# IEooc_Background2_Exercise1: Global Warming Potential (GWP) calculations

***Goal:*** *Understand and replicate central calculations of the atmospheric physics of greenhouse gases (GHG) and the global warming potential to compare the impact of different GHG on global warming.*

***Hint:*** *The numeric values in this exercise were taken from the 4th IPCC Assessment Report (AR), where enough documentation is provided to reproduce the final GWP results. Numbers from the newly released 6th AR are also provided in the sample solution, but without calculation details.*

**Task 1: $CO_2$ content of the atmosphere:** With a given average $CO_2$-volume concentration of the atmosphere of 410 ppm: (1 ppm = 1 part per million)

(a) How much is that in %?
(b) How much volume of $CO_2$ is contained in a cubic meter ($m^3$) of air?
(c) How large is the mass share of $CO_2$ in the atmosphere (for dry air), both in % and in ppm, under the assumption that both $CO_2$ and air can be described as an ideal gas?

**Task 2: specific radiative forcing**: To determine the global warming potential of a kg of individual substances, the concentration-specific atmospheric radiative forcing $a_{a\_i}$ of a greenhouse gas must be converted to a mass-based one, $a_{m\_i}$. The concentration-specific atmospheric radiative forcing $a_{a\_i}$ of a greenhouse gas is given as the contribution to total radiative forcing of the atmosphere (in $W/m^2$) of a billionth of volume share of this gas in the atmosphere (1 part per billion ($10^9$) = 1 ppb):

$$[a_{a\_i}] = W \cdot m^{-2} \cdot ppb^{-1}$$
$$[a_{m\_i}] = W \cdot m^{-2} \cdot kg^{-1} \quad (1)$$

For example, $a_{a\_CH4}$ was determined to be $(5.7\pm1.4)\cdot10^{-4}$ $W/m^2/ppb$ (see Table 7.15 in Chapter 7, Part I of the 6th IPCC Assessment Report).

Use $a_{a\_i}$ to determine the quantity $a_{m\_i}$, which is the mass-based atmospheric radiative forcing (per kg of gas *i*), using relevant ancillary quantities such as the molar mass and the total mass of the atmosphere. Write down your result as an equation!

**Task 3: Atmospheric decay of methane:** The following relationship holds for the time decay of any given quantity of methane in the atmosphere:

$$R_{CH4}(t) = e^{-\frac{t}{\tau_{CH4}}} \quad (2)$$

Here, $R_{CH4}(t)$ denotes the share of the original amount of methane, emitted at time $t = 0$, which is still present at time $t$. $\tau_{CH4}$ is a constant.

For methane: $\tau_{CH4}$ = 12.4 yr (11.8±1.8 yr according to the 2022 update in chapter 7 of part I of the 6$^{th}$ IPCC Assessment report)

(a) How large is the remaining share of the original methane emissions after the time $\tau_{CH4}$ has passed?
(b) After which time is half (50%) of the original amount left (so-called half-life?) For the case of an exponential decay, write down your result as equation! (The result holds for all exponential decays, including radioactive decay or the decomposition of toxic substances in landfills.)
(c) Plot the function $R_{CH4}(t)$! (0-100 years)
(d) How large is, according to the above equation, the average lifetime of the $CH_4$ emitted to the atmosphere?

**Source:** Numbers and equations from: "Anthropogenic and Natural Radiative Forcing", Table 8.A.1 in part I of the 5$^{th}$ IPCC Assessment report, and from: "Anthropogenic and Natural Radiative Forcing, Supplementary Material", Section 8.SM.11.1: Equations for the Global Warming Potential of part I of the 5$^{th}$ IPCC Assessment report.

**Hint:** A graphical representation of data always needs to have:

- A title or, when inserted into a text, a caption.
- A legend
- Units for the x and y axes
- Small changes and annotations can quickly be done/inserted by taking a screenshot of the raw plot and editing the plot using MS Paint or so. That is sufficient for term papers and reports.

**Task 4: Atmospheric decay of carbon dioxide:** The following relation holds for the decay of a given amount (set here to 100%) of carbon dioxide ($CO_2$) in the atmosphere:

$$R_{CO2}(t) = a_0 + \sum_{i=1}^{3} a_i \cdot e^{-\frac{t}{\tau_i}} \quad (3)$$

Here, $R_{CO2}(t)$ denotes the share of the original amount of the gas at time $t = 0$, which is still present in the atmosphere at time $t$. The values of the different parameters are given in Table 1:

**Table 1:** Numerical values for the parameters in the equation for $R_{CO2}$ above. **Sources**: Numbers and equations from: "Anthropogenic and Natural Radiative Forcing", Table 8.A.1 in part I of the 5th IPCC Assessment report as well as: "Anthropogenic and Natural Radiative Forcing, Supplementary Material", Section 8.SM.11.1: Equations for the Global Warming Potential of part I of the 5th IPCC Assessment report.

| **Variable/Order** | **0** | **1** | **2** | **3** |
|---|---|---|---|---|
| **a** | 0.2173 | 0.2240 | 0.2824 | 0.2763 |
| **τ** | --- | 394.4 | 36.54 | 4.304 |

(a) How large is the share of the original amount of $CO_2$ after 10/20/50/100/200/500/1000/many, many years?

(b) After how many years has the share of the remaining $CO_2$ in the atmosphere fallen down to 50%? Here, an approximate answer, based on the numerically obtained values for the different future years, is sufficient to determine the year around which $R_{CO2}(t)$ is about 0.5.

(c) How large is (by the equation above) the average lifetime of $CO_2$ emitted to the atmosphere?

(d) Plot the function $R_{CO2}(t)$!

**Task 5: Global warming potential of methane for different time horizons.**

Determine the global warming potential of methane for a time horizon of 20 years and for 100 years! Use the results of the above tasks and note (see info below)* that the specific radiative forcing for methane is increased by an additional factor of 1.65!

To solve this task, the above equations for $R_i$ can be integrated analytically, or the $R_i$ values of the individual years can be integrated numerically in Excel.

**Data:**

- Decay curves of the different GHG: see tasks 3 and 4.
- Specific radiative forcing of the different gases:

| | | | |
|---|---|---|---|
| $CO_2$: | 1.75435E-15 | $Wm^{-2}kg^{-1}$ | See AR5 WG I, 8.SM.11.3 'Updates of Metric Values' |
| $CH_4$: | 1.27991E-13 | $Wm^{-2}kg^{-1}$ | See AR5 WG I Ch 8, Table 8.A.1 |
| $N_2O$: | 3.84645E-13 | $Wm^{-2}kg^{-1}$ | See AR5 WG I Ch 8, Table 8.A.1 |

- Correction factor $c_i$ for each gas to consider secondary (like decomposition effects on ozone and stratospheric water vapor)*

| | |
|---|---|
| $CO_2$ | 1 |
| $CH_4$ | 1.65 |
| $N_2O$ | 1 |

*) See the following quotation from section 7.6.1.3 from part I of the $6^{th}$ AR: "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. Chemical reactions from emitted compounds can produce or destroy other greenhouse gases or aerosols."