Correspondence to
harde@hsu-hh.de

Vol. 3.1 (2023)
pp. 114 - 118

Reply to a Comment on:
Understanding Increasing Atmospheric CO_2

Hermann Harde

Helmut-Schmidt-University, Hamburg, Germany

Abstract

This reply refutes all misstatements, that were published by F. Engelbeen as Comment on an article "*Understanding Increasing Atmospheric CO_2*" by Hermann Harde.

Keywords: Carbon cycle; absorption time; anthropogenic emissions; natural emissions

Submitted 24-03-2023, Accepted 29-03-2023. https://doi.org/10.53234/scc202301/28

1. Introduction

All climate experts agree that the basis for calculating changes of the CO_2 concentration in the atmosphere is the balance equation or Conservation Law, which sums up all in- and outfluxes of the atmosphere. However, differences exist in the interpretation, how strongly fluxes from anthropogenic sources can affect this balance and how far natural emissions have to be considered.

In three articles of this journal this has been discussed extensively (see: Harde & Salby 2021; Berry 2021; Schrøder 2022) with the concordant result that mostly nature must be made responsible for the observed CO_2 increase. A critical Comment of Andrews (2023) was refuted by Harde (2023) and Berry (2023), but a further Comment (Engelbeen 2023), that mostly refers to the last clarification of Harde (2023), alleges a number of misstatements, in particular concerning the balance equation, which need to be rejected and corrected by this reply.

2. Some Clarifications on the Balance Equation

Generally, the balance for changes of the atmospheric CO_2 concentration can be expressed as:

$$\frac{dC_{CO_2}}{dt} = e_A + e_N - a_N \tag{1}$$

with dC_{CO2}/dt as the concentration changes per time interval dt, e_A as anthropogenic emission rate, e_N as natural emission rate and a_N as natural absorption rate.

The changes over one year $\delta C_{CO2}/\delta t$ can relatively well be derived from CO_2 measurements at Mauna Loa (CDIAC 2022), and the anthropogenic emissions deduced from the Global Carbon Budget (GCB 2022). Thus, rearranging (1) in the form

$$\frac{\delta C_{CO_2}}{\delta t} - e_A = e_N - a_N, \tag{2}$$

the left-hand side is known within some narrower bounds, and therefore also the difference of natural emissions and absorption, quantities which can only roughly be estimated, is known with the same accuracy.

So far there is no larger discrepancy between experts, also not to Engelbeen's Fig. 1, only that the calculations in Harde & Salby (2021) and Harde (2023) also include Land Use Changes, which were neglected in his Fig. 1. But the further interpretation of the right-hand side of (2) differs significantly with dramatic consequences for the right understanding of the carbon-cycle.

So, in Section 2 of Engelbeen's Comment (2023) we read:

- *Even without knowing any natural CO_2 flux on earth, the net result of all natural CO_2 fluxes is exactly known within narrow borders,* and later*: This alone is already sufficient to exclude any net contribution from natural sources, even if an individual CO_2 input like from all volcanoes on this world doubled or tripled in some year.*
- *As long as the increase of CO_2 in the atmosphere is less than human emissions, there is zero contribution from natural sources and sinks to the increase in the atmosphere.*
- *It doesn't matter how huge the natural inputs and outputs are: these form a cycle and a cycle has zero impact on the amounts of CO_2 in the atmosphere and only the difference between all the natural ins and outs together does change the CO_2 quantity in the atmosphere. That difference is exactly known from two accurately known variables: human emissions and increase in the atmosphere. …. Only if the increase in the atmosphere gets larger than from human emissions alone, the increase would be in part caused by natural causes.*

These are quite strong statements, which have to be considered in some more detail.

Indeed, for a decoupled cycle of natural CO_2 fluxes and an absorption rate, that is exactly compensating any natural variations, independent of the human emissions and therefore independent of the instantaneous atmospheric CO_2 concentration, it is per se sufficient to consider only *the net of all natural CO_2 fluxes, to exclude any net contribution from natural sources*. This is the case:

- for the simple Airborne Fraction Model with an actual anthropogenic emission rate $e_A \approx 5.5$ ppmv/yr, an airborne fraction $AF \approx 46\%$ and an absorption rate $a_N = (1\text{-}AF)\cdot e_A$,
- it also holds for the more advanced Bern-Model (Joss et al. 1996) assuming only anthropogenic emissions as δ-pulses in the form $e_A(t') \cdot R(t-t') \cdot dt'$, with $R(t\text{-}t')$ as the pulse response function, which represents 5 essentially independent decay channels, one even with an infinite absorption time (zero absorption),
- and it holds for several hybrid models, considering only an excess concentration C'_{CO2} above an equilibrium level, e.g., $C^{eq}_{CO2} = 280$ ppmv at 1750, with an absorption rate $a_N = C^{eq}_{CO2}/\tau_{NR} + C'_{CO2}/\tau_A$, where τ_{NR} is the residence or turnover time of CO_2 molecules belonging only to the natural cycle with $\tau_{NR} \approx$ 3-4 yrs, and τ_A is the adjustment time for the excess concentration caused only by anthropogenic emissions with $\tau_A \approx 50$ yrs.

