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Is Net Zero Necessary?

Meeting the Paris Agreement Temperature Target with 39% Global Emissions Reductions by the 2070s

by

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Abstract

Global Carbon Project (GCP) data shows that natural processes have been sequestering atmospheric CO2 on a yearly basis in proportion to how much the atmospheric CO2 concentration has risen above pre-Industrial levels, the so-called CO2 “sink rate”. Here it is argued that the future trajectory of the sink rate has not been adequately addressed, which has led to overestimation of future atmospheric CO2 concentrations, and thus of global warming. Additionally, use of the CO2 “airborne fraction” concept has led to some misunderstanding regarding how natural processes remove CO2 from the atmosphere, including unrealistic projections of future sink rates. The 20 land models and 10 ocean models used to estimate rates of CO2 removal from the atmosphere produce a wide variety of results. The GCP averages all of these model results together to obtain a best estimate of the yearly CO2 fluxes. Based upon this average, assuming a linearly declining sink rate into the future derived from GCP data, emissions reductions of only 1% per year totaling 39% below 2023 emissions are required over the next 50 years to stabilize atmospheric CO2 near 457 ppm. Assuming the IPCC best estimate of climate sensitivity of 3 deg. C to a hypothetical doubling of atmospheric CO2, this would meet the 2015 Paris Agreement target of less than 2 deg. C of eventual global-average surface warming. But if observation-based estimates of climate sensitivity around 2 deg. C are assumed, then the 1.5 deg. C Paris goal is easily met. These results, though, are very dependent upon the assumed linear decrease of the future sink rates.

1. Introduction

Future projections of global warming depend upon two major components: (1) the uncertain sensitivity of the climate system to increasing atmospheric concentrations of CO_2, and (2) the uncertain future trajectory of those CO_2 concentrations.

Climate sensitivity is currently believed by the Intergovernmental Panel on Climate Change (IPCC, 2021) to be "very likely" in the range of 2 to 5 deg. C, with a best estimate of 3 deg. C, based mostly upon theoretical climate models. Recent observational studies are closer to 2 deg. C or less (Lewis & Curry, 2018; Spencer & Christy, 2024).

For future CO_2 projections, a yearly increase in the CO_2 content of the atmosphere (dCO_2/dt) depends upon human CO_2 emissions (mainly fossil fuel burning and land use changes) exceeding the rate at which land and ocean sinks remove excess CO_2 from the atmosphere. When these two components of climate change have been combined, it has become clear that in order to limit future warming to less than 2 deg. C, anthropogenic emissions will need to be reduced -- but by how much?

In 2008-2009, a flurry of published papers (see Fankhauser et al., 2022 for a review) supported the claim that the only roadmap to climate stabilization was to essentially eliminate anthropogenic CO_2 emissions altogether, leading to the "Net Zero" targets promoted by the 2015 Paris Agreement. As a result, Net Zero emissions targets are now widely assumed to be necessary to keep future global warming to below 2 deg. C, preferably closer to 1.5 deg. C. It is widely claimed (but seldom justified) that near-zero emissions will need to be achieved relatively rapidly, by 2050 or 2060, to achieve these warming targets.

But claims that Net Zero carbon emissions are necessary to achieve these goals are based upon faulty and outdated modeling that can no longer be considered consistent with the observed behavior of the global carbon cycle and climate system. Here I address the future trajectory of atmospheric CO_2 concentrations. It has long been recognized that as human emissions have increased, so too have the amounts of CO_2 removed by nature, processes that sequester carbon on land and in the ocean. All that is necessary for CO_2 levels to be stabilized is for human emissions to be reduced to the point that they no longer exceed the natural rate of CO_2 removal. This statement is non-controversial and is consistent with the annual global carbon budget calculations (e.g. Friedlingstein et al., 2023) relied upon by climate researchers worldwide.

Here I address the question, assuming a modest (1% per year) reduction in global anthropogenic CO_2 emissions, how will nature respond?

2. What Determines How Fast Nature Removes CO2 from the Atmosphere?

The land and ocean processes that lead to a net natural removal of atmospheric CO_2 in the presence of elevated CO_2 concentrations are myriad and complex. An excellent overview of these processes and our current state of understanding of them is provided by Crisp et al. (2022).

