23	341 771	374 321	+9.5
N_2O	1 091	310	296	338 111	322 841	-4.5
Total:				**4 004 682**	**4 021 962**	**+0.4**

17. Annex III shows the CO_2 equivalents of emissions reported by all Annex I Parties for 1990 and 2001 calculated using SAR and TAR GWPs.

B. Kyoto Protocol provisions

18. The Kyoto Protocol, in its Article 5.3, states that the GWPs used to calculate CO_2 equivalents shall be those accepted by the IPCC and agreed upon the Conference of the Parties (COP) at its third session. Article 5.3 further states that based on the work of, inter alia, the IPCC and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as a

meeting of the Parties to the Kyoto Protocol shall regularly review and, as appropriate, revise the GWPs of the Kyoto GHGs. Any revision to a GWP shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

19. Decision 2/CP.3 on methodological issues relating to the Kyoto Protocol reaffirms that the GWPs used by Parties should be those provided by the IPCC in its SAR, based on the effects of GHGs over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in GWP estimates. For information purposes only, Parties may also use another time horizon, as provided in the SAR.

20. In addition, the use of the Kyoto Protocol mechanisms, i.e. the clean development mechanism (CDM, Article 12), Joint Implementation (JI, Article 6) and International Emissions Trading (IEM, Article 17), requires the application of GWP values (see decisions 16/CP.7, 17/CP.7, 18/CP.7 and 19/CP.7). For example, CH_4 emission reductions achieved through a CDM project have to be converted into CO_2 equivalent units to yield certified emission reduction units.

IV. Discussion

21. GWPs represent a metric that allows the relative climate effects of various GHGs to be estimated, compared and aggregated. They are presently used in the work under the Convention and the Kyoto Protocol. The GWP metric has advantages (e.g. simplicity in use) as well as uncertainties (radiative forcing and lifetime/decay estimates for GHGs). It also requests the choice of a time horizon.

22. As noted in chapter III, the COP, in its various decisions, has included the use of the GWP values provided by the IPCC in its SAR, based on the effects of GHGs over a 100-year time horizon. The IPCC has provide updated information on GWPs in its TAR; it is likely to do so in its Fourth Assessment Report. Also, as stated in the TAR, a number of studies have suggested modified or different indices (than GWP) for evaluating relative future climate effects.

23. Questions that may effect the use of GWPs in future work under the Convention, include:

(a) How and when should new GWP values be incorporated into the work of the Convention?

(b) How should the Convention apply updated, i.e. changing, GWP values in the future?

(c) Which time horizon(s) is (are) most appropriate to achieve the goals of the Convention?

(d) Could considering alternative metrics than GWP support the work under the Convention?

Annex I

Calculation of Global Warming Potentials

1. Global Warming Potentials of given substances are calculated with the following equation (IPCC TAR, 2001):

$$GWP(x) = \frac{AGWP(x)}{AGWP(r)} = \frac{\int_0^{TH} a_x \cdot [x(t)]\, dt}{\int_0^{TH} a_r \cdot [r(t)]\, dt} \qquad \text{(E.1)}$$

where:

x	=	Substance in question (usually a GHG)
r	=	Reference gas (usually CO_2)
GWP	=	Global Warming Potential
AGWP	=	Absolute Global Warming Potential
TH	=	Time horizon
a	=	Radiative efficiency ($W/m^2/kg$)
[x(t)]	=	Time-dependent decay in abundance of the instantaneous release of substance *x*
[r(t)]	=	As above, but for the reference gas *r*

2. The numerator in equation E.1 expresses the integrated forcing of a pulse emission of substance *x* over the chosen time horizon *TH*, and is called Absolute Global Warming Potential of the substance. The denominator represents the same, but for the reference gas *r*, which is CO_2 in the context of this paper. A GWP therefore represents the integrated forcing of a pulse emission of a substance relative to that one of CO_2 over a chosen time period.