All these categories are distinguished by focussing exclusively on changing anthropogenic emissions, while natural emissions in advance are excluded or are supposed to form a closed cycle. Under these conditions is the right-hand side of (2) not really the net of all natural fluxes, but represents the anthropogenic absorption rate. It is obvious that under such assumptions native emissions cannot have any impact. A conclusion that *there is zero contribution from natural sources and sinks to the increase in the atmosphere*, is no more and no less circular reasoning.

It is also in contradiction to the Equivalence Principle, when additional native emissions can be compensated by 100%, while human emissions, or their equivalent mass units, are only partially absorbed and some fraction remains for ever in the atmosphere or is absorbed significantly slower. And what kind of 'closed' cycle shall this be with a constant net balance for all natural fluxes and continuous uptake of human emissions? Is this stored in a separate native reservoir?

As elaborately discussed in Harde (2023), a realistic absorption rate, which is in agreement with all observations and physical principles, is scaling proportional to the instantaneous CO_2 concentration and does not discriminate between native or anthropogenic emissions. Then, with an additional native emission rate Δe_N and a unitary effective residence or absorption time τ_{eff} for all

molecules, including partial re-emission from extraneous reservoirs[1], (2) becomes:

$$\frac{\delta C_{CO2}}{\delta t} - e_A = e_{N0} + \Delta e_N - \frac{C_{CO2}}{\tau_{eff}}, \tag{3}$$

or as excess concentration $C'_{CO2} = C_{CO2} - C^{eq}_{CO2}$ relative to the quasi-steady state concentration $C^{eq}_{CO2} = 280$ ppmv in 1750 and with $e_{N0} = a_{N0} = C^{eq}_{CO2}/\tau_{eff}$ we get:

$$\frac{\delta C'_{CO2}}{\delta t} - e_A = \Delta e_N - \frac{C'_{CO2}}{\tau_{eff}}. \tag{4}$$

It is evident that with additional emissions, anthropogenic or natural ones, also the absorption rate is increasing to compensate these additional emissions and to adapt to a new equilibrium. But the decisive difference to the previously discussed approaches is that this absorption no longer distinguishes between different sources; the total concentration in (3) and in the same way the excess concentration in (4) are determined by the common emissions, which together are defining a unitary absorption rate for human and native emissions.

In this context it is also important to note that absorption and emission of CO_2 at the surface is not simple mixing like liquids with different alcoholic content, as unfortunately confused by some people (Andrews 2023). CO_2 is mixing in the atmosphere with the other gases, but at the surface it is absorbed, partially even changing its compound in seawater or in the biosphere, and it is again released decades to thousands of years later, strongly dependent on chemical and biological reactions, which on their part are controlled by temperature and humidity.

Therefore, different to the illusion of *clear thinkers* the right-hand side of (4) does not represent only *the net result of all natural fluxes*, but also contains the human uptake. A constant difference doesn't say anything, particularly not when the total emissions and absorption develop largely parallel to each other.

So, for an increasing concentration over time, but less than the anthropogenic emissions e_A, i.e., $0 < \delta C'_{CO2}/\delta t < e_A$, this leads to an inequality for the absorption rate with:

$$\Delta e_N < \frac{C'_{CO2}}{\tau_{eff}} < \Delta e_N + e_A\,. \tag{5}$$

Of course, can this inequality be satisfied for $\Delta e_N = 0$, when $C'_{CO2}/\tau_{eff} < e_A$. With an excess concentration $C'_{CO2} \approx 130$ ppmv and anthropogenic emissions of $e_A \approx 5.5$ ppmv/yr this is the case for a residence time $\tau_{eff} > 24$ yrs. But from observations of the ^{14}C-decay and independently from the seasonal emission-absorption cycles (Harde & Salby, 2021) we know that the absorption time cannot be larger than 10 yrs. This already excludes an assumption of zero native emissions.

