Correspondence to Ferdinand.engel-been@telenet.be
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Comment on Understanding Increasing Atmospheric CO_2 by Hermann Harde

Ferdinand Engelbeen
Antwerp, Belgium

Abstract

While many of the points made by Harde (2023) [1] are right, a few points are not right and need correction. That includes allegations of certain statements of the IPCC they never did or intended in the way that Harde interpretated.

Keywords: CO_2 levels

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1. **Introduction.**

I was preparing a large comment on the paper by Harde and Salby (2022) [2], but the comment by Andrews (2023) [3] was published before mine was finished. Most points I was preparing were already given by Andrews, so I don't need to repeat them here.

Even if Andrews did mention several items in a simple way, that doesn't mean that these remarks are wrong, neither is a more technical explanation right if the reasoning behind it is wrong…

2. The mass balance.

Whatever the CO_2 sources and sinks in the atmosphere, the carbon mass balance must be closed at any moment of time. No carbon can created from nothing, no carbon destroyed. Except… ^{14}C which is created by cosmic rays and destroys itself by radioactive decay. Because that are extremely small quantities, that doesn't influence the mass balance of the bulk CO_2 amounts.

Let us have a look at the mass balance over the past 60+ years since the exact CO_2 measurements at Mauna Loa started, together with the South Pole:

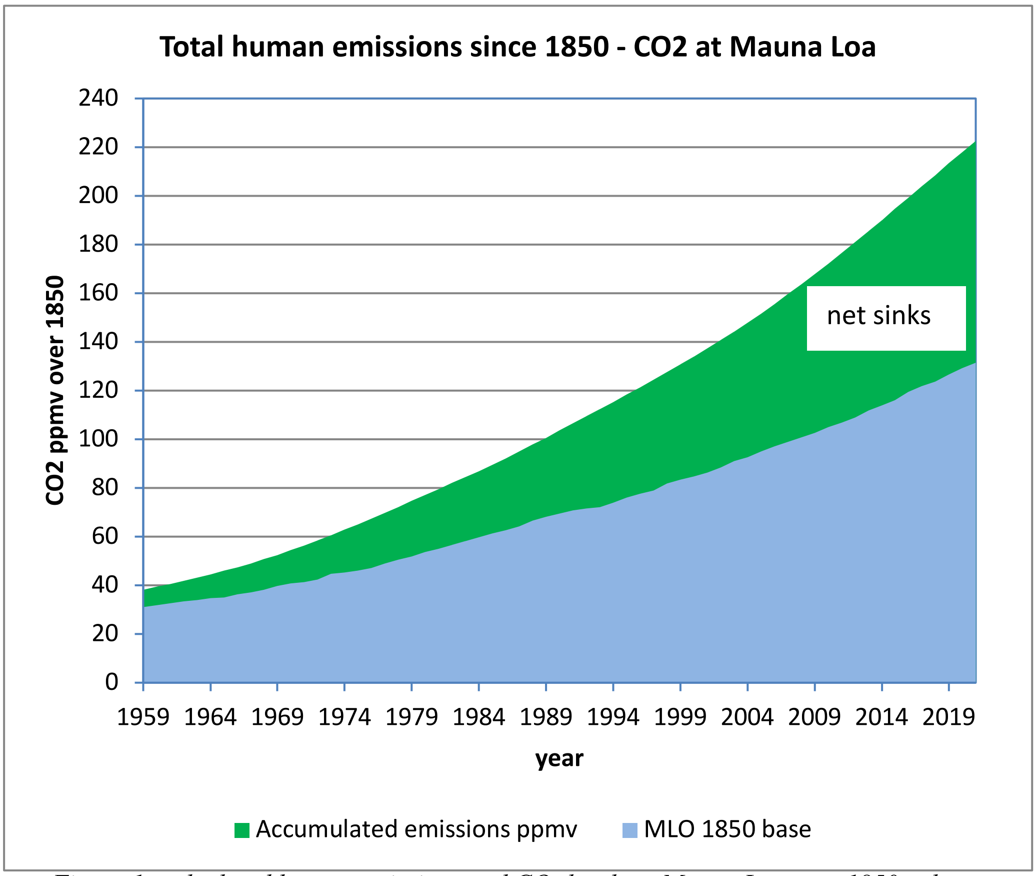

Figure 1: calculated human emissions and CO_2 levels at Mauna Loa over 1850 values. Human emissions of the Global Carbon Project [4] Mauna Loa data of the NOAA Carbon Tracker [5]

The emissions data are from the Global Carbon Project and compiled into one Excel file by Dave Burton [4]. The accuracy of the emission data is quite high, as based on fossil fuels sales (taxes!). Maybe somewhat underestimated, certainly not overestimated. As the Mauna Loa data also are quite accurate (NOAA Carbon Tracker [5]), the difference between both is also quite accurate. Thus 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.

