Central Coast Climate Science Education
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Energy Budgets, Peak Global Temperatures, and Their Implications

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For whom this essay is intended

For all those wishing a better understanding of the concept of an "energy budget" and the consequences of not meeting such a budget by failing to rapidly reduce greenhouse gas emissions.

Summary

The concept of a '*carbon budget'* is explained and the consequences of exceeding such carbon budgets are described. The essential lesson is that each pound of CO_2 emission that are avoided lessons the impacts of climate disruption. Conversely, each pound emitted increases such impacts. In addition, it increases the likelihood of crossing *'tipping points'*: irreversible and very serious changes in the climate system which may last for centuries or even millennia.

It is essential that we continue to work strenuously to reduce emissions as rapidly as possible. But it is also ill-advised to state that "the we are doomed" if a particular budget is not met, as that induces a feeling of hopelessness. It is also urgent that we all keep our focus on the overarching need of reducing emissions, rather than focusing primarily on one's favorite method of achieving these reductions.

Some readers may have read statements something like "We only have 8 years left to avoid a climate catastrophe." This statement is based upon the concept of a *carbon budget*. In this essay, I want to discuss the concept of a carbon budget, what would be necessary to meet such a carbon budget, and, importantly, the implications of failure to meet various carbon budgets. I will close with some editorial opinions on the necessity of focusing on the goal of meeting such budgets rather than rigid ideas of what constitutes the best pathway for meeting a given budget.

Carbon Budgets

In the IPCC Sixth Assessment Report of Working Group 1, which is the group of thousands of climate scientists charged with assessing the basic science, (see IPCC AR6 WG1[1]) we read in section 5.5.2.1 the (somewhat lengthy!) definition of "remaining carbon budgets" as "*the maximum amount of cumulative net global anthropogenic CO2 emissions expressed from a recent specified date that would result in limiting global warming to a given level with a given probability…"* but they then add the additional remark that *"studies…apply a variety of definitions that result in published remaining carbon budget estimates [referring to the] cumulative emissions at the time when global-mean temperature increase would reach, exceed, avoid, or peak at a given warming level with a given probability."*

The basic concept underlying the notion of a carbon budget is the result of numerous investigations by climate scientists that peak global temperatures are roughly proportional to the total ("cumulative") amount of carbon dioxide emitted up to the time of reaching zero emissions.

This is stated in AR6 WG1:

"This Report reaffirms with high confidence the AR5 finding that there is a near-linear relationship between cumulative anthropogenic CO2 emissions and the global warming they cause. Each 1000 Gigatonnes of CO_2 emissions is assessed to likely cause [between] a 0.27 °C to 0.63 °C increase in global surface temperature with a best estimate of 0.45 °C … This relationship implies that reaching net zero anthropogenic CO_2 emissions is a requirement to stabilize human-induced global temperature increase at any level…"

The following figure is taken from the same section of the report as the quote above. *This is an important graphic to illustrate the concept of the carbon budgets so it is worth spending some time discussing.* You may find it helpful to print this graph out to follow the discussion:

[1] The full report is here: https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf and the section discussing the concept of carbon budgets is also found in the less technical "Summary for Policy Makers", section D1.1

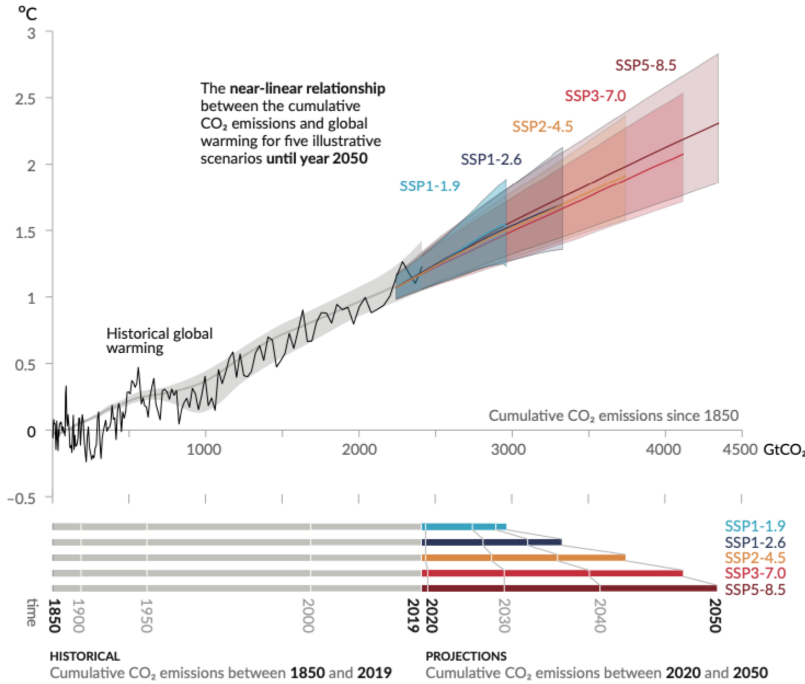

Figure 1. This figure is figure SPM.10 in IPCC AR6-WG1 "Summary for Policy Makers." The vertical axis shows the increase in global temperatures that result as a consequence of the estimated cumulative carbon dioxide emissions (measured in gigatonnes of CO_2), which is shown on the horizontal axis. Both the temperature increase and the cumulative emissions are measured from the year 1850. See the text for further explanation.

