Carbon Budgets - an Alternative Analysis

Bruce Parker (bruce@chesdata.com)

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

The total temperature increase expected at the end of this century will primarily be due to five major factors: (1) the quantity of CO_2 emissions this century (both anthropogenic and natural), (2) the amount of this CO_2 that is absorbed by the oceans and biosphere, (3) the total non-CO_2 radiative forcing (which is primarily influenced by the quantity of anthropogenic and natural methane emissions in the last decade of this century) , (4) how much the albedo changes in the Arctic region, and (5) how the clouds change in response to global warming (note that the latter two usually included as components of climate sensitivity). Of these, humans only can affect three: anthropogenic CO_2 emissions, atmospheric aerosols (which are mostly dependent on emissions from the burning of coal), and anthropogenic methane emissions, as the others represent a natural response to global warming .

In order to prevent a very serious disruption to our civilization, climate scientists would like to the total temperature increase to be "well under 2° C". Even though such an increase would almost certainly result in catastrophic sea level rise[1], significant additional economic losses from natural disasters and ocean acidification, and significant disruption to our agricultural system as weather patterns change, the disruptions to our civilization would likely be not be catastrophic.

For emission scenarios that limit the equilibrium temperature increase in 2100 to between 1.5°C and 2.0°C, an "anthropogenic carbon budget" can defined as the maximum net anthropogenic CO_2 that can be emitted in order to limit the equilibrium temperature increase in 2100 to that range.

Current climate models can be used to develop a formula which provides a rough estimate of the atmospheric CO_2 in 2100 based on CO_2 emissions from 2016-2100[2]: "2100 CO2 PPM" = 0.2586 * CO2 Emissions 2016-2100 + 342.87. And since there is a known relationship between climate sensitivity, equilibrium temperature, and radiative forcing (Radiative forcing = 5.35 * Ln(1 + Equilibrium Temperature / Climate Sensitivity)), a formula can also be developed which allows a "CO2 budget" to be estimated for an equilibrium temperature, climate sensitivity, and amount of non-radiative forcing in 2100[2]: CO2 Budget = (278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35) - 342.87)/ 0.2586.

The following tables contain CO_2 Emissions budgets (for both anthropogenic and natural emissions) for temperature increases of 1.5° C and 2.0° C for various climate sensitivities and non-CO_2 radiative forcings. Note that N_2O and CFCs have combined RFs of .34, .43, and .52 W/m-2 in RCPs 2.0, 4.5, and 6.0 respectively[3], so getting below a non-CO_2 RF of 0.3 or 0.4 W/m-2 will not be possible unless aerosols (either from the burning coal or from solar radiation management) are present in large quantities.

CO2 Budget 2016-2100 = (278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35) - 342.87)/ 0.2586																	
CO2 Budget 2019-2100 = CO2 Budget 2016-2100 - 35																	
		Temp Increase:	**1.5**	**°C**													
		Climate Sensititivity															
		2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
Non-CO2 RF (W/m-2)	**0.0**	520	447	386	334	290	252	218	188	162	138	117	98	81	65	50	37
	0.1	485	414	354	303	259	222	189	160	134	111	90	71	54	38	24	11
	0.2	451	381	322	272	229	192	160	132	106	83	63	45	28	12	-2	-15
	0.3	418	348	291	242	200	164	132	104	79	57	37	18	2	-13	-27	-40
	0.4	385	317	260	212	171	135	104	77	52	30	11	-7	-23	-38	-52	-64
	0.5	352	286	230	183	143	108	77	50	26	5	-15	-32	-48	-63	-76	-88
	0.6	321	255	201	154	115	81	51	24	0	-21	-40	-57	-72	-87	-100	-112
	0.7	290	225	172	126	88	54	24	-2	-25	-45	-64	-81	-96	-110	-123	-135
	0.8	259	196	143	99	61	28	-1	-27	-49	-70	-88	-105	-120	-133	-146	-157
	0.9	229	167	116	72	34	2	-26	-51	-74	-94	-112	-128	-143	-156	-168	-180
	1.0	200	139	88	45	9	-23	-51	-76	-98	-117	-135	-151	-165	-178	-190	-202
	1.1	171	111	61	19	-17	-48	-75	-100	-121	-140	-157	-173	-187	-200	-212	-223
	1.2	142	84	35	-6	-42	-72	-99	-123	-144	-163	-180	-195	-209	-222	-233	-244
	1.3	115	57	9	-31	-66	-96	-123	-146	-166	-185	-202	-217	-230	-243	-254	-265
	1.4	87	31	-16	-56	-90	-120	-145	-168	-189	-207	-223	-238	-251	-264	-275	-285
		CO2 Budget 2019-2100 (Emissions - GTC)															

