Selecting and Using GWP values for Refrigerants

Summary

Refrigerant GWP values have been revised with each new IPCC Assessment Report. Regulations and guidance for the use of GWP values typically use the most up to date GWP values at the time the regulations were created.

EFCTC updates its data tables to include the values from the most recent IPCC Assessment Report.

The F-Gas Regulation 517/2014 uses Fourth Assessment Report AR4 values and has measures that use GWP limits for applications and servicing. In addition, it has a cap and reduction, based on CO_2 equivalents, for the HFCs that can be placed on the market, using quotas issued to producers and importers of HFCs. The GWP values used in the F-Gas Regulation are in the downloadable logbook that can be used to meet the servicing and maintenance requirements. The previous F-Gas Regulation 842/2006 used IPCC Third Assessment Report TAR GWP values.

The UNFCCC adopted AR5 values for reporting emissions under the Paris Agreement. All the IPPC Assessment Reports and GWP values are available here. The Sixth Assessment Report (AR6) August 2021 has updated GWPs, see IPCC Working Group I- Climate Change 2021, The Physical Science Basis- 7.SM Chapter 7: The Earth's 2 energy budget, climate feedbacks and climate sensitivity - Supplementary Material.

For refrigerant users and equipment designers, the values contained in the F-Gas Regulation 817/2014 annex (IPCC Fourth Assessment Report AR4 GWP values) are the most appropriate at present. However, for emission reporting AR5 values may be appropriate. Companies designing refrigerants should also be aware of any potential impacts from the use of AR5 or AR6 values. The Commission is empowered by the F-Gas review article to update the GWPs of the substances listed in the F-Gas Regulation annexes.

Companies voluntarily reporting their emissions as part of their corporate social responsibility reporting could select IPCC Second Assessment Report SAR, TAR, AR4, AR5 or AR6 values. However, it is essential that only one database is used to ensure consistency and to enable trends in emissions to be clearly seen. The source of the GWPs should be referenced. Any change in GWP source values should be noted and the

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emissions restated when the change is made. The use of 20- and 500-year time horizon GWPs is not recommended.

F-gas Regulation and Kigali Amendment HFC Phase-downs

The UNFCCC adopted AR5 values for reporting emissions under the Paris Agreement. The Montreal Protocol and F-gas Regulation 517/2014 adopted AR4 values for HFC consumption and production under the Kigali Amendment. Both the Kigali Amendment and the F-gas Regulation set baselines and then require consumption reductions against these baselines. Changing the GWPs, for the F-gas Regulation, would also change the baselines as CO_2e, resulting in very limited, if any overall effect, except to cause a discrepancy and confusion between measures/reporting under the Montreal Protocol and EU Regulation. The most important feature is to set a consistent HFC phase-down.

Effect of different GWP sets on the EU total supply as CO_2e for the F-gas Regulation

The effect of different GWP sets (F-gas AR4, AR5, and AR6) on the EU total supply as CO_2e is shown in the chart. Clearly the different GWP sets have a similar effect on all years including the HFC phase-down baseline years. This is also shown for EU HFC total supply by the percentage increase for CO_2e using AR6 values compared to F-gas AR4 GWP values. The percentage increases for 2007 to 2017 are within the range 11 to 13%. The increase is 9% in 2018 and 2019 mainly due to a relatively much larger reduction in HFC-143a supply. The table shows the HFC GWP values for AR4, AR5 and AR6.

The GWP threshold values contained in the F-gas Regulation are set to encourage the use of lower GWP refrigerants to help deliver the phase-down. These are not arbitrary but selected based on available refrigerants and achievable targets. When these were set the uncertainty in refrigerant GWP values was already known (in the range 30-50%) and any GWP changes do not invalidate the existing policy framework.

