Expectation Questions

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http://ccdatacenter.org/documents/ExpectationQuestions.pdf

Abstract

Climate change poses an existential treat to our civilization, with the possibility of very serious climate disruption (and possible societal collapse) by the end of this century. Some climate scientists currently believe that many hundreds of gigatons CO2 may need to be removed from the atmosphere by 2100 (and possibly much earlier) in order to prevent catastrophic climate disruption. Since the costs of this removal could be quite significant (and possibly in the hundreds of trillions of dollars[1]), we need to have a serious discussion both on the expected costs of preventing catastrophic climate disruption and whether or not our society will be willing to fund the costs.

Background

The Earth's average global temperature has increased about 1.1° C since pre-industrial times, primarily from the increase of greenhouse gases in the atmosphere caused by the burning of fossil fuels and land use changes. If anthropogenic greenhouse gas emissions are not reduced significantly in the coming years, the total temperature increase could easily exceed 3° by 2100, which might cause catastrophic changes to our climate. It is already too late to prevent catastrophic sea level rise (which will likely be more than three feet by 2100) and it is likely too late to prevent really serious ocean acidification (which is likely once atmospheric CO2 reaches 450 PPM). But is it too late to prevent "catastrophic climate change"? The latest IPCC report (*Global Warming of 1.5°C*, released in October 2018) clarified the need to limit the temperature increase to "well under 2.0° C by 2100". Although it is technically possible to do this, it might beyond the reach of what our society is willing to pay for. What is the proper response to this report? How are the following questions best answered?

1. Is our civilization "doomed"? (and if not, under what circumstances would we be "doomed"?)
2. Is it time to "panic" (but really make significant sacrifices in the short term to reduce greenhouse gas emissions)? (If not now, under what circumstances should we panic?)
3. Can "negative emission technologies" be implemented at the scale needed to limit the temperature increase to a 1.5° C or 2.0° C?
4. What will it cost to limit the temperature increase to a specific level (1.5° C, 2.0° C, etc.)?
5. Will the politicians be willing to commit the necessary funds to "solve climate change"?
6. Are there politically and socially acceptable greenhouse gas emission pathways that can limit the temperature increase to a 1.5° C or 2.0° C?
7. If politicians are not willing to commit the necessary funds are we likely headed towards a "hothouse Earth"? (Under what circumstances would a "hothouse Earth" be deemed inevitable unless some sort of "solar radiation management" were implemented?)
8. Should we implement some "solar radiation management" technologies to buy some time to bring the cost of removing CO2 from the atmosphere down to a level that would limit the temperature increase to a 1.5° C or 2.0° C?

Question 5 is the most critical one to answer (and we should not assume that future generations will "foot the bill" simply because "they have to"). "Climate optimists" believe the that the answer to Question 5 is "Yes", while "climate pessimists" believe that CO2 removal costs will not decline quickly enough to allow for the funding of CO2 removal from the atmosphere at the necessary scale. But in order to answer Question 5 we need to get a better idea of what the remaining carbon budget is and what likely future emissions are apt to be. The amount of CO2 that will needed to be removed from the atmosphere to meet a specific temperature target can then be calculated. And, given an estimate of how the expected CO2 removal costs will decline over the next 30 or so years, an estimate of the total CO2 removal costs can then be made.

Additional Thoughts

Most analyses of the Earth's expected temperature increase (and the associated "carbon budget") are based on the IPCC's "Assessment Reports". And many of these analyses include emission pathways (usually including negative emissions) that purport to show that it is still possible to meet a 1.5° C or 2.0° C temperature increase. As a result, most people assume that all we need to do to "solve" climate change is give our politicians the necessary "political will" to pass laws that will result in emissions following one of these emission pathways. Unfortunately the task is much, much more difficult than most people realize. This is because there are at least four main problems with IPCC's reports: (1) the IPCC's estimates are likely quite conservative[2]; (2) the results are not presented is a way that allows a "correction" to be made in the light of newer knowledge[3]; (3) many of the assumptions/results are not presented in such a way as to allow a discussion as to both their technical feasibility and their political and social acceptability[4]; and (4) it is very difficult to determine what the associated costs might be for meeting a specific temperature increase target[5].