So, with $\tau_{eff} \leq 10$ yrs the actual excess absorption rate must be $C'_{CO2}/\tau_{eff} \geq 13$ ppmv/yr. Then, (5) is also satisfied for additional native emissions $\Delta e_N > (C'_{CO2}/\tau_{eff} - e_A) \geq 7.5$ ppmv/yr, and for an actually observed CO_2 increase of $\delta C'_{CO2}/\delta t \approx AF \cdot e_A \approx 2.5$ ppmv$/yr$, from (4) we even derive an emission rate of $\Delta e_N = 10$ ppmv/yr, which is almost twice the anthropogenic emissions.

Whereas τ_{eff} cannot be larger than 10 yrs, it can be significantly shorter. With an estimated total emission $e_T = 106.8$ ppmv/yr as average over the period 2010 – 2019 (see IPCC, AR6 2021, Fig. 5.12) and an average atmospheric concentration of $C_{CO2} = 400$ ppmv, we get an effective absorption time of $\tau_{eff} = C_{CO2}/e_T \approx 3.8$ yrs. With this faster absorption and with the observed increase $\delta C'_{CO2}/\delta t \approx 2.5$ ppmv$/yr$, according to (4), then natural emissions even contribute $\Delta e_N = 31.2$ ppmv/yr to the increase, which is almost 6 times more than the human emissions.

These examples clearly refute Engelbeen's claim that "*there is zero contribution from natural*

[1] Not to complicate the further discussion, here we abstain to distinguish between a direct and effective absorption time. For details, see Harde & Salby (2021) and Harde (2023).

sources and sinks to the increase of CO_2 in the atmosphere, as long as this increase is less than human emissions", and also his statement at the end of Section 2: "*Any theory that results in a substantial net addition of CO_2 by the natural cycles violates the carbon mass balance and therefore is rejected"* is nonsense and misses any scientific basis.

The preceding considerations and examples are in full agreement with the balance equation for atmospheric CO_2 and are exclusively based on fundamental physical relations like the Equivalence Principle. Different to the artificially introduced cycles and time constants, on the one hand for a more or less closed natural cycle, and on the other hand for the adjustment of anthropogenic emissions, we demonstrate that all observations, even the seasonal cycles are exactly reproduced with a unitary time scale, which controls the total balance of emissions and absorption.

3. Interpretation of the IPCC

In Section 3 Engelbeen further claims, the IPCC was misinterpreted. Here some short answers:

- He believes, *IPCC never assumed a fixed airborne fraction of what remains in the atmosphere from human emissions*. Engelbeen should study AR6, Chapter 5.2.1.2 and look to Fig. 5.7.
- He claims: *The IPCC never said or implied that the increase in the atmosphere is proportional to human emissions*. Again, we refer to AR6, Chapter 5.2.1.2, where he can read: "*Based on the airborne fraction (AF), it is concluded with medium confidence that both ocean and land CO_2 sinks have grown consistent with the rising of anthropogenic emissions*". In addition, everyone who looks closer to the Bern-Model (Joos et al. 1996), will see that the absorption is assumed to scale proportional to the δ-pulse emission.
- Engelbeen's considerations about a thermal contribution apparently completely embezzle the much stronger soil emissions, permafrost, volcanos and El Niños (Salby & Harde 2022).
- He questions that *the IPCC ever made a differentiation between natural and human CO_2 for any physical process*. Isn't it a differentiation, when natural fluxes are assumed to form a cycle with a residence time of about 3 yrs, even for additional native emissions, and only anthropogenic emissions or their equivalent mass will stay forever in the atmosphere?
- He claims: "*The Bern model and other models do not assume that the different reservoirs absorb CO_2 in series, they assume that the sinks work in parallel, with the fastest process leading"*. When this would really be true, how does he explain, when the IPCC supposes that the removal of all the human-emitted CO_2 from the atmosphere by natural processes will take a few hundred thousand years, and the Bern Model considers for 18% of anthropogenic emissions an infinite cumulation in the atmosphere? The different exponential decays by far do not represent saturation or a parallel uptake, but stand for different exchange processes from photosynthesis to silicate weathering (AR5, Chapter 6, Box 6.1), apparently working in series. Parallel sinks ad up to a total uptake and can well be described by a single exponential.