It has long been recognized that, due to natural processes of removal of excess atmospheric CO_2, the long-term rate of increase in atmospheric CO_2 has averaged about 45% of yearly anthropogenic emissions. This led to the concept of the "airborne fraction" (AF, see e.g. Canadell et al., 2007), which is the yearly change in CO2 (dCO2/dt) divided by yearly human emissions. The AF is often described as "the yearly fraction of human emissions that remain in the atmosphere" (e.g. Bennett et al., 2024). Most research on the value of the airborne fraction has concluded that it is slowly increasing, purportedly suggesting that nature's ability to remove excess CO2 from the atmosphere is slowly declining.

The AF concept, though, does not reflect how nature works and it can lead to misunderstanding about natural carbon removal processes.

Some of the methodological problems with AF have been recently addressed by Bennedsen et al. (2023) who try to formulate a new version of the AF that is more useful. But the most severe problem I see is that, while the AF is supposed to indicate how fast CO2 is removed from the atmosphere, it is referenced to anthropogenic *emissions* rather than to CO2 *sinks*. As a result, the value of the yearly AF becomes nonsensical under a scenario (like Net Zero) where CO2 emissions are rapidly reduced. The AF only remains well-behaved as long as CO2 emissions continue on an exponential upward trajectory. Importantly, the CO2 sink rate does not have this problem, and so the sink rate will be used in what follows.

I submit that nature does not "know" how much CO2 is emitted into the atmosphere by humanity's burning of fossil fuels each year. With current atmospheric CO2 running about 420 ppm, which is 51% above pre-Industrial levels (estimated to be 278 ppm), the annual anthropogenic emissions of 5 ppm is only 3.5% of the current CO2 excess of (420-278=) 142 ppm. *Nature does not respond to this small yearly incremental increase, but to the large "excess" of CO2 that has built up in the atmosphere over the last 300+ years.*

3. The CO2 Sink Rate has been Declining… Maybe

The latest (Friedlingstein et al., 2023) yearly global carbon budget estimates based upon a variety of observations, anthropogenic emissions estimates, and carbon cycle modeling efforts, lead to the following best estimate of the yearly CO2 sink rate from 1960 to 2022 (Fig. 1). Also shown is an assumed extrapolation of that sink rate into the coming decades using a regression fit to the data.