		Temp Increase:	**2.0**	**°C**													
		Climate Sensititivity															
		2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
Non-CO2 RF (W/m-2)	**0.0**	789	691	610	541	482	431	386	346	311	280	252	226	203	181	162	144
	0.1	749	653	573	506	448	398	354	315	280	249	222	197	174	153	134	116
	0.2	710	616	538	471	414	365	322	284	250	220	192	168	145	125	106	89
	0.3	672	579	502	437	381	333	291	253	220	190	164	139	117	97	79	62
	0.4	634	543	468	404	349	302	260	223	191	162	135	112	90	70	52	36
	0.5	597	508	434	371	318	271	230	194	162	133	108	84	63	44	26	10
	0.6	561	474	401	339	286	241	201	165	134	106	81	58	37	18	0	-16
	0.7	525	440	368	308	256	211	172	137	106	79	54	31	11	-8	-25	-40
	0.8	490	406	336	277	226	182	143	109	79	52	28	6	-14	-33	-49	-65
	0.9	456	374	305	247	197	153	116	82	52	26	2	-20	-39	-57	-74	-89
	1.0	423	341	274	217	168	125	88	55	26	0	-23	-45	-64	-81	-98	-112
	1.1	390	310	244	188	139	98	61	29	1	-25	-48	-69	-88	-105	-121	-136
	1.2	357	279	214	159	112	71	35	3	-25	-50	-72	-93	-111	-128	-144	-158
	1.3	325	249	185	131	84	44	9	-22	-49	-74	-96	-116	-135	-151	-166	-181
	1.4	294	219	156	103	58	18	-16	-47	-74	-98	-120	-139	-157	-174	-189	-202
		CO2 Budget 2019-2100 (Emissions - GTC)															

- Yellow cells show combinations of CS and NonCO2 RF for a post 2018 budget of around 190 GTC (roughly that put forward by the IPCC and National Academy of Science and adjusted for 2016-2019 emissions[4]).
- Orange cells show combinations of CS and NonCO2 RF for a post 2018 anthropogenic budget of around 70 GTC (assuming natural emissions of roughly 120 GTC[5])
- Green cells show the total CO2 budget for a value of climate sensitivity slightly below that which was demonstrated by the models that best capture current conditions[6,7]
- Purple cells show the CO2 budget for the non-CO2 radiative forcing for RCP 4.5[3]

Many of the emissions from natural feedbacks are temperature-dependent. Given a likely temperature increase of at least 2° C by 2050 (see http://ccdatacenter.org/documents/TempIncreaseExpectations.pdf) it seems reasonable that cumulative emissions from natural emissions will likely be in the range of 120-200 GTC by 2100 (not including methane from methyl hydrates)[5,8] . Given that anthropogenic emissions are likely to be over 600GTC between 2019 and 2100 (see tables below), for all practical purposes there is no anthropogenic budget left.