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Chart- EU Reported Total Supply of HFCs, Effect of GWP on CO_2e

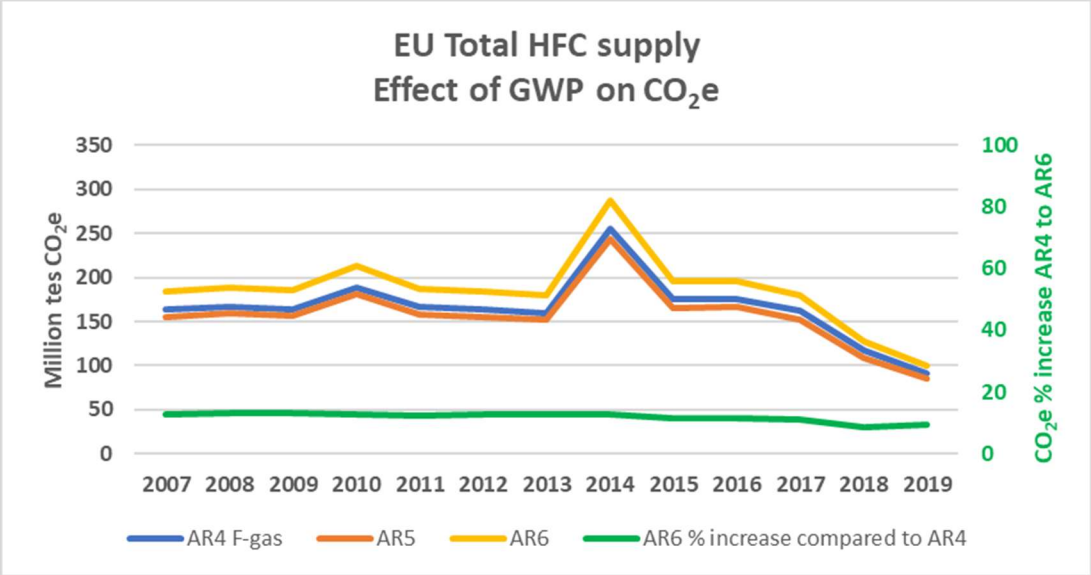

Chart Explanatory notes:

EEA report for Fluorinated greenhouse gases 2020 *is used for HFC total supply, very minor differences (not visible on this chart) are due to some confidential data in the EEA report for minor individual HFCs. The percentage increases for 2007 to 2017 for AR6 compared to AR4 are within the range 11 to 13%. The increase is 9% in 2018 and 2019 mainly due to a relatively much larger reduction in HFC-143a supply.*

HFC GWP values are relative: *The GWP of an HFC is its global warming impact relative to the impact of the same quantity of carbon dioxide over a given time period (usually 100 years). The GWPs reported in AR6 are based on Hodnebrog [2] and in this paper the changes to the parameters in the absolute $AGWP_{CO2}$ is the dominant factor for the HFC GWP increases. The GWP-100 values in Hodnebrog are about 14% higher than if the old $AGWP_{CO2}$ from AR5 had been used. AR6 GWP values are based on Hodnebrog but also include the carbon cycle response for non-CO_2 compounds to treat CO_2 and non-CO_2 compounds consistently, therefore its inclusion more accurately represents the climate effects of non-CO_2 species (see IPCC AR6 Physical Science Basis 7.6.1.3 Carbon cycle responses and other indirect contributions).*

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Table: HFC GWP(100) values for AR4, AR5 and AR6

Designation	Formula	F-Gas Regulation AR4	AR5	AR6
HFC-23	CHF_3	14800	12400	14600
HFC-32	CH_2F_2	675	677	771
HFC-125	CHF_2CF_3	3500	3170	3740
HFC-134a	CH_2FCF_3	1430	1300	1530
HFC-143a	CH_3CF_3	4470	4800	5810
HFC-152a	CH_3CHF_2	124	138	164
HFC-227ea	CF_3CHFCF_3	3220	3350	3600
HFC-236fa	$CF_3CH_2CF_3$	9810	8060	8690
HFC-245fa	$CHF_2CH_2CF_3$	1030	858	962
HFC-365mfc	$CF_3CH_2CF_2CH_3$	794	804	914

Global Warming Potential (GWP) - how is it defined

Simple Definition

The GWP of a refrigerant is its global warming impact relative to the impact of the same quantity of carbon dioxide over a 100-year period.

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Complete Definition

The Global Warming Potential of a refrigerant is defined as the integrated radiative forcing over a "time horizon" of 100 years following an assumed release of 1kg, divided by the integrated radiative forcing over the same period from release of 1 kg of carbon dioxide. Radiative forcing is the specific increase in infrared absorption in $Wm^{-2}ppb^{-1}$ (Watts per square metre at the Earth's surface per part per billion concentration of the material). All effects beyond 100 years are disregarded; thus, Global Warming Potential captures all of the effect of an HFC but less than 40% of the total effect from CO_2 [1].

Why are GWPs used?