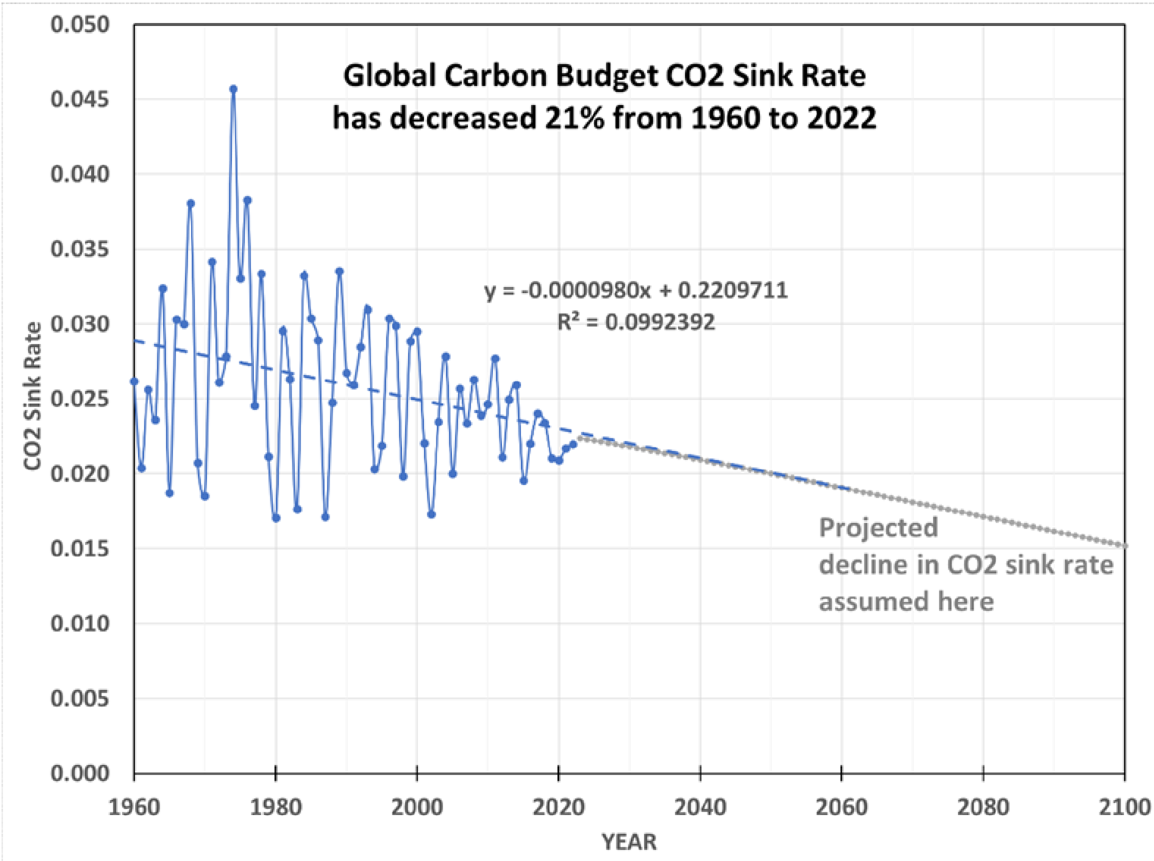

Fig. 1. Global Carbon Project best estimate of the yearly CO2 sink rate.

A declining sink rate means nature is becoming less able to absorb excess CO2 from the atmosphere. While one would think this decrease is obvious from Fig. 1, it is based upon the average of 20 different land models, 10 different ocean models, and 7 ocean carbon budget model estimates, many of which show a wide range of estimates regarding both the absolute magnitude and the trends in CO2 removal for the years 1959-2022. They are all averaged together in Fig. 1.

The 20 land and 10 ocean model estimates of yearly CO2 sinks are shown in Fig.2.