Taking into account the new knowledge of the climate system that has been obtained since the last set of IPCC Assessment Reports was published and given a better understanding of what society is realistically willing to do to reduce greenhouse gas emissions, how do we develop a "reasonable" set of projections (for various sets of assumptions) for the Earth's temperature increase through 2100? To do so, we need good answers (including sets of possible values for some) to the following questions:

1. How much has the temperature already increased? What is the current "energy imbalance"? What is the current CO2e of the various greenhouse gases?[6] What is the RF of the various greenhouse gases and other forcing agents?
2. How much will energy demand increase?[7,8,9]
3. How much of the energy demand can be met by renewable energy (including hydro and nuclear)?
4. How fast can we realistically "decarbonize"?
5. What are some reasonable pathways for anthropogenic fossil fuel consumption?[10,11]
6. How much of the CO2 from the burning of fossil fuels can be captured by CCS?
7. How big a role will BECCS play in electricity generation?
8. What are some reasonable pathways for natural GHG emissions? (deforestation, wildfires, soils, reservoirs, peat, permafrost, etc.) (a set of these will be needed for various possible

temperature "profiles" as the temperature increases over the desired target and then approaches the temperature target)

9. How much of the emitted CO2 will remain in the atmosphere? (Two cases - (1) net CO2 emissions become zero or negative; and (2) natural emissions become significant and are not offset by direct air capture or negative emissions)
10. What are some realistic pathways for anthropogenic methane emissions? What will need to be "sacrificed" for each pathway? (E.g., give up meat, etc.)
11. What are some realistic pathways for anthropogenic N2O emissions?
12. How are aerosols related to fossil fuel consumption? Does that change with BECCS or CCS? How much of a temperature increase will aerosols mask?
13. What are realistic pathways for other "forcing agents"?
14. How much will the surface albedo in the Arctic change and how much of that change is accounted for in the calculated climate sensitivity?
15. Given all of the above, what is the expected temperature increase? (for combinations of "pathways")[12,13]
16. Given all of the above, what is the expected temperature increase if fossil fuel consumption is ended by 2050? by 2075? (for combinations of "pathways")
17. If we don't employ negative emissions technologies, which combinations of the above paths lead to a "hothouse Earth" because of natural emissions? What is the likely highest emissions scenario that avoids a "hothouse Earth"?
18. How much CO2 would need to be removed from the atmosphere to reach a target temperature increase of 1.5°C? 2.0°C? (for combinations of "pathways")
19. What is the expected cost of the removal? (for combinations of "pathways")
20. How much of the removal could be "market based" and pay for itself?
21. How much might people be willing to pay for CO2 removal? (In a recent poll, seventy percent of Americans say they would vote against a $10 monthly fee tacked on to their power bill. Forty percent would oppose a $1 monthly increase https://www.theatlantic.com/science/archive/2019/01/do-most-americans-believe-climate-change-polls-say-yes/580957/)
22. What is the criteria for employing solar radiation management? When is generally accepted that we are on a "hothouse Earth" pathway and that it becomes obvious that NETS will not be deployed at scale?

End Notes

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[1] **A very rough estimate of CDR costs through 2100 for various fossil fuel emissions**.

Assumes all CO2 emissions from 2019 through 2100 will have to be captured and sequestered (it is possible that any remaining carbon budget - perhaps 200 GTC - will be offset by anthropogenic CH4 emissions, a reduction of atmospheric aerosols, natural emissions, and changes to the surface albedo in the Arctic region; and this assumption simplifies the calculations).Note that emissions are likely to increase through at least 2050 (see endnote 7).

9.86	**2015 Fossil Fuel Emissions (GTC)**
1.6	**2015 land use emissions (GTC)**
2070	**Year when land use emissoins reach zero**
0.029	**Land use decline/year (GTC)**
33	**Anthropogenic Emissions 2016-2018 (GTC**

	Peak Yr:	2030			2040			2050		
	Pct Chg to	0	1	2	0	1	2	0	1	2
Annual Pct	0	848	972	1113	848	1050	1303	848	1123	1499
Change of	-1	603	714	843	668	861	1104	723	991	1360
Peak Yr After	-2	400	481	582	489	646	864	559	783	1123
		Emissions 2019-2100 (GTC)			Emissions 2019-2100 (GTC)			Emissions 2019-2100 (GTC)		