And indeed, it goes completely wrong, when so-called climate experts and clear thinkers consider a separate cycle only for natural CO_2 fluxes with a residence time of 3-4 yrs, and have to introduce artificially an additional time scale with an adjustment time of about 50 yrs, only to explain a pure anthropogenic impact and to exclude any natural contribution to the growing CO_2 level. In Section 2 we have already discussed that such an approach violates the Equivalence Principle and is also in contradiction to observations of the ^{14}C-decay, from which we derive an absorption time shorter than 10 yrs. Direct absorption processes can even be as short as one year, as this follows from the faster oscillations on the $^{14}CO_2$ decay (Salby & Harde 2021) and also from cross-correlation analyses of interannual CO_2 and temperature fluctuations (Humlum et al. 2013; Salby 2013).

4. Conclusion

With this reply we firmly reject the false claims, that were published by Engelbeen (2023) as Comment on an article "*Understanding Increasing Atmospheric CO_2*" by H. Harde (2023).

Instead annunciating such comments with untenable and dubious statements Engelbeen and his clear thinkers should reflect their own delusions, which are in contradiction to the Equivalence Principle, in conflict with the observed ^{14}C-decay time, and which cannot explain the seasonal emission-absorption cycles of atmospheric CO_2.

Chief-Editor: Prof. Jan-Erik Solheim; **Debate-Editor**: Prof. Olav Martin Kvalheim

References

Andrews, D. E., 2023: *Clear Thinking about Atmospheric CO_2*, Science of Climate Change, Vol. 3.1, pp. 33 - 45, https://doi.org/10.53234/scc202301/20

AR5 – IPCC's Fifth Assessment Report, 2013: T. F. Stocker et al. (Eds.): *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

AR6 – IPCC's Sixth Assessment Report, 2021: V. Masson-Delmotte et al.: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I,* Cambridge University Press.

Berry, E., 2021: *The Impact of Human CO_2 on Atmospheric CO_2,* Science of Climate Change, Vol. 1.2, pp. 213 - 249, https://doi.org/10.53234/scc202112/13

Berry, E., 2023: *Nature Controls the CO_2 Increase,* Science of Climate Change, Vol. 3.1, pp. 68 – 91, https://doi.org/10.53234/scc202301/21.

CDIAC: Carbon Dioxide Information Analysis Center, 2022, https://cdiac.ess-dive.lbl.gov/trends/co2/recent_mauna_loa_co2.html

Engelbeen, F., 2023: *Comment on Understanding Increasing Atmospheric CO_2 by Hermann Harde*, Science of Climate Change, Vol. 3.1, pp. 107-113, https://doi.org/10.53234/scc202301/26

Global Carbon Budget (GCB) 2022: https://www.carbonbrief.org/analysis-global-co2-emissions-from-fossil-fuels-hit-record-high-in-2022/

Harde, H., M. L. Salby, 2021: *What Controls the Atmospheric CO_2 Level?* Science of Climate Change, Vol. 1.1, pp. 54 - 69, https://doi.org/10.53234/scc202106/22.

Harde, H., 2023: *Understanding Increasing Atmospheric CO_2*, Science of Climate Change, Vol. 3.1, pp. 46-67, https://doi.org/10.53234/scc202301/23

Humlum, O., K. Stordahl, and J.-E. Solheim, 2013: *The phase relation between atmospheric carbon dioxide and global temperature*, Global and Planetary Change, vol. 100, pp. 51–69.

Joos, F., M. Bruno, R. Fink, U. Siegenthaler, T. F. Stocker, C. Le Quéré, J. L. Sarmiento, 1996: *An efficient and accurate representation of complex oceanic and biospheric models of anthropogenic carbon uptake*, Tellus B 48, p 397, https://doi.org/10.1034/j.1600-0889.1996.t01-2-00006.x

Salby, M. L., 2013: *Relationship Between Greenhouse Gases and Global Temperature*, Video Presentation, April 18, 2013, Helmut-Schmidt-University Hamburg https://www.youtube.com/watch?v=2ROw_cDKwc0.

Salby, M. L., H. Harde, 2021: *Control of Atmospheric CO_2 - Part I: Relation of Carbon 14 to Removal of CO_2*, Science of Climate Change, Vol. 1.2, pp. 177 - 195, https://doi.org/10.53234/SCC202112/30

Salby, M. L., H. Harde, 2022: *Theory of Increasing Greenhouse Gases*, Science of Climate Change, Vol. 2.3, pp. 212 - 238, https://doi.org/10.53234/scc202212/17.

Schrøder, H., 2022: *Less than half of the increase in atmospheric CO_2 is due to the burning of fossil fuels*, Science of Climate Change, Vol. 2.3, pp 1-19, https://doi.org/10.53234/scc202111/17