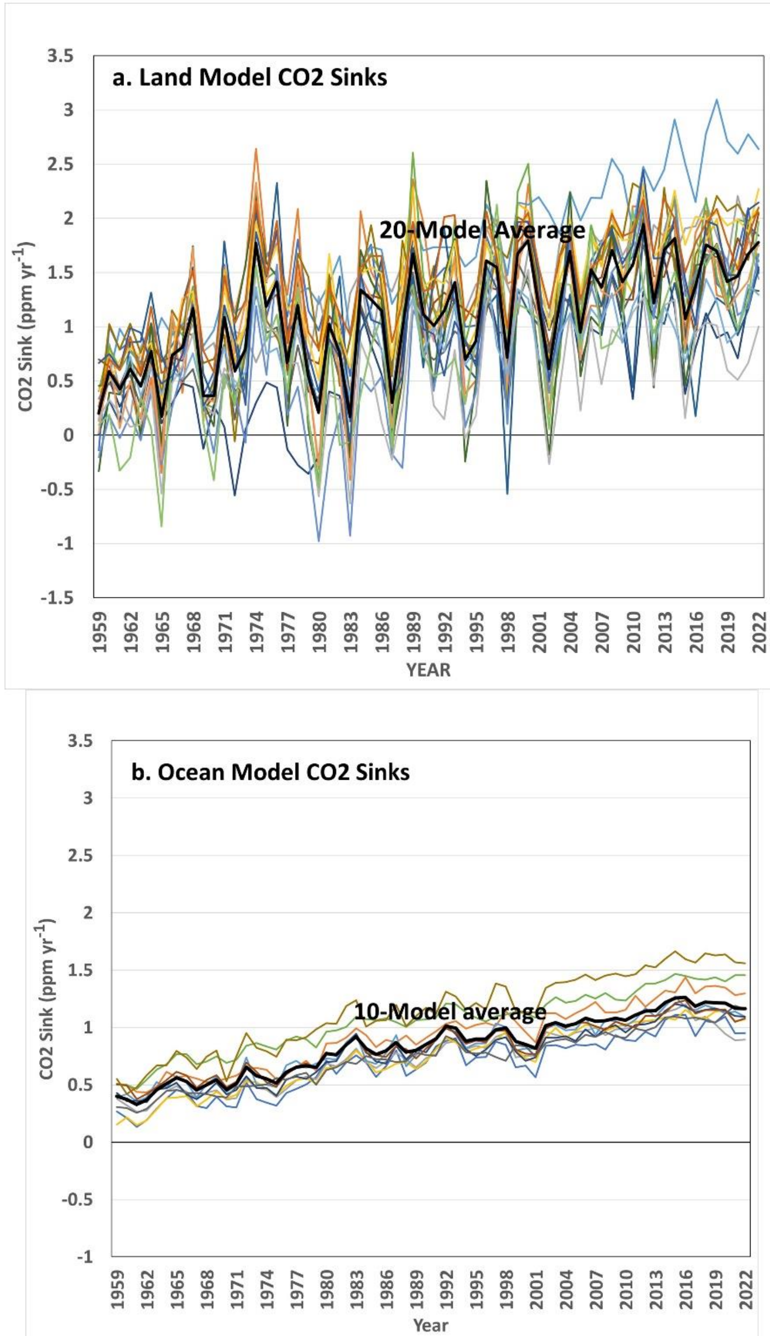

Fig. 2. Global carbon project estimates of yearly land (a) and ocean (b) sinks of CO_2.

I point this inter-model disagreement out as a reminder that the theoretical understanding of the processes that remove excess CO_2 from the atmosphere, while known qualitatively, still has large quantitative uncertainties, especially over land.

I will ignore these uncertainties and use the regression line fit in Fig. 1 for the calculations that follow. In contrast to my assumed linear decrease into the future (post-2022), though, are carbon budget modeling efforts which have suggested the sink rate will decline more rapidly in the future (an issue I will explore further in section 5, below). If true, a more rapidly declining sink rate would mean atmospheric CO2 would rise more rapidly, and climate change will then also be more rapid. Some of these modeling efforts supposedly justify Net Zero emissions targets.

Next, let's examine a modest emissions reduction scenario, and assume that the linear extrapolation of the sink rate decrease in Fig. 1 will be operating into the future.

4. How Does a Sink Rate Decline Affect Net Zero?

Net Zero is based upon some studies which claim that climate stabilization with warming less than 2 deg. (preferably 1.5 deg. C) requires the virtual elimination of CO2 emissions by 2050. I believe this is inconsistent with both observations and with how Nature responds to "extra" CO2 in the atmosphere.

4.1 The Carbon Budget Side

The latest (Friedlingstein et al., 2023) yearly global carbon budget estimates based upon a variety of observations, anthropogenic emissions estimates, and carbon cycle modeling efforts, lead to the best-estimate sources (orange curve) and sinks (blue curve) of atmospheric CO2 between 1850 and 2022 shown in Fig. 3.