	Peak Yr:	2030			2040			2050		
	Pct Chg to	0	1	2	0	1	2	0	1	2
Annual Pct	0	881	1005	1146	881	1076	1317	881	1156	1532
Change of	-1	684	776	881	727	880	1069	774	1004	1317
Peak Yr After	-2	557	628	709	622	746	900	695	893	1160
		Emissions 2019-2100 (GTC)			Emissions 2019-2100 (GTC)			Emissions 2019-2100 (GTC)		

300	**$/Ton C for Carbon capture ($80/Ton CO2)**

	Peak Yr:	2030			2040			2050		
	Pct Chg to	0	1	2	0	1	2	0	1	2
Annual Pct	0	254	292	334	254	315	391	254	337	450
Change of	-1	181	214	253	200	258	331	217	297	408
Peak Yr After	-2	120	144	175	147	194	259	168	235	337
		CDR Costs Through 2100			CDR Costs Through 2100			CDR Costs Through 2100		

	Peak Yr:	2030			2040			2050		
	Pct Chg to	0	1	2	0	1	2	0	1	2
Annual Pct	0	264	301	344	264	323	395	264	347	460
Change of	-1	205	233	264	218	264	321	232	301	395
Peak Yr After	-2	167	188	213	187	224	270	209	268	348
		CDR Costs Through 2100			CDR Costs Through 2100			CDR Costs Through 2100		

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[2] **IPCC's Conservative Estimates**

"There are political games going on in the IPCC and their modelers can't look beyond the model. The IPCC only uses stuff in refereed journals, which is already four to five years outdated, and they cut off three years early for peer review, so it is at least ten years outdated, and I'm looking at stuff that is happening today." Wanless sees the IPCC as "consensus science," by which he means it always pushes toward the lowest common denominator, meaning the person with the lowest projections forces the sum of everyone else's projections downward. The people who lowball the projections are always influencing the assessment, downplaying how bad things really are."

("The End of Ice: Bearing Witness and Finding Meaning in the Path of Climate Disruption", Dahr Jamail)

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[3] **"Correction" of Results**

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[4]**Presentation of Results**

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[5]**Expected Costs**

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[6]