The following tables show the CO2 emissions from 2019-2100 for various combinations of fossil fuel reductions (without BECCS, CCS, or CDR)

9.86	2015 Fossil Fuel Emissions (GTC)
1.6	2015 land use emissions (GTC)
2070	Year when land use emissions reach zero
0.029	Land use decline/year (GTC)
35	CO2 Emissions 2016-2018

	Peak Yr:	2020			2025			2030		
	Pct Chg to Peak Yr:	0	1	2	0	1	2	0	1	2
Annual Pct Change After Peak Yr	0	846	888	931	846	929	1020	846	970	1111
	-1	597	626	656	624	683	748	649	741	846
	-2	445	466	488	484	529	578	522	593	674
	-3	348	365	382	393	429	467	437	495	560
	-4	285	298	312	332	362	393	379	427	482
		Emissions 2019-2100			Emissions 2019-2100			Emissions 2019-2100		

Footnotes

<table>
<tr><td>1</td><td>http://ccdatacenter.org/documents/SeaLevelRiseExpectations.pdf</td></tr>
<tr><td>2</td><td>http://ccdatacenter.org/documents/CO2UptakeExpectations.pdf</td></tr>
<tr><td>3</td><td>
<table>
<tr><th></th><th></th><th></th><th colspan="5">IPCC Radiative Forcing Estimates</th></tr>
<tr><th>Greenhouse Gas</th><th>Chemical Formula</th><th>Residency Time</th><th>2011</th><th>2100 - RCP 2.6</th><th>2100 - RCP 4.5</th><th>2100 - RCP 6.0</th><th>2100 - RCP 8.5</th></tr>
<tr><td>Carbon dioxide</td><td>CO_2</td><td>5-200</td><td>1.68</td><td>2.22</td><td>3.54</td><td>4.70</td><td>6.49</td></tr>
<tr><td>Nitrous oxide</td><td>N_2O</td><td>114</td><td>0.17</td><td>0.23</td><td>0.32</td><td>0.41</td><td>0.49</td></tr>
<tr><td>CFCs</td><td></td><td>45-85</td><td>0.34</td><td>0.10</td><td>0.10</td><td>0.10</td><td>0.10</td></tr>
<tr><td>Methane</td><td>CH_4</td><td>12</td><td>0.97</td><td>0.27</td><td>0.41</td><td>0.44</td><td>1.08</td></tr>
<tr><td>Other Climate Factors</td><td></td><td></td><td>-0.87</td><td>-0.22</td><td>0.13</td><td>0.35</td><td>0.34</td></tr>
<tr><td>Non-CO2 Rad. Forc.</td><td></td><td></td><td>0.61</td><td>0.38</td><td>0.96</td><td>1.30</td><td>2.01</td></tr>
<tr><td>Total</td><td></td><td></td><td>2.29</td><td>2.60</td><td>4.50</td><td>6.00</td><td>8.50</td></tr>
</table>
IPCC Physical Basis AR5</td></tr>
<tr><td>4</td><td>NAS 2017 CSSR Budget = 236 GTC (assume the budget is post 2015)
https://science2017.globalchange.gov/downloads/CSSR_Ch14_Mitigation.pdf)
IPCC post 2015 Budget = 220 GTC (for a 66% chance of not exceeding 2.0 °C)
(https://docs.google.com/spreadsheets/d/1odltJu_rxabdVXv_pACMBNIRiFSkc_HqJn-V8z0av2w/edit#gid=731498129)</td></tr>
<tr><td>5</td><td>http://ccdatacenter.org/documents/NaturalEmissionsExpectations.pdf</td></tr>
<tr><td>6</td><td>(Footnote #68 in What Lies Beneath (download PDF from https://www.breakthroughonline.org.au/Xu, Y & Ramanathan, V 2017, ‘Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes’, Proceedings of the National Academy of Sciences, vol. 114, pp. 10315-10323.</td></tr>
<tr><td>7</td><td>http://ccdatacenter.org/documents/ClimateSensitivityExpectations.pdf</td></tr>
<tr><td>8</td><td>http://ccdatacenter.org/documents/GlobalWarmingFeedbackExpectations.pdf</td></tr>
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