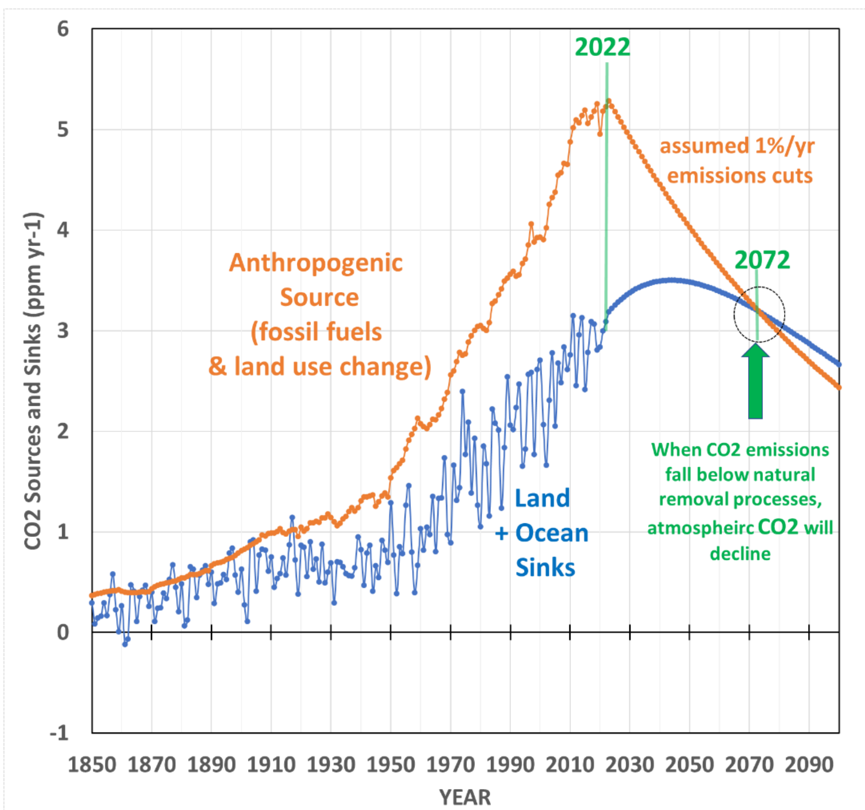

Fig. 3. CO2 budget estimates of yearly sources and sinks of atmospheric CO2, 1850-2022 from the Global Carbon Project. The projected future sinks are based upon the linear extrapolation in Fig. 1 and the atmospheric CO2 concentration, while future CO2 emissions assume a 1% per year reduction. When emissions equal sinks in 2072, atmospheric CO2 stops rising, and begins to decline.

If we assume rather modest 1% per year reductions in global CO_2 emissions shown in Fig. 3, and the linearly declining sink rate from Fig. 1, the atmospheric CO_2 concentration that results from this scenario is shown in Fig. 4.

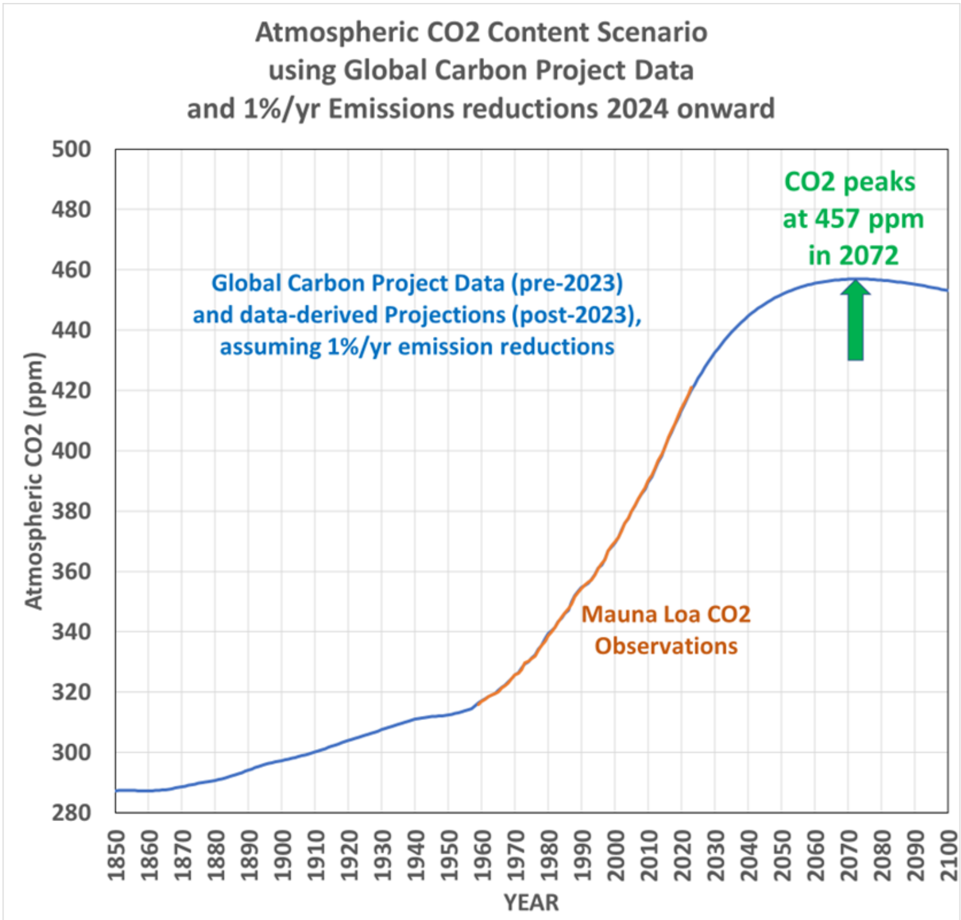

Fig. 4. Historical (2022 and prior) and future (2023 onward) projection of atmospheric CO_2 concentration under the emissions reduction scenario addressed here, along with a linearly declining CO_2 sink rate.