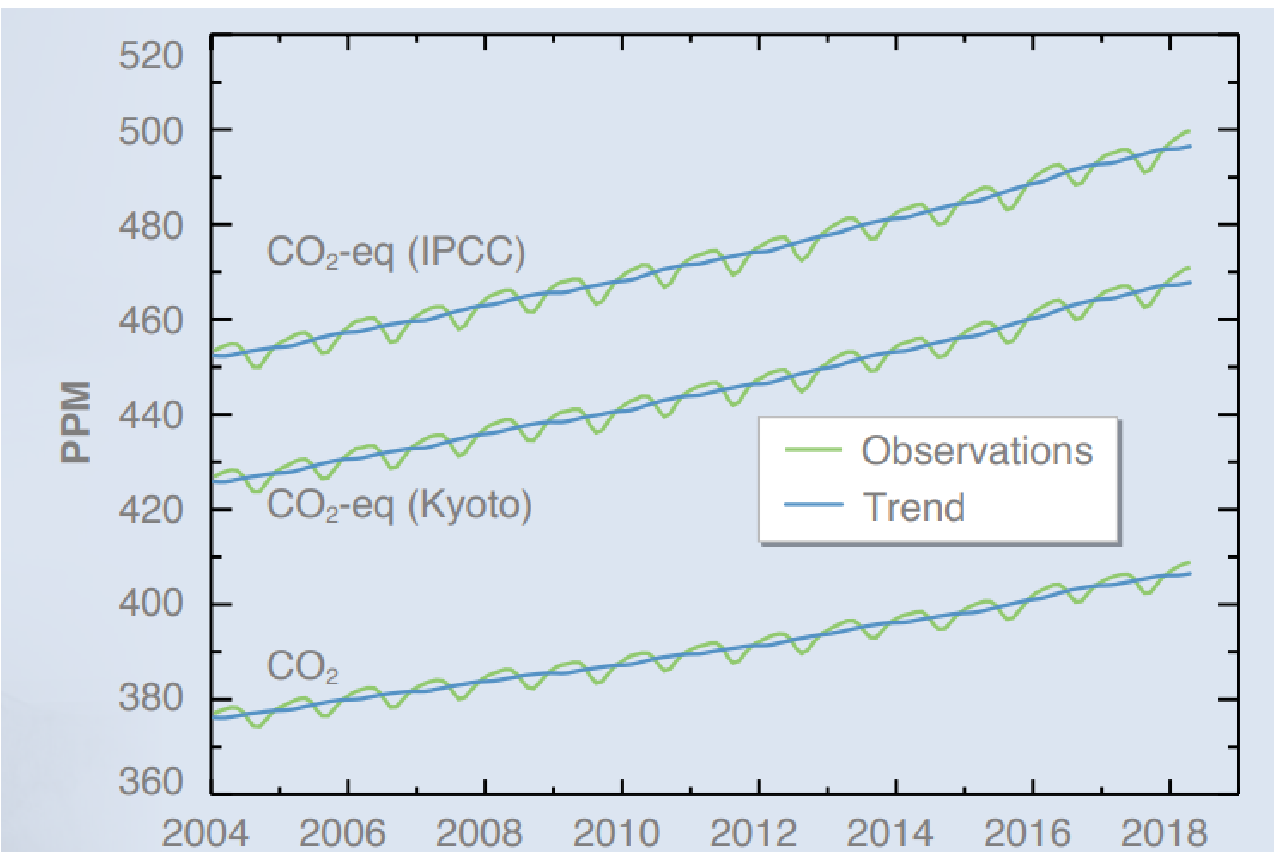

Figure 21. Current GHG concentrations

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf

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[7] **Expected Global Energy Use Through 2050**

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf (Page 10)

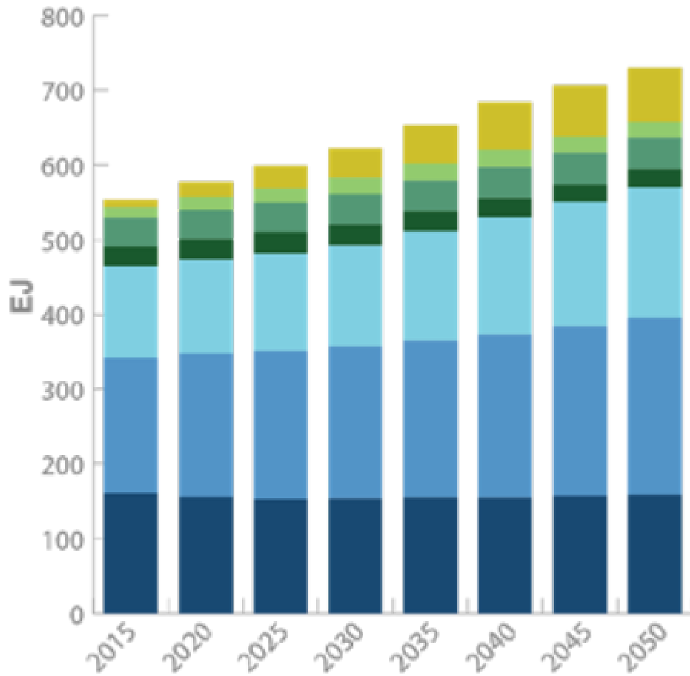

Figure 6. Global Energy Use (exajoules)

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[8] **Forecast of Global GDP**