The figures don't include land use changes which are more uncertain but simply add to total human emissions, which means that the net sinks in reality are even larger.

Even if one doesn't like the ice core CO_2 data and starts everything in 1960 from zero, accumulated human emissions increased faster than the increase in the atmosphere.

Thus indeed, human emissions do exceed the increase in the atmosphere and the difference must be absorbed somewhere in nature no matter the distribution over the different reservoirs.

If one looks at the derivatives, that is even more interesting:

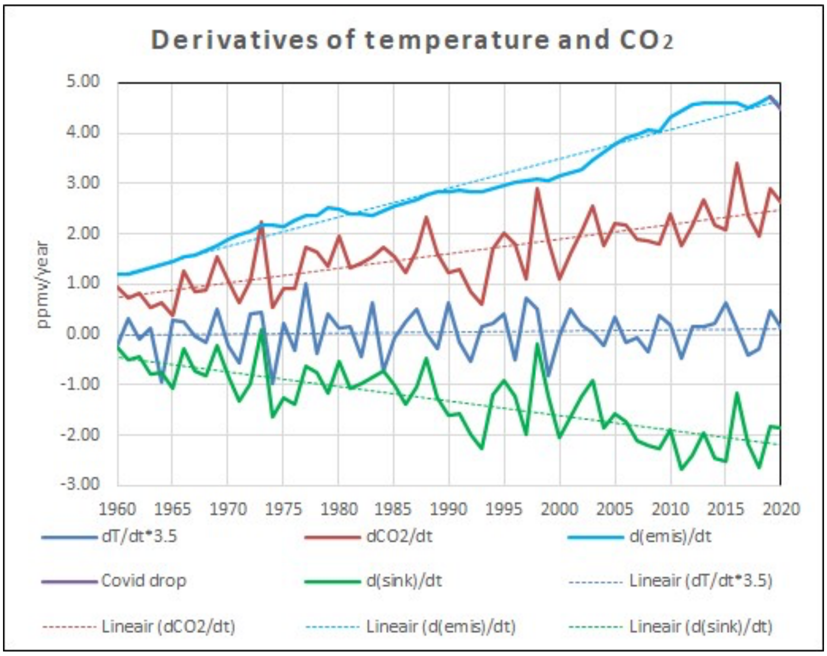

Figure 2: derivatives of human emissions, CO_2 increase, absorption and temperature. The green line is the simple subtraction of the CO_2 increase in the atmosphere from human emissions and reflects the net sink capacity by nature. The small purple dent is the influence of Covid on human emissions, hardly of interest. Temperature data are enhanced with a factor 3.5 to show about the same amplitude as for CO_2. CO_2 data from the Global Carbon Project [4] and the NOAA Carbon Tracker [5] and T data are from HasCRUT4gl via WfT [6].

Except for a few borderline El Niño years, in all years nature was a *net* sink for CO_2. Obviously, the temperature derivative drives the variability in net sink capacity with a small lag, with as result that there is a (delayed) correlation between temperature rate of change changes and CO_2 rate of change changes in the atmosphere.

Also obvious is that the temperature derivative is *not* the driver for the CO_2 increase in the atmosphere, as there is hardly a slope in the derivative, only a small offset from zero, which gives a more or less linear increase of temperature in the oceans and atmosphere of about 0.63 K in the period 1958-2020.
Per Henry's law, that gives a change in dynamic equilibrium between ocean surface and atmosphere of less than 10 ppmv CO2 extra in the atmosphere over the full period (see chapter 2.).

On the other hand, human emissions are about twice the increase in the atmosphere and the slope also is twice as steep as for the increase, leading to a slightly quadratic increasing CO_2 level in the atmosphere of about 100 ppmv over the same period. The effect is that the net flux from atmosphere into the oceans increased over the full period and that the temperature increase only played a role in reducing the net CO2 flux from atmosphere into the ocean surface with less than 10%.

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. The sum of all natural fluxes since 1958 was negative (near) all the time.

As long as the increase of CO_2 in the atmosphere is less than human emissions, there is zero net 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 all natural 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.

The only way that natural fluxes could be the cause of the increase, is when the total natural emissions and total natural sinks exactly followed human emissions in timing and increase: a quadruple increase between 1960 and 2000. Only in that case, human emissions would be overwhelmed by the increased natural cycle. That also would result in a residence time that is ¼ of the current one, which is not observed at all…

Any theory that results in a substantial net addition of CO2 by the natural cycles violates the carbon mass balance and therefore is rejected.