Under this scenario, atmospheric CO_2 peaks at 457 ppm 50 years after emissions reductions started, with a total emissions reduction of 39%.

4.2 The Climate Response Side

Using various estimates of climate sensitivity to a doubling of atmospheric CO_2 ("2XCO2") it is a simple matter to compute how much global-average surface warming will result. In Table 1, a wide range of assumed ECS values are scaled with the factor of 0.644 (because 457 ppm peak CO_2 from Fig. 4 is 64.4% of the way to 2XCO2) to determine how much warming would result from a peak atmospheric CO_2 value of 457 ppm.

Notes	Assumed ECS from 2XCO2 (555 ppm)	Warming from 450 ppm
ECS from obs (Lewis & Curry, 2018)	1.6	**1.03**
	1.8	1.16
ECS from obs (Spencer & Christy, 2023)	2	**1.29**
	2.2	1.42
	2.4	1.55
	2.6	1.68
	2.8	1.81
IPCC "Best Estimate" (AR6)	3	**1.94**
	3.2	2.07
	3.4	2.19
	3.6	2.32
	3.8	2.45
	4	2.58

Table 1. Future equilibrium warming assuming a variety of equilibrium climate sensitivities (ECS) and the 457 peak CO2 concentration after 50 years of 1% per year emissions reductions.

As can be seen, using a linearly declining sink rate combined with 1% per year emissions reductions meets the Net Zero goal after 50 years, with less than 2 deg. C of eventual warming assuming the IPCC best estimate of ECS = 3 deg. C. If ECS is really closer to 2 deg. C, as suggested by energy budget calculations based upon observed warming rates of land and ocean (including the deep ocean, Lewis & Curry, 2018; Spencer & Christy, 2024), then the 'optimistic' Paris Agreement goal of limiting warming to 1.5 deg. C is easily met.

5. The CO2 Sink Rate Wild Card

The future trajectory of the CO2 sink rate (along with the climate sensitivity of the climate system) is critical to how much future warming occurs. Carbon cycle modelers will, no doubt, object to my linear projection of sink rates into the future based upon the last 60+ years of data. Their anticipation, based upon carbon cycle modeling, is that the sink rate will decrease more rapidly in the coming years, leaving more CO2 in the atmosphere, thus causing even more future global warming. Keep in mind that their anticipation is in the face of the large quantitative uncertainty exhibited by the 20 land models and 10 ocean model estimated CO2 sinks shown in Fig. 2.

So, let's examine one of the modeling examples of a rapidly declining sink rate. The following emissions scenarios shown in Fig 5 are from Raupach et al. (2014) which examined from a modeling perspective how the climate system would respond to a variety of scenarios that assume various total future accumulated anthropogenic emissions (Q). Of special interest to Net Zero goals is the scenario (dark blue line) representing a total end to anthropogenic emissions in only one year.