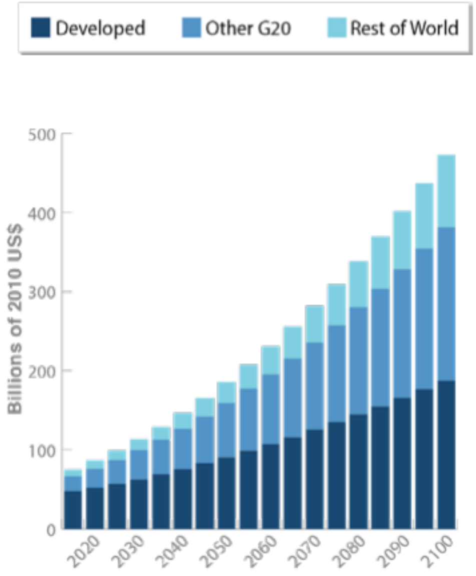

Figure 3. World GDP

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf

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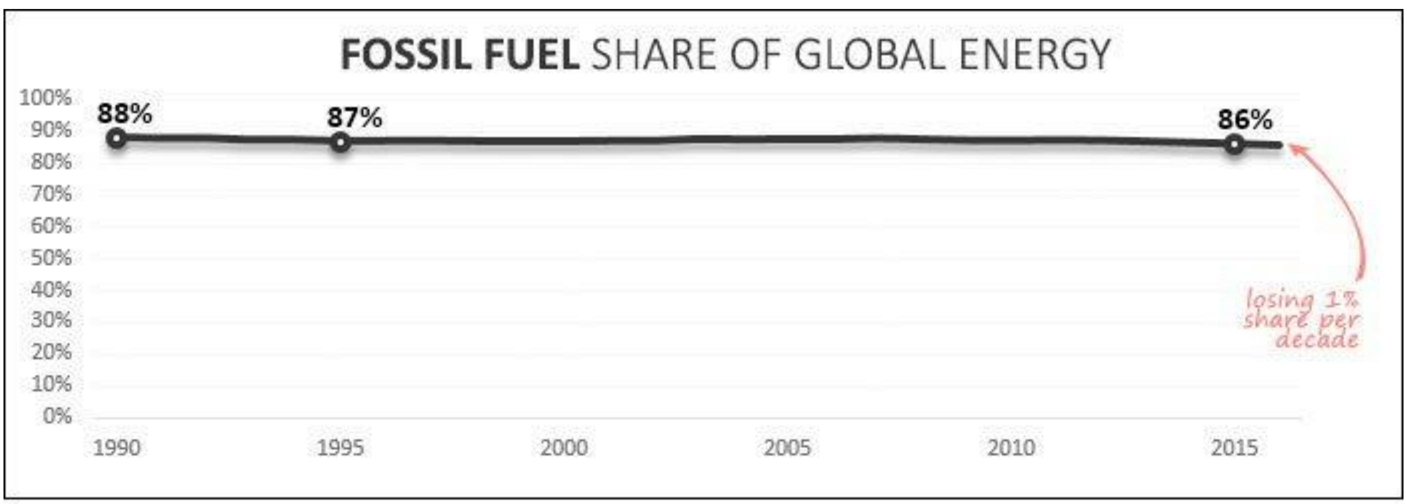
[9]



GLOBAL FOSSIL FUEL CONSUMPTION, 1990 - 2016. Percent of total energy consumption. SOURCE: Sum of Oil, Gas and Coal consumption vs total energy in BP Statistical Review of World Energy June 2017. CHART by Barry Saxifrage at VisualCarbon.org, June 2017

https://twitter.com/kencaldeira/status/948093886508892160

MIT Outlook 2018 has fossil fuel share of global energy decreasing from 84% (93 exajoules) in 2015 to 78% (114 exajoules) in 2050

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf (Page 10)

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[10] **Global Annual Greenhouse Gas Emissions Through 2050**