Basically, the intention is to put all greenhouse gas emissions onto a common scale and GWP, however imperfect, remains the recommended metric to compare future climate impacts of emissions of long-lived gases.

The adequacy of the GWP concept has been widely debated since its introduction; uncertainties and changes arise from the models used to calculate radiative forcing.

However, the main problem arises from using CO_2 as the reference gas because of the very long "tail" on its atmospheric lifetime. This is shown in the chart, which compares rates of removal of CO_2 from the atmosphere according to different IPCC Assessment Reports.

The Intergovernmental Panel on Climate Change (IPCC) have concluded that “However as long as it has not been determined, neither scientifically, economically nor politically, what the proper time horizon for evaluating ‘dangerous anthropogenic interference in the climate system’ should be, the lack of temporal equivalence does not invalidate the GWP concept or provide guidance as to how to replace it.”

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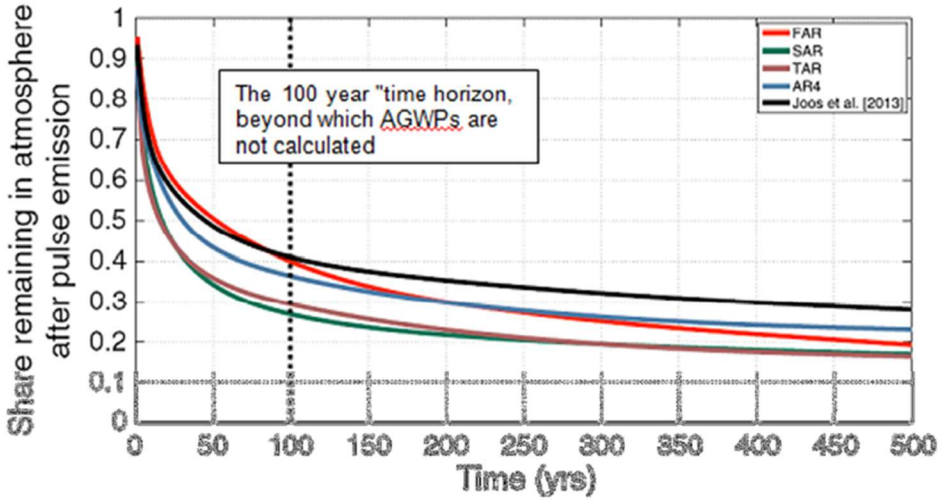

Chart: *The decays in atmospheric concentration of a pulse emission of carbon dioxide used for the First, Second, Third and Fourth Assessment Reports (FAR, SAR, TAR and AR4, respectively) and the values from Joos et al. 2013 [1]*

GWPs are Relative to CO_2

The Global Warming Potential (GWP) of a gas is the ratio of the time-integrated radiative forcing of a pulse emission of the gas (the absolute GWP, or AGWP) relative to the radiative forcing of a similar pulse of carbon dioxide (CO_2) over the same time interval. The generally accepted time interval ("horizon") is 100 years.

$$GWP = AGWP_{GHG} / AGWP_{CO2}$$

The time-integrated radiative forcing takes account of the reduction in atmospheric concentration of the gas (related to its Atmospheric Lifetime) and is equal to the concentration integrated over 100 years multiplied by the Radiative Efficiency (RE). This relationship works for both the greenhouse gas and for

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carbon dioxide. But carbon dioxide has many different atmospheric loss processes, each contributing to its atmospheric lifetime. This is the subject of ongoing reassessment.

What has actually changed with the AR6 GWP values: AR6 GWP values are based on the Hodnebrog [2] reported values. The paper provides an updated and extended assessment of RE (radiative efficiencies) and GWPs for halocarbons. Changes to the parameters in $AGWP_{CO2}$ impact all GWP values, and the GWP-100 values presented in the paper are about 14% higher than if the old $AGWP_{CO2}$ from AR5 had been used. *So even without any changes in the RE or atmospheric lifetime for a refrigerant its GWP can change as it is a relative value. This applies to HCFC-22.* Uncertainties in GWPs are estimated to still be in the approximate range of 30-50%. Updated GWP-100 values are higher for all HFCs, and this is due to a combination of updated $AGWP_{CO2}$, higher RE values for several compounds and longer lifetimes for most HFCs. *The $AGWP_{CO2}$ is the dominant factor for the HFC GWP changes.*

The effect of a compound on climate is not limited to its direct radiative forcing. Compounds can perturb the carbon cycle affecting atmospheric CO_2 concentrations. AR6 GWP-100 values include the carbon cycle response for non-CO_2 compounds to treat CO_2 and non-CO_2 compounds consistently, therefore its inclusion more accurately represents the climate effects of non-CO_2 species. This correction was excluded in the Hodnebrog paper. See IPCC AR6 Physical Science Basis 7.6.1.3 Carbon cycle responses and other indirect contributions.