2. The misinterpretations of what the IPCC said.

In formula (4a) and (4b) of Harde (2023) [1] implies that the IPCC assumes a fixed airborne fraction of what remains in the atmosphere from human emissions. As far as I know, the IPCC never said or implied such assumption. The net sink capacity depends of the extra CO_2 in the atmosphere (whatever the source) above equilibrium, not the emissions of one year. The only reason that the increase in the atmosphere is such a fixed ratio to human emissions is that human emissions are linearly increasing each year leading to a slightly quadratic accumulation of human emissions (as mass, not the original molecules!) in the atmosphere and thus of the sink rate. That gives a rather fixed ratio between accumulated human emissions and increase in the atmosphere. See the linear trends in Figure 2.

About the allegations of Harde (2023) [1] in his chapter 3.1.: as already said, the IPCC never said or implied that the increase in the atmosphere is proportional to human emissions. The increase in the atmosphere is a matter of emissions minus absorptions. The net effect depends of the total extra CO_2 pressure (pCO_2) in the atmosphere (whatever the cause: human or natural) above the long-time equilibrium with the oceans surface pCO_2 per Henry's law.
The latter influenced by temperature with a modest change: 12-16 ppmv/K (Takahashi et al, 2002 [7]), or about 13 ppmv increase since the LIA. That is all.

For the current (area weighted) average sea surface temperature, the dynamic equilibrium between oceans and atmosphere would be around 295 ppmv per Henry's law, not 415 ppmv. The 120 µatm (~ppmv) pCO_2 difference between the real pCO_2 in the atmosphere and the oceans pCO_2 is what drives *net* CO_2 from the atmosphere into the oceans, even when that is a dynamic equilibrium where lots of CO_2 are emitted by warm waters in the tropics and absorbed by cool waters near the poles.
See further Feely et al (2001) [8] for the observed net CO_2 uptake by the oceans for the reference year 1995.

About the allegations in chapter 3.2: as far as I know, the IPCC never made a differentiation between natural and human CO_2 for any physical process.
Neither did they assume a constant natural cycle: the graphs provided by the IPCC show an increasing natural cycle, also caused by human emissions, e.g. thanks to more vegetation… See the IPCC carbon cycle graph (2013) [9].

The crux of the matter is in chapter 3.3: 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. That is clearly shown by Peter Dietze (1997) [10] on the blog of the late

John Daly and the later discussion between Peter Dietze and Fortunat Joos, inventor of the Bern model, and several others also on the blog of the late John Daly (2001) [11].
The main error of the Bern model is that it assumes a saturation of all reservoirs, which is true only for the ocean surface layer but by far not for vegetation (maximum uptake around 1500 ppmv) and absolutely not for the deep oceans, which are far from saturated, but have a limited exchange rate with the atmosphere via the sinking polar waters.

From reference [8] by Feely e.a.:

"The pCO_2 in surface seawater is known to vary geographically and seasonally over a range between about 150 µatm and 750 µatm, or about 60% below and 100% above the current [note: reference year 1995] *atmospheric pCO_2 level of about 370 µatm."*

As the deep ocean waters are fed with the sinking cold ocean waters near the poles with about 150 µatm pCO2, the deep oceans are and remain by far undersaturated for CO_2, even if they are slightly warmer (4-5ºC) than the sinking polar waters (still less than 200 µatm pCO_2).

A recent paper by Seltzer, Alan, et al (2023) [12] also shows an undersaturation of noble gases in the deep oceans, due to the slow air-ocean gas transfer at the sink places.

Compared to the enormous amount of CO2 and derivatives in the deep oceans (about 37,000 PgC according to the IPCC [9]), the total human contribution since the start of the industrial revolution is about 1% of the total inorganic carbon species in the deep oceans. Once in equilibrium, that would give an increase of only 3 ppmv CO2 in the atmosphere, but that needs a lot of time because of the limited exchange rate between deep oceans and atmosphere...

Where it goes completely wrong is in:

„The direct absorption time of CO_2 is therefore equal to its residence time"

That is absolutely *not* the case. It is the same error that (too) many made in the past and present: the residence time is how fast CO_2 in the atmosphere is *ex*changed with CO_2 from other reservoirs but *that has zero impact on the total amount of CO_2 in the atmosphere.*
The only way extra CO_2 above the dynamic equilibrium can be removed out of the atmosphere is by the difference in total inputs and total outputs and that is a much slower process: about 50 years e-fold time as observed over the past 60+ years.

That needs a lot of explanation and that will be for another paper, as many others, from Segalstad (1998) [13] via Berry (2019) [14] to formula (2.1) in Salby and Harde (2022) [2] all made the same error by confusing the residence time with the relaxation time, the latter is the time needed to remove any excess CO_2 (from whatever cause) above the long-time dynamic equilibrium out of the atmosphere.

Conclusion

Too many misinterpretations of what the IPCC said by Hermann Harde and still promoting alternatives for the human caused CO_2 increase in the atmosphere which violate the carbon mass balance…

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