3. If the GWP is to be calculated for a GHG and the reference gas and the time horizon are chosen to be CO_2 and 100 years, respectively, the equation to calculate the GWP is a specific case of equation E.1 and reads as follows:

$$GWP(GHG) = \frac{AGWP(GHG)}{AGWP(CO_2)} = \frac{\int_0^{100\,years} a_{GHG} \cdot [GHG(t)]dt}{\int_0^{100\,years} a_{CO_2} \cdot [CO_2(t)]dt} \qquad \text{(E.2)}$$

4. The table below lists values of the radiative efficiency a_{GHG} and the lifetime for key GHGs, which can be derived from the time-dependent decay *[GHG(t)]* of these GHGs.

Radiative efficiency and lifetime of GHGs (Source: IPCC TAR)

Gas	Radiative efficiency ($W/m^2/ppmv$)	Lifetime (years)
CO_2 at 278 ppmv (pre-industrial)	0.0192	no single number
CO_2 at 364 ppmv	0.01548	
CH_4	0.37	12
N_2O	3.1	114
HFC-134a	150	13.8
CF_4	80	50 000
SF_6	520	3 200

Annex II

Global Warming Potentials published by the Intergovernmental Panel on Climate Change

1. The table below summarizes Global Warning Potentials (GWPs) for a choice of greenhouse gases (GHGs) as published in the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). The values correspond to a chosen time horizon of 100 years and to the use of CO_2 as reference gas (see equation E.2 in annex I).

Global Warming Potentials for a 100-year time horizon from various IPCC sources

Gas	IPCC 1992	IPCC 1994	IPCC 1995 (SAR)	IPCC 2001 (TAR)
CO_2 (reference gas)	1	1	1	1
CH_4	11	24.5	21	23
N_2O	270	320	310	296
HFC-23	-	12 100	11 700	12 000
HFC-32	-	580	650	550
HFC-41	-	-	150	97
HFC-125	3 400	3 200	2 800	3 400
HFC-134	-	1 200	1 000	1 100
HFC-134a	1 200	1 300	1 300	1 300
HFC-143	-	290	300	330
HFC-143a	3 800	4 400	3 800	4 300
HFC-152	-	-	-	43
HFC-152a	150	140	140	120
HFC-161	-	-	-	12
HFC-227ea	-	3 300	2 900	3 500
HFC-236cb	-	-	-	1 300
HFC-236ea	-	-	-	1 200
HFC-236fa	-	8 000	6 300	9 400
HFC-245ca	-	610	560	640
HFC-245fa	-	-	-	950
HFC-365mfc	-	-	-	890
HFC-43-10mee	-	1 600	1 300	1 500
CF_4	-	6 300	6 500	5 700
C_2F_6	-	12 500	9 200	11 900
C_3F_8	-	-	7 000	8 600
C_4F_{10}	-	-	7 000	8 600
$c\text{-}C_4F_8$	-	9 100	8 700	10 000
C_5F_{12}	-	-	7 500	8 900
C_6F_{14}	-	6 800	7 400	9 000
SF_6	-	24 900	23 900	22 200

Source: Climate Change, 1992; Climate Change, 1994; Second Assessment Report, 1995; Third Assessment Report, 2001.

2. Differences between GWPs from different IPCC reports are due to both natural reasons, such as the dependence of GWPs on the changing CO_2 concentration level (see section II.2) and adjustments due to improved scientific knowledge.

3. Difference also occur as a result of decisions made on including certain indirect effects in the GWPs. The large change between the GWPs of CH_4 published in the 1992 and 1994 IPCC reports, for instance, is a result of including the indirect effects of tropospheric ozone production and stratospheric water vapour production in the GWP calculation. More detailed information is to be found in the respective IPCC reports.

4. IPCC SAR and TAR estimate an accuracy for GWP values of ±35 per cent.

Annex III

Greenhouse gas emissions reported by Parties

1. The table below compares emissions reported by Parties included in Annex I of the Convention calculated using SAR or TAR GWP values.[1] The values given in the table summarize emissions of CO_2 (excluding land-use change and forestry), CH_4 and N_2O and are given in gigagram CO_2-equivalent. These three key GHGs included in the table account, on average, for about 98 per cent of the total emissions reported by Parties. Emissions of SF_6, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) were omitted from the table because not all Parties have reported consistently on these substances.