In this figure, the jagged black line shows the *observed* temperature rise that has taken place between 1850 and 2020. The cumulative emissions that have already occurred as of 2020 are about 2450 gigatonnes of CO_2.

CO_2 emissions from fossil fuel combustion are estimated by records kept of each country's annual energy usage and the amount of CO_2 that combustion of a given type of fuel yields. Adding up annual values gives the cumulative emissions from fossil fuel combustion.[2] Additional CO_2 emissions result from land uses such as deforestation, [3] which may contribute up to 25% of CO_2 emissions.[4]

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[2] https://ourworldindata.org/contributed-most-global-co2; Scroll down to the graph "CO2 emissions," click on "add country" then add the "World" to the list of countries and use this interactive graphic.

[3] http://theclimatebook.org/ **Note:** Confusion can arise when comparing emission values from different references, depending upon whether the emissions include land use changes (such as deforestation) which may account globally to as much as a quarter of CO_2 emissions. Or only emissions from fossil fuel combustion. The discussion in The Climate Book refers only to the latter, whereas the IPCC discussion above includes land use changes. Other estimates may also include equivalent amounts of CO_2 from other greenhouse gases. In addition, emission amounts are sometimes given in terms of tonnes of *carbon* rather than tonnes of *carbon dioxide*. The data in the "our world in data" reference above—see their footnote 2, is CO_2 from fossil fuel combustion only.

[4] https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

The shaded gray band and the faint thin gray line bracketing the jagged black line, both extending up to the present (about the year 2020, where the cumulative emissions have reached about 2450 giagtonnes) depict the range and central estimate, respectively, of the amount of warming that climate scientists have attributed solely to human activities and not natural causes. *The fact that the observed temperature lies within the gray band since cumulative emissions reached about 1000 gigatonnes implies that essentially* <u>*all*</u> *observed warming since then is likely human-caused.*

Note the few dates marked underneath the gray bars. See also the graphic in footnote 2 (but add the "World" to their list of countries) as well as on the 2nd page of "TheClimateBook" , footnote 3 (but before the table of contents, not the actual page number 2.) We learn that more than half the cumulative fossil fuel emissions occurred between 1990 and 2020 than all such emissions prior to 1990, and only about 13% prior to 1950, since 1850. (There is only a minute amount prior to 1850.)

The colored shaded areas in the graph and the 5 colored bands below the graph itself, which start in 2020, show five possible emissions "scenarios" (see this reference[5]) or "narratives," called "shared socioeconomic pathways" (SSP) which the world might follow, depending on the policies the nations of the world adopt. (SSP 1 through 5; the numbers following these SSP designations—e.g. 1.9 in SSP1-1.9 --is a measure of the amount of energy prevented from escaping into space because of the greenhouse effect of CO_2.) The wiki reference provided in footnote 5 describes them as " *scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies*." They are also used by the IPCC in the 6th Assessment Report to help illuminate the consequences of various policies.

The end points of each of the colored bars shows the estimated cumulative emission that will be reached by the year 2050 for each of the scenarios. The width and center line at the end of each of the five wedges indicates the uncertain range and best estimate, respectively, that there is a 50% probability that the temperature will not exceed the values indicated on the vertical axis. For example, in scenario SSP1, if by 2050 the cumulative emissions have been limited to 3000 gigatonnes of CO_2, then the "best estimate" is that there is a 50-50 chance that the temperature rise will not exceed 1.5 ^{o}C. But since we have already emitted about 2450 gigatonnes, the remaining <u>*carbon budget*</u> is now just 3000 – 2450 = 550 gigatonnes. For comparison, this amount of cumulative emission was achieved around 1950. If we want to have a higher probability that this limit will not be exceeded, then the center line of the SSP1 wedge would have to be shifted to the left. For example, it is estimated that to have a 2/3 chance of not exceeding 1.5 ^{o}C, the remaining carbon budget shrinks by about 70%. *At the current rate of emissions that budget will be used up in less than a decade.*

One sometimes reads comments that leave the impression that if we miss this budget (as frankly now seems all but certain) then "the world is doomed." Such statements are ill advised because they lead to a sense of despair and hopelessness. The important fact is

[5] https://en.wikipedia.org/wiki/Shared_Socioeconomic_Pathways

this: **Every additional tonne of emissions we *avoid* will decrease additional warming. By the same token, every additional tonne of emissions produced will lead to additional warming, which will lead, on the whole, to increasingly severe consequences. and increase the likelihood of crossing dangerous *"tipping points"* in the climate system, as discussed below.**

The negative consequences that the world *is already experiencing* are now becoming obvious to all but the most obtuse individuals, whether it is severe drought, severe heat waves, increasing intensity of floods, devastating wildfires, and severe tropical storms. And the consequences involving crop failures and food scarcity which are driving climate refugees, are also becoming more and more frequent and apparent.