It is worthwhile noting that the GWPs of two of the major GHGs - methane and nitrous oxide (N_2O) - have changed by +33% and –12% respectively between SAR and AR6.

	SAR	TAR	AR4	AR5	AR6	Change SAR to AR6
Methane	21	23	25	28	27.9	33%
Nitrous Oxide	310	296	298	265	273	-12%

The 100 year time horizon for GWPs

The UNFCCC adopted AR5 values for reporting emissions under the Paris Agreement and the Montreal Protocol and F-gas Regulation 517/2014 adopted AR4 values for HFC consumption and production under the Kigali Amendment. Wide variations in GWPs may be quoted and mis-used for HFCs. GWP values for

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time horizons of 20, 100 and 500 years are published by IPCC in their Assessment Reports and the values change between the reports, which are produced roughly every five years.

GWPs are calculated relative to CO_2 up to the "time horizon", with all effects beyond that time period being disregarded. Because CO_2 has an atmospheric lifetime much longer than HFCs, then a shorter time horizon result in higher GWPs for HFCs. The most commonly used HFCs are removed from the atmosphere quickly compared to CO_2 so that short time horizons overstate their relative contribution to global warming. This is why 100-year time horizon was selected to provide an appropriate compromise between short- and long-term effects.

Short-lifetime greenhouse gases such as commonly used HFCs affect the climate in qualitatively different ways to CO_2, with constant rates of emission leading to an approximately constant level of raised global average temperature but not a sustained and continually increasing warming.

Uncertainties of GWP Values- why they have changed over time

GWP values have been refined over the past two decades with the development of atmospheric science. As GWPs of refrigerant are relative to CO_2, any change in the calculated global warming impact (radiative forcing) of CO_2 directly affects the refrigerant GWP.

In addition, GWPs also depend on the atmospheric lifetime and infra-red absorption spectra (radiative efficiencies) of the refrigerants. Atmospheric lifetime is linked to the reaction rates for the various processes that convert the refrigerant into very low GWP breakdown products and improved knowledge about atmospheric science and radiative efficiencies for HFCs has led to revisions in their GWPs.

Uncertainty in refrigerant GWP is stated to be ±30-50% (Hodnebrog 2020). Uncertainties in refrigerant GWPs are dominated by the uncertainty in the reference gas, CO_2.

The GWPs listed in the Assessment Reports for 100-year time horizons are shown in the table for the most widely used HFCs. Also shown are the GWPs for methane and nitrous oxide.

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How important are the differences in GWP?

Time Horizon

The use of 100-year time horizons is recommended and indeed these are the only GWPs referenced in the Kyoto Protocol and F-Gas Regulation for compliance and reporting purposes. At UNFCCC COP24 it was decided to use GWP-100 for reporting national emissions to the Paris Agreement. GWPs at a 20-year time horizon are sometimes quoted to accentuate the contribution of HFCs to global warming. Using 20-year time horizons for HFCs distorts the relative contribution of CO_2 (over 90% of it is ignored) and does not contribute to an informed and objective assessment of the use of HFCs. Similarly, 500-year time horizon GWPs should not be used for HFCs as they do not reflect the agreed balance between short- and long-term effects. It is not permissible, from scientific or legal points of view, to mix GWP time horizons or to cherry pick values from the databases in different IPCC Reports.

IPCC in AR6 Physical Science Basis Chapter 7 Executive Summary states:
"The choice of emission metric affects the quantification of net zero GHG emissions and therefore the resulting temperature outcome after net zero emissions are achieved. In general, achieving net zero CO_2 emissions and declining non-CO_2 radiative forcing would be sufficient to prevent additional human-caused warming. Reaching net zero GHG emissions as quantified by GWP-100 typically results in global temperatures that peak and then decline after net zero GHGs emissions are achieved, though this outcome depends on the relative sequencing of mitigation of short-lived and long-lived species"

The GWPs for 20, 100- and 500-year time horizons are shown in the table for the most widely used HFCs and HFOs. The fifth Assessment Report (AR5) does not contain values for 500-year GWPs.