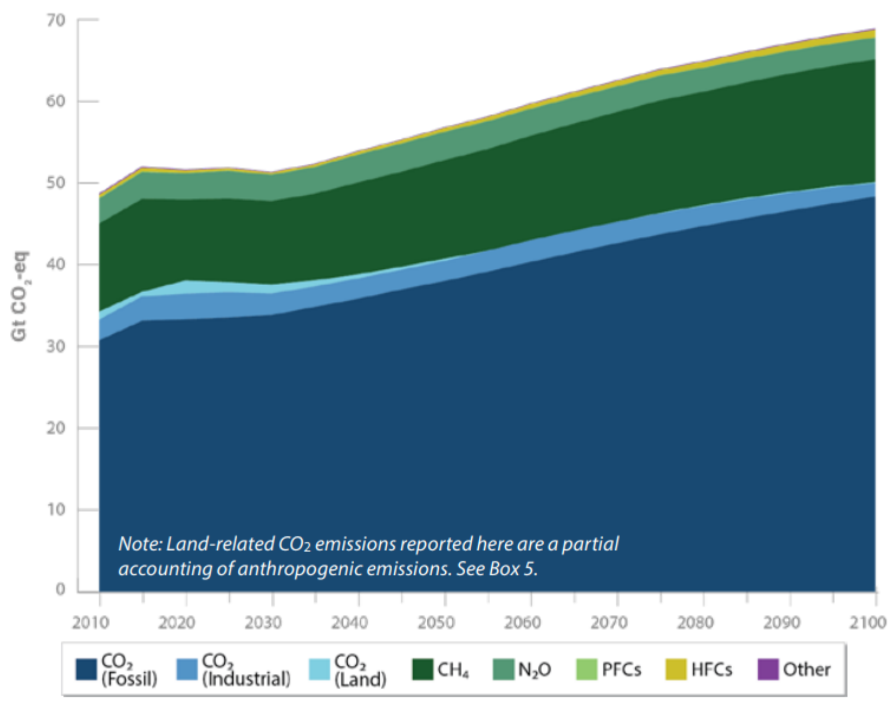

Figure 19. Global annual greenhouse gas emissions

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf

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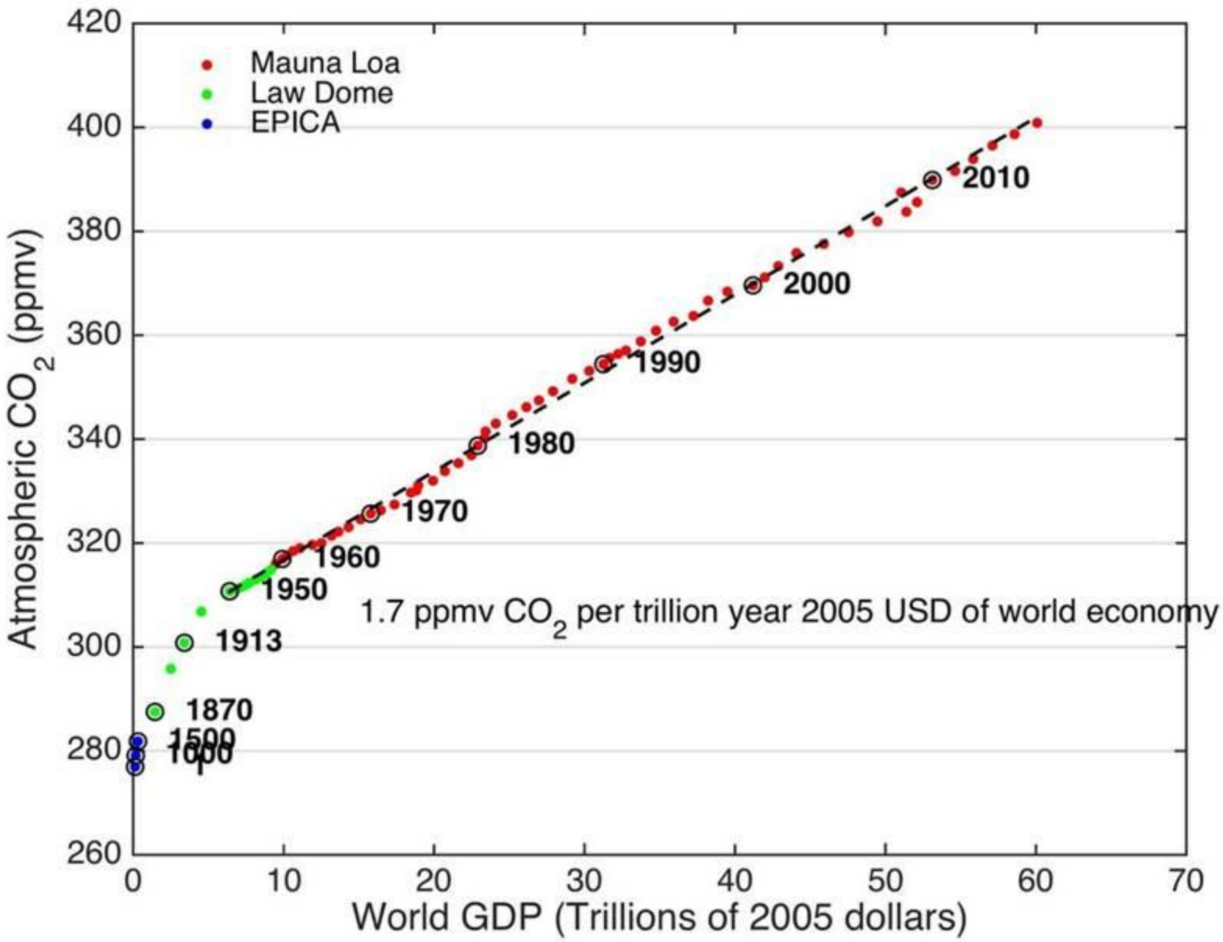
[11] Another interesting fact and figure - CO2 PPM has been correlated very strongly to global GDP since about 1950. The figure has been updated from the original in:

No way out? The double-bind in seeking global prosperity alongside mitigated climate change (2012)