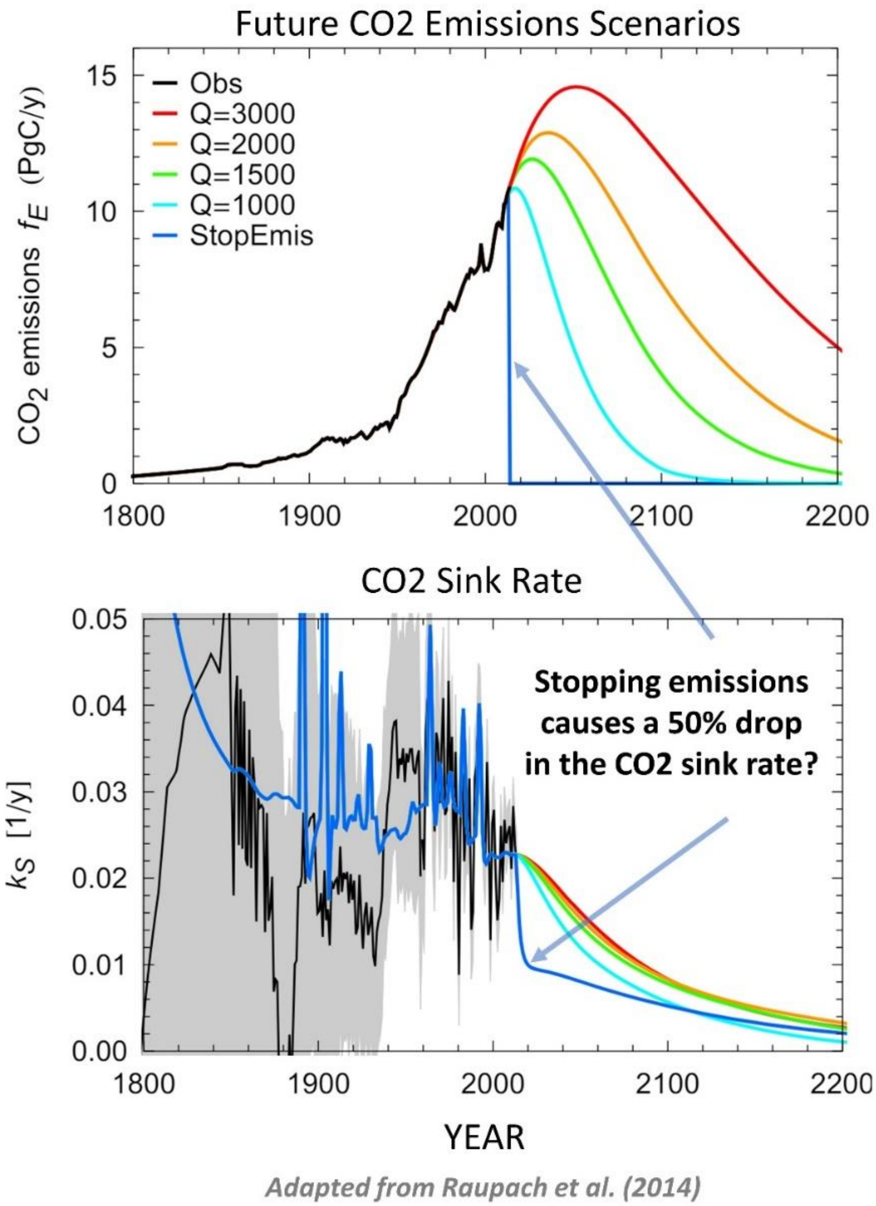

Fig. 5. How the atmospheric sink rate (bottom) responds to various cumulative emissions (Q) scenarios (top), based upon a carbon cycle and climate model (adapted from Raupach et al., 2014). The black line represents historical observations, and the grey shaded area shows the envelope of uncertainty of those observations, which was very large prior to 1960. Note the model projection of a rapidly dropping sink rate if anthropogenic emissions were abruptly stopped.

I claim that the rapid drop in the CO2 sink rate under the scenarios involving rapid reductions in anthropogenic emissions is unphysical.

What is happening in their model to cause this behavior is not immediately obvious to me, so what follows is just speculation. In their model, there are various CO2 sinks with a wide range of response times, which actually do exist in nature. But because those sink responses are tied to yearly emissions rather than atmospheric CO_2 content (which would be more realistic), a sudden cessation of anthropogenic emissions causes the fastest response time to abruptly reduce the amount of CO_2 removed from the atmosphere. The result will be too much CO_2 remaining in the atmosphere, and then too much future global warming.

Let us perform a thought experiment to examine what actually happens under an extreme Net Zero scenario. According to the recent value of the sink rate, nature is currently removing CO_2 at a rate of about 2.5% of the atmospheric content excess over pre-Industrial levels, which in 2023 was (421-278=) 143 ppm "excess". Now let us assume that the small (but persistent) anthropogenic source of ~5 ppm per year is suddenly halted. Nature cannot tell the difference between anthropogenic CO_2 molecules and the pre-existing atmospheric CO_2 molecules. Nature just sees what is in the atmosphere, which is 143 ppm above pre-Industrial levels plus a "new" (but comparatively tiny) CO_2 flux from anthropogenic sources. I submit that it is unphysical to believe that nature suddenly responds to just the relatively tiny loss of 5 ppm anthropogenic input instead of the large 143 ppm excess still in the atmosphere, and then reduces its rate of removal by over 50% (the dark blue line, bottom of Fig. 5) within a couple of years. This makes no physical sense.