Tamsin Edwards is a climate scientist at Kings College, London, UK.[6] She was one of the lead authors in a portion of IPCC AR6 and is a skilled communicator concerning climate science. She has contributed a brief essay to The Climate Book by Greta Thunberg which I reviewed in a previous post in Central Coast Climate Science.[7] The title of her essay is "What Happens at 1.5, 2.0, and 4.0 ^{o}C of Warming?"[8] This short essay is worth reading in full but I have reproduced the tabular summary entitled:

Extreme weather events that happened once per decade before human influence will be:

	1.5C	**2C**	**4C**
Extreme Heat	**4x more likely**	**6x more likely**	**9x more likely**
Heavy rain	**50% more likely**	**70% more likely**	**300 % more likely**
Drought	**2x more likely**	**2x more likely**	**4x more likely**

But there are many other effects that will get more severe, e.g., sea level rise with its profound direct human as well as economic impacts. And the impacts are not limited to human beings but to a large portion of the entire animal and vegetable kingdoms.

It is also the case that these adverse impacts are not distributed uniformly but have the most severe impacts on the poorest and least developed populations of the world which, ironically, have contributed only a very tiny fraction of the cumulative emissions, as convincingly documented in the reference provided in footnote 2.

For all these reasons the Paris Agreement has set a goal of limiting the temperature rise to 1.5 or at most 2 ^{o}C, while more recent discussions have acknowledged the need for

[6] https://www.kcl.ac.uk/people/tamsin-edwards
[7] http://www.centralcoastclimatescience.org/uploads/5/3/8/1/53812733/thunberg_book.pdf
[8] https://theclimatebook.org/en-us/endnotes/how-our-planet-is-changing/2-24-what-happens-at-1-5-2-and-4c-of-warming/

developed nations to help the underdeveloped nations to adapt to current and future climate disruption.

Additionally, continued emissions increase the likelihood that humans may push some important properties of the earth's climate system past *tipping points.*

I like to visualize the idea of a tipping point by thinking of pushing a car stalled in a dip in the road. At first, you may have to push it up hill and if you get a little tired it may want to roll back a bit. But after you reach the crest of the hill the car will slide down the hill on its own. At first you may be able to slow the car by holding it back, but as the hill steepens it may become beyond your ability to stop it. It's motion downhill has become *irreversible* and it will not come to rest until it reaches a new low dip in the road.

An excellent, but brief, discussion of climate tipping points can be found in the short contribution by climate scientist Johan Rockstrom[9] in article 1.8 page 32 of The Climate Book referenced in footnote 7. While some of these tipping points may take decades or centuries for the full climate change to be realized, *their effects cannot be reversed by human intervention*, at least for many centuries, and some of these effects can persist for millennia.

Examples of tipping points, discussed by Rockstrom, include: very large rises in sea level brought about by disintegration of the Greenland ice sheet and the western portion of the vast Antarctic ice sheet; transition of the Amazon rain forest to an arid savannah with corresponding loss of absorption of carbon dioxide; disruption of the monsoon pattern over India and elsewhere on which so much of their food production relies; disruption of ocean circulation in the Atlantic, causing dramatic changes in various aspects of climate all over the world. Indeed, Rockstrom emphasizes how interconnected these various tipping points are to each other.

But, not only is it not helpful to create despair and hopelessness by saying "the world is doomed", it is also not helpful to disparage the positive efforts to reduce emissions that are being made. The investment and deployment of renewables such as wind, solar and accompanying battery storage, have dramatically increased. Yes, they are inadequate to avoid the consequences of exceeding 1.5 and likely even a 2 ^{o}C increase in global temperature. But it now seems likely that the far more catastrophic rise of 3 or even 4 ^{o}C may be avoided with the likelihood of passing some critical tipping points being reduced and pushed back in time. But it behooves us all to continually work as hard as we can to get the world to quickly do better.

Those of us who are of my generation, (which I suspect are most of the readers of this post) will not experience the worst impacts of a warming world. But if we care about those who *will*, both the living younger generations, especially those in much of the developing world, and the yet unborn generations, then we must continue to do all we possibly can to make curtailment of fossil fuels an urgent priority.

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[9] https://en.wikipedia.org/wiki/Johan_Rockström

It is thus distressing to me that discussions about combating climate disruption frequently devolve to a focus on each of our favorite methods for achieving rapid reductions, losing sight of the overarching goal for rapid fossil fuel use reduction and diminished greenhouse gas emissions by the best combination of methods.

Specifically, I am discouraged by fairly rigid advocacy either for, or against, the role of nuclear energy, either fission (or as discussed in a forthcoming post, fusion) in providing energy which does not emit CO_2. The downsides and risks of nuclear fission (or, in the future, possibly fusion) should not be cavalierly dismissed, nor should they be considered so intractable that use of nuclear energy is dismissed out of hand.

What is needed is an informed and unemotional examination on a local, regional, national, and global basis from a risk &cost/benefit point of view as we are all capable of. To do less than this will simply diminish our chances of avoiding even more severe climate disruption.

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