Abstract. In a prior study (Garrett, 2011), I introduced a simple economic growth model designed to be consistent with general thermodynamic laws. Unlike traditional economic models, civilization is viewed only as a well-mixed global whole with no distinction made between individual nations, economic sectors, labor, or capital investments. At the model core is a hypothesis that the global economy's current rate of primary energy consumption is tied through a constant to a very general representation of its historically accumulated wealth. Observations support this hypothesis, and indicate that the constant's value is λ = 9.7 ± 0.3 milliwatts per 1990 US dollar. It is this link that allows for treatment of seemingly complex economic systems as simple physical systems. Here, this growth model is coupled to a linear formulation for the evolution of globally well-mixed atmospheric CO_2 concentrations. While very simple, the coupled model provides faithful multi-decadal hindcasts of trajectories in gross world product (GWP) and CO_2. Extending the model to the future, the model suggests that the well-known IPCC SRES scenarios substantially underestimate how much CO_2 levels will rise for a given level of future economic prosperity. For one, global CO_2 emission rates cannot be decoupled from wealth through

efficiency gains. For another, like a long-term natural disaster, future greenhouse warming can be expected to act as an inflationary drag on the real growth of global wealth. For atmospheric CO_2 concentrations to remain below a "dangerous" level of 450 ppmv (Hansen et al., 2007), model forecasts suggest that there will have to be some combination of an unrealistically rapid rate of energy decarbonization and nearly immediate reductions in global civilization wealth. Effectively, it appears that civilization may be in a double-bind. If civilization does not collapse quickly this century, then CO_2 levels will likely end up exceeding 1000 ppmv; but, if CO_2 levels rise by this much, then the risk is that civilization will gradually tend towards collapse.

https://www.earth-syst-dynam.net/3/1/2012/



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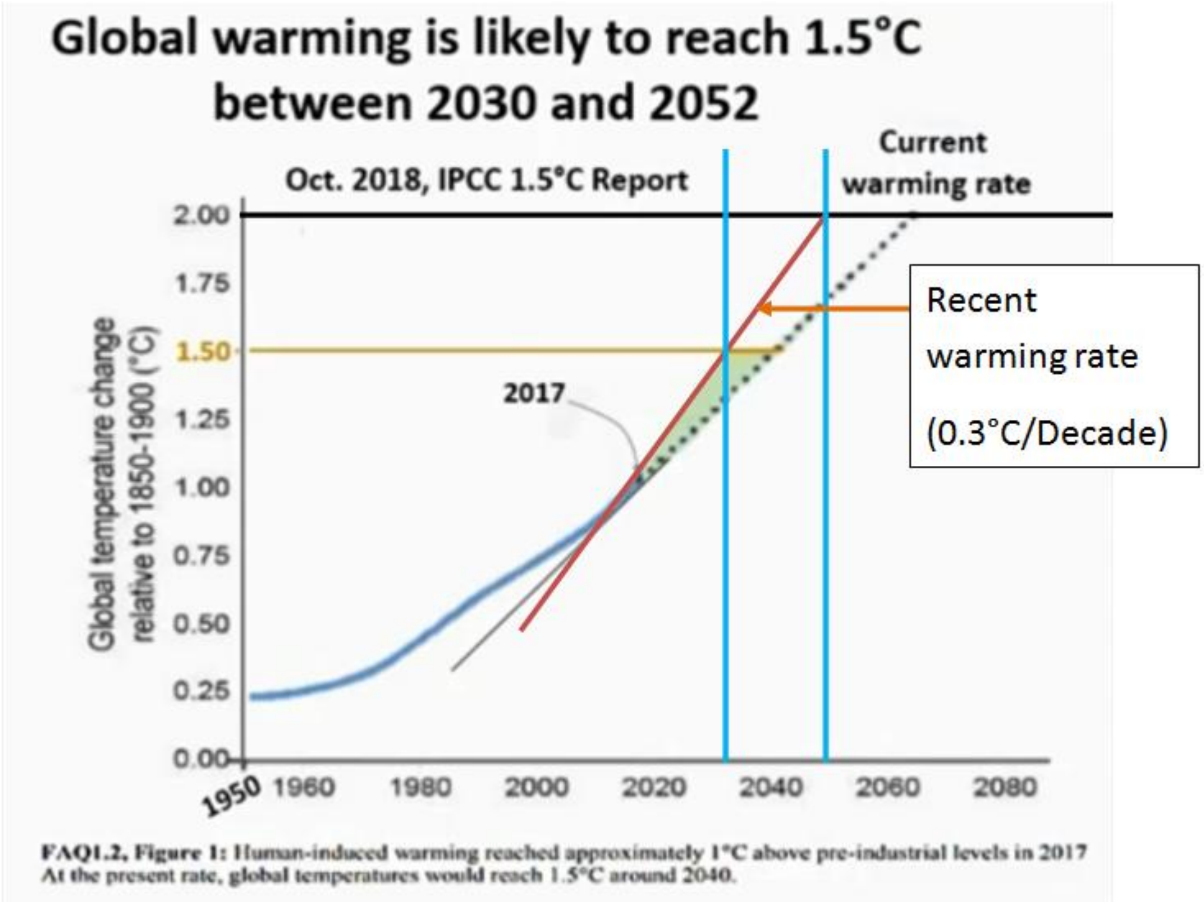