It is for this reason I do not believe that current modeling efforts are accurately handling the processes that remove CO_2 from the atmosphere. While I am not familiar with the modeling assumptions in the 20 land models represented in Fig. 2, I submit that the huge range of disagreement between them supports a more empirical approach, where we simply assume the CO_2 sink rate that has been observed over the last 60 years will continue to decline linearly for the next 50 years, which is the time horizon I addressed above.

It should also be pointed out that it is not entirely obvious that the CO_2 sink rate has been declining (Spencer, 2023) or that the airborne fraction has been increasing (Bennett et al., 2024).

At a minimum, I think it is non-controversial to state that the future trajectory of the CO_2 sink rate is a major wild card in global warming projections.

6. Discussion & Conclusions

The concept of Net Zero anthropogenic CO_2 emissions has become a fixture of energy policy goals for many years, with serious discussions of the concept as far back as the 1990s. The scientific basis for Net Zero was supported by a flurry of papers published in 2008 and 2009 that claimed (or assumed) that climate stabilization required the virtual elimination of anthropogenic emissions, preferably by the year 2050. Now that more recent data are available regarding how nature sequesters atmospheric CO_2, the scientific basis for these claims can be reexamined.

The claim that anthropogenic carbon emissions have altered, and will continue to alter, the global carbon budget is not in dispute. Nor is it disputed that the resulting changes to the carbon cycle and climate system last for centuries, if not for millennia (in the deep ocean). What is in dispute is the claim that these emissions need to be eliminated in order to stabilize future temperatures at a level that is mostly benign to both nature and to humans. I believe the relatively few studies that have come to that conclusion were not well formulated, and are based upon concepts which are not in accord with the observed behavior of the global carbon cycle.

It has long been known that CO2 only rises to the extent than anthropogenic emissions exceed natural sinks. All that is required for CO2 levels to stop rising is for emissions to be reduced to the point where they no longer exceed the sinks. This is not controversial, and simply represents CO2 budget 'bookkeeping'. Exactly how this would be accomplished, though, depends upon the future trajectory of those natural sinks as well as anthropogenic emissions.

For emissions, I assumed modest (1% per year) reductions in global CO2 emissions relative to 2023 emissions. For the natural CO2 sinks I have examined a scenario based upon global carbon budget inventories that suggest the rates of CO2 removal are beginning to decline in intensity, and so I have assumed a linearly declining CO2 sink rate that matches best estimates of that value over the last 60+ years.

Under this observations-based scenario, the atmospheric CO2 concentration levels off in the year 2072 at about 457 ppm, which is only 65% of the way to doubling of pre-Industrial CO2 concentrations (2XCO2). The resulting eventual warming then depends upon the climate sensitivity assumed. Using the IPCC AR6 best estimate of ECS = 3 deg. C, and assuming little or no additional emissions reductions past 2072, the resulting eventual warming for 457 ppm is 1.94 deg. C, which meets the Paris Agreement goal of keeping future warming to below 2 deg. C. If the real ECS of the climate system is closer to 2 deg. C, as is indicated by observations-based energy budget studies, then future warming remains below the more optimistic 1.5 deg. C Paris target.

There is little doubt these conclusions, which suggest Net Zero goals are unnecessary, will be controversial. But they are based upon the latest and best estimates of the observed behavior of the global carbon cycle in terms of net global CO2 fluxes. As discussed above, they are very dependent upon the future rate at which natural processes remove CO2 from the atmosphere, through the CO2 sink rate. I have argued that future projections of a rapidly declining sink rate are inconsistent with observations and are the result of flawed modeling assumptions.

The results suggest that Net Zero is an unnecessarily restrictive policy goal, and that climate stabilization that limits warming to 1.5 – 2 deg. C can be achieved with relatively modest emissions reductions of approximately 40% by the 2070s, rather than the current Net Zero goal of essentially 100% reductions by 2050.

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