Total emissions of CO_2, CH_4 and N_2O calculated using GWP values from the SAR or the TAR for the years 1990 and 2001 (years used in lieu of those are explicitly listed)

Party	Emissions of the year 1990 (Gg CO_2 equivalent)			Emissions of the year 2001 (Gg CO_2 equivalent)		
	SAR	TAR	SAR→TAR change (%)	SAR	TAR	SAR→TAR change (%)
Australia	419 912	430 185	+2.4	year 2000: 499 966	510 054	+2.0
Austria	76 588	77 343	+1.0	84 145	84 740	+0.7
Belarus	133 555	135 062	+1.1	year 2000: 71 343	72 273	+1.3
Belgium	141 125	141 644	+0.4	149 184	149 633	+0.3
Bulgaria	year 1988: 144 397	145 966	+1.1	65 775	66 340	+0.9
Canada	598 744	603 326	+0.8	711 026	717 606	+0.9
Croatia	31 006	31 193	+0.6	year 1995: 22 252	22 416	+0.7
Czech Republic	192 019	193 107	+0.6	146 773	147 397	+0.4
Denmark	69 174	69 224	+0.1	68 710	68 849	+0.2
Estonia	43 494	43 863	+0.8	19 416	19 587	+0.9
Finland	77 138	77 365	+0.3	80 156	80 347	+0.2
France	560 513	562 913	+0.4	556 368	558 906	+0.5
Germany	1 203 413	1 209 069	+0.5	983 154	985 402	+0.2
Greece	103 702	104 055	+0.3	127 742	128 317	+0.4
Hungary	years 1985-87: 101 633	102 781	+1.1	77 996	78 588	+0.8
Iceland	2 529	2 551	+0.9	2 583	2 604	+0.8
Ireland	53 241	53 943	+1.3	69 423	70 150	+1.0
Italy	507 707	509 543	+0.4	541 531	542 997	+0.3
Japan	1 187 108	1 187 654	+0.0	1 269 382	1 269 721	+0.0
Latvia	29 181	29 402	+0.8	11 497	11 685	+1.6
Liechtenstein	218	219	+0.6	year 1999: 218	220	+0.5

[1] The status of reporting used for drawing up this table is consistent with the information contained in documents FCCC/SBSTA/2003/14 and FCCC/WEB/2003/3 (web document with tables), published on 17 October 2003. A comparable table, possibly for other reporting years, can also be prepared for non-Annex I Parties once the initial national communications are complete.

Total emissions of CO_2, CH_4 and N_2O calculated using GWP values from the SAR and the TAR (continued)

Party	Emissions of the year 1990 (Gg CO_2 equivalent)			Emissions of the year 2001 (Gg CO_2 equivalent)		
	SAR	TAR	SAR→TAR change (%)	SAR	TAR	SAR→TAR change (%)
Lithuania	50 933	51 505	+1.1	year 1998: 22 520	22 718	+0.9
Luxembourg	13 448	13 487	+0.3	6 052	6 093	+0.7
Monaco	100	100	0.0	140	140	0.0
New Zealand	61 149	63 123	+3.2	72 072	74 082	+2.8
Norway	46 795	47 159	+0.8	54 141	54 555	+0.8
Poland	year 1988: 564 419	569 714	+0.9	380 610	383 226	+0.7
Portugal	61 441	62 066	+1.0	83 754	84 417	+0.8
Romania	year: 1989: 264 280	268 019	+1.4	147 583	149 960	+1.6
Russian Federation	2 998 767	3 048 607	+1.7	year 1999: 1 834 717	1 860 827	+1.4
Slovakia	71 909	72 274	+0.5	49 918	50 190	+0.5
Slovenia	year 1986: 19 817	19 976	+0.8	year 1996: 19 688	19 838	+0.8
Spain	284 321	286 003	+0.6	377 060	379 570	+0.7
Sweden	72 229	72 449	+0.3	69 745	69 912	+0.2
Switzerland	52 828	53 144	+0.6	52 747	53 000	+0.5
Ukraine	919 220	937 213	+2.0	year 1998: 454 934	467 626	+2.8
United Kingdom	729 760	734 018	+0.6	646 086	648 564	+0.4
United States of America	6 045 271	6 088 649	+0.7	6 825 250	6 863 779	+0.6
European Community	4 152 231	4 173 204	+0.5	4 057 639	4 073 470	+0.4

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