(Figure is a slight modification of a screenshot from Peter Carter's "Global Warming Acceleration" YouTube video)

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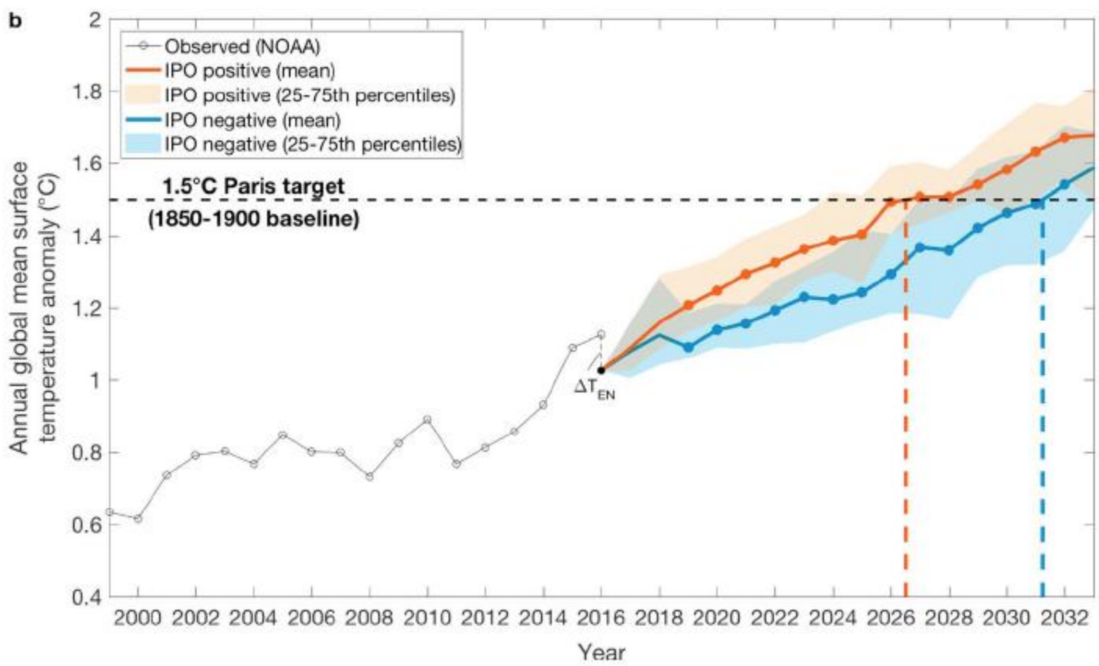
[13] **The global temperature could reach 1.5° C as early as 2026**



Projected temperature rises with IPO in positive mode (red) and negative mode (blue) (Henley and King, 2017)

JACOB et al: the world is likely to pass the +1.5°C threshold around 2026 for RCP8.5, and "for the intermediate RCP4.5 pathway the central estimates lie in the relatively narrow window around 2030. In all likelihood, this means that a +1.5°C world is imminent."

KONG AND WANG: the threshold of 1.5°C warming will be reached in 2027, 2026, and 2023 under RCP2.6, RCP4.5, RCP8.5, respectively.

XU and RAMANTHAN: suggesting that the 1.5°C would be exceed around 2028.

ROGELJ et al: then SSP5 exceeds 1.5°C in 2029 and SSP4 by 2031.
https://www.resilience.org/stories/2018-04-05/1-5c-of-warming-is-closer-than-we-imagine-just-a-decade-away/