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GWPs for some HFCs, HFOs and HCFOs (CO_2 = 1 at any time horizon) [3]

Assessment	AR4			AR5		AR6		
Time Horizon, years	*20*	**100**	*500*	*20*	**100**	*20*	**100**	*500*
HFC-32	*2330*	**675**	*205*	*2430*	**677**	*2690*	**771**	*220*
HFC-125	*6350*	**3500**	*1100*	*6090*	**3170**	*6740*	**3740**	*1110*
HFC-134a	*3830*	**1430**	*435*	*3910*	**1300**	*4140*	**1530**	*436*
HFC-143a	*5890*	**4470**	*1590*	*6940*	**4800**	*7840*	**5810**	*1940*
HFC-152a	*437*	**124**	*38*	*506*	**138**	*591*	**164**	*46.8*
HFO-1234yf	*n.a.*	*n.a.*	*n.a.*	*1*	**<1**	*1.81*	**0.501**	*0.143*
HFO-1234ze(E)	*n.a*	*n.a*	*n.a*	*4*	**<1**	*4.94*	**1.37**	*0.391*
HFO-1336mzz(Z)	*n.a*	*n.a*	*n.a*	*6*	**2**	*7.48*	**2.08**	*0.592*
HCFO-1233zd(E)	*n.a*	*n.a*	*n.a*	*5*	**1**	*14*	**3.88**	*1.11*

Using IPCC Assessment Report GWP values

Comparing technology options

The GWPs of the widely used HFC refrigerant components (HFC-32, HFC-125, HFC-134a, HFC-143a) have changed by 14%,7%,7% and 30% respectively between the AR4 and AR6 values. These changes have little impact on decision making when used for TEWI (Total Equivalent Warming Impact) or LCCP (Life Cycle Climate Performance) calculations, which are used to compare alternative technology options.

Reporting to UNFCCC under the Paris Agreement and the Montreal Protocol

The UNFCCC for reporting emissions under the Paris Agreement, adopted AR5 values for the purposes of national reporting of greenhouse gas emissions (national "Greenhouse Gas Inventories"). These are different from the values used during the first commitment period of the Kyoto Protocol to the Convention (which used GWPs from the Second Assessment Report). In addition to the greenhouse gases included in

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the 2006 IPCC Guidelines, the 2019 Refinement includes gases for which global warming potential (GWP) values are given in one of the subsequent IPCC Assessment Reports, unless the gases are covered by Annexes A through E of the Montreal Protocol. (Annex F of the Montreal Protocol lists hydrofluorocarbons, which are included in the 2019 Refinement.) The 2019 Refinement also provides estimation methods for halogenated greenhouse gases for which GWP values were not available from IPCC Assessment Reports at the time the 2019 Refinement was developed [4]. IPCC AR6 GWP values are expected to be published during 2021. The European F-Gas Regulation (517/2014) also uses GWPs from AR4. The Montreal Protocol as a result of the Kigali Amendment includes AR4 GWP values for HFCs in its Annexes.

Sources:

[1] The first 2/3 of a CO_2 emission is removed from the atmosphere relatively quickly (within 100 years or so). The other 1/3 remains for several thousand years. This affects the choice of time horizon.

[2] Hodnebrog, Ø., Myhre, G., Kramer, R. J., Shine, K. P., Andrews, T., Faluvegi, G., Kasoar, M., Kirkevåg, A., Lamarque, J.-F., Mülmenstädt, J., Olivié, D., Samset, B. H., Shindell, D., Smith, C. J., Takemura, T., Voulgarakis, A.: The effect of rapid adjustments to halocarbons and N2O on radiative forcing, npj Climate and Atmospheric Science, Issue 3, 2020, Pages 1 ff., DOI: https://doi.org/10.1029/2019RG000691

[3] From IPCC AR4 Table 2.14 and AR5 Table 8.A.1, and AR6 IPCC Working Group I- Climate Change 2021, The Physical Science Basis- 7.SM Chapter 7: The Earth's 2 energy budget, climate feedbacks and climate sensitivity - Supplementary Material

[4] See https://www.ipcc.ch/site/assets/uploads/2019/06/19R_V0_01_Overview_advance.pdf

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