AREC
Raumberg-Gumpenstein
Agriculture

An institution of the Federal Ministry of Agriculture, Forestry, Regions, and Water Management
Raumberg 38, 8952 Irdning-Donnersbachtal, Austria

Radiative Efficiency

Energy Changes Everything

Steel is an extremely robust material that, when subjected to high amounts of energy, not only glows but also loses its strength and can be forged. This transformation occurs because the bonds between the atoms change. At the same time, the energetically altered steel emits heat.

The same applies to greenhouse gases: Adding energy causes the molecules in their inner structures to vibrate. They also generate heat and radiate it. The energy source is the sun's infrared radiation in direct or indirect form, reflected by the earth. Individual greenhouse gases differ greatly in this respect.

The potential for energy absorption and heat generation is called radiative efficiency

Energy Absorption of the Gases

Chemical elements have a nucleus and free electrons on so-called orbital shells. The element hydrogen (H) is in the 1st period and has an s-orbital. Carbon (C), nitrogen (N), and oxygen (O) are elements of the 2nd period with 3 and 4 p-orbitals, respectively. The number and type of orbitals determine how much energy an atom can absorb or release.

Atoms form molecules and bond with atomic bonds of different strengths. Their strength also determines the capacity of the energy. C and O in CO_2 each have a double bond, N_2 has a triple bond, C and H only have a single bond.

The spatial dimension of the bonds determines whether a molecule can only vibrate or whether rotation is also possible.

The basic structure, bond energy and freedom to vibrate determine the possible heat generation of a molecule.

Calculation of the Radiative Efficiency

Based on the gas concentration in the atmosphere, Myhre et al. (2013) calculate the heat release for the individual greenhouse gases using the following formulas:

$$CO_2 = 5.35\ln(\frac{C}{C_0})$$

$$CH_4 = 0.036(\sqrt{M} - \sqrt{M_0})\ x\ [f(M, N_0) - f(M_0, N_0)]$$

$$N_2O = 0.12(\sqrt{N} - \sqrt{N_0})\ x\ [f(M0, N) - f(M_0, N_0)]$$

$$f\ (M, N) = 0.47\ln[1 + 2.01x10^{-5}(M, N)0.75 + 5.31x10^{-15}M(MN)^{1.52}]$$

$C_0 = CO_2\ in\ ppm$ $M_0 = CH_4\ in\ ppb$ $N_0 = N_2O\ in\ ppb$

$C = C_0 + 1$ $Einheit: Wm^{-2}ppm^{-1}$

"For the purpose of mass effectiveness, a difference of 1 ppm or ppb is assumed between C_0 and C, M_0 and M, and N_0 and N. The baseline concentrations are 391 ppm for CO_2, 324 ppb for N_2O, and 1809 ppb for CH_4. This is the average of the last 20 years of Mauna Loa measurements (Guggenberger et al. 2022).

From Concentration to Quantity

The heat energy according to Myhre et al. (2013) is based on the gas concentration in the atmosphere. For regionalization, a reference to the amount of emissions must be established. Ridoutt (2020) provides the calculation method:

$$Wm^{-2}kg^{-1}{}_{THG} = \frac{\frac{RF}{1\,ppm}\ \frac{Air\ g}{mol}\ 10^6}{\frac{THG\ g}{mol}\ 5.14x10^{18}}$$

$RF = Radiativ\ Forcing\ Wm^{-2}ppm^{-1}$

$Air = 28.97\ g/mol$ $CO_2 = 44.01\ g/mol$

$CH_4 = 16.04\ g/mol$ $N_2O = 44.0128\ g/mol$

$Atmosphärische\ Masse = 5.14x10^{18}$ kg

$Skalierungsfaktor: 10^6$

$W = 1000\ mW$ $Mt = 10^9 kg$

The results for radiative efficiency are as follows:

- Carbon dioxide (CO_2): 0,0017465 mW/m²/MT
- Nitrous oxide (N_2O): 0,4221823 mW/m²/MT
- Methane (CH_4): 0,1457072 mW/m²/MT

(mW = milliwatt, MT = megatonne)

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