Developing a Really Simple CO2 Emissions Budget Formula

Bruce Parker (bruce@chesdata.com) 12/2/2019

Develop a formula for calculating a CO2 budget

Use the data from the recent IPCC1.5°C report to determine correlations between data elements:

2100 CO2 PPM = 0.285657 * CO2 Emissions 2018-2100 - 351.9582

(Note that the computed PPM differs from the scenario PPM by 1.2% to 2.0%)

(This reflects model differences on how much of the emitted CO2 ends up in the atmosphere)

CH4 Radiative Forcing in 2100 = 0.0019 x Average CH4 Annual Emissions + 0.0019

N2O Radiative Forcing in 2100 = 0.0003 x N2O Emissions 2018-2100 (Mt) + 0.0185

"Other" radiative forcing (RF other than from CO2, CH4, and N2O) = -0.05 W/m2

Combine with "standard climate formulas

Equilibrium Temp Incr. = Climate Sensitivity * (CO2 PPM - CO2Orig PPM)/ CO2Orig PPM

Radiative Forcing=ln(CO2 PPM / CO2Orig PPM) * 5.35

to get CO2 emissions budget 2018-2100 =

$$3.5007 * CO2OrigPPM * (1 + ET / CS) * e^{(- Non\text{-}CO2RF /5.35)} - 1232.1$$

where Non-CO2RF =(0.0019*CH4Emissions+0.0003* N2OEmissions -0.03)

How good is the model?

The following table shows how well the calculation using CH4 and N2O emissions compares with the scenario values.

FAIR Scenarios where the P66 Temperature increase is >= 1.4 and CO2 Emissions > 60GTC					
Number of Scenarios	Percentage of Difference Between Scenario CO2 Emissions and Emissions Calculated Based on CH2 and N2O				
	<5%	<10%	<15%	<20%	<25%
182	29	58	80	92	95
135*	40	76	88	96	97
45*+	44	71	84	91	91
30*#	50	96	100	100	100
	Percentage of scenarios where the calculated emissions differ from the scenario emissions by less than a given percent				
*"Other radiative forcing" between -0.18 and 0.1 W/m2					
+ P66 Temperature increase between 1.45 and 1.55					
# 30 of 35 scenarios which used the 'AIM/CGE 2.0' model					

(The IPCC emissions for the 67 percentile for 1.5°C were 115 GTC - 10% of this is 11 GTC. For the formula which uses values for all of the non-CO2 RF, the calculation is within 10% for 95% of the 182 scenarios)

Comparing the model to the RCPs

Scenario Values	RCP			
	2.6	4.5	6	8.5
50% Temp Incr 2100 (°C)	1.55	2.29	2.64	4.18
CO2 PPM 2100	420	538	670	936
Emissions				
CO2 (GTC - Cumulative)	274	726	1035	1746
CH4 (MT - 2100)	143	143	143	143
N2O (Mt- Cumulative)	528	697	874	1049
Radiative Forcing (W/M2)				
Carbon dioxide	2.22	3.54	4.70	6.49
Methane	0.27	0.41	0.44	1.08
Nitrous oxide	0.23	0.32	0.41	0.49
CFCs (Montreal Protocol)	0.10	0.10	0.10	0.10
HFCs	0.13	0.08	0.05	0.18
PFCs and SF6	0.02	0.026	0.05	0.04
Tropospheric O3	0.17	0.27	0.27	0.60
Aerosol	-0.12	-0.12	-0.12	-0.12
Other Factors*	-0.41	-0.13	0.11	-0.37
Non-CO2 RF	0.110	0.550	0.860	0.930
Non CO2, CH4, N2O RF	-0.120	0.230	0.450	0.440
Total	2.600	4.500	6.000	8.500

#	Calculations				
	50% RCP Temp Incr Rel 1986–2005	0.94	1.68	2.03	3.57
1	Temp Incr rel 1870	1.55	2.29	2.64	4.18
2	CO2 PPM 2100	430	559	648	851
3	CO2 PPM 2100	421	539	669	935
4	PPM Percent Increase Diff	6	8	-6	-13
5	CO2e PPM 2100	452	645	853	1361
6	Climate Sensitivity	2.48	1.74	1.28	1.07
7	CO2 Emissions budget (NonCO2 RF)	318	804	1311	2773
8	CO2 Emissions budget %Diff From Emissions	16	11	27	59
9	CO2 Emissions budget (CH4 and N2O)	243	852	1499	3083
10	CO2 Emissions budget %Diff From Emissions	-11	17	45	77

#	Calculation Formula
1	global mean surface temperature change (°C) relative to 1870 (50%)
2	0.285657 * CO2 Emissions 2018-2100 + 351.95
3	PPM CO2 =278 * Power(2.718,CO2 Radiative Forcing/5.35)
5	PPM CO2 =278 * Power(2.718,CO2e Radiative Forcing/5.35)
6	Climate Sensitivity = Equilibrium Temperature/((PPM/278)-1)
7	3.5007 * CO2OrigPPM * (1 + ET / CS) * e (- Non-CO2RF /5.35) - 1232.1
9	3.5007 * CO2OrigPPM * (1 + ET / CS) * e (- (CH4E*0.0019+0.0003*N2OE-0.04122) /5.35) - 1232.1

Create tables based on the CO2 emissions budget formula:

		Climate Sensitivity:2.6									
		Temp Increase: 1.5 °C									
		Cumulative N2O Emissions (Mt)									
		500	550	600	650	700	750	800	850	900	950
CH4 Emissions 2100	**150**	197	193	189	185	181	177	173	169	165	162
	250	147	143	140	136	132	128	124	121	117	113
	350	99	95	92	88	84	81	77	73	70	66
	450	53	49	46	42	38	35	31	28	24	21
	550	8	4	1	-2	-6	-9	-13	-16	-20	-23

CO2 Emissions budget from 2018-2100 For CH4 and N2O(Emissions - GTC)

Use the formula to determine the "model sensitivity":

		Climate Sens.	Temp Increase	Radiative Forcing	Atmos. CO2	CO2 Emis	CH4 Annl Emis	N2O Emis	$100/ Ton CO2
Climate Factor	**Amt**		°C	W/m2	PPM	(GTC)	(MT)	(MT)	**$Billion**
Climate Sensitivity	0.1		0.063	0.074	5.685	19.9	39.3	248.8	7,303
°C	0.1	0.156		0.117	8.941	31.3	61.8	391.3	11,487
W/m2	0.1	0.135	0.085		7.713	27.0	53.3	337.5	9,909
PPM CO2	1.0	0.017	0.011	0.013		3.5	6.9	43.8	1,285
CO2 Emissions (GTC)	10	0.050	0.031	0.037	2.857	10.0	19.7	125.0	3,670
CH4 Ann. Emissions (MT)	10	0.025	0.016	0.019	1.457	5.1		63.8	1,872
NO2 Emissions (MT)	100	0.040	0.025	0.030	2.285	8.0	15.8		2,936

(Note: the CH4 numbers do not include a 25% adjustment - see below)

Assuming capture and sequestration costs were $100/Ton CO2 ($365/Ton C):

It could cost about $11 Trillion to decrease the global temperature 0.1°C by removing 31.3 GTC of CO2 from the atmosphere.

The cost of reducing the atmospheric concentration of CO2 is a little over $1Trillion/PPM

CO_2 Emissions budget Adjustment Worksheet

Emissions for CH4 and N2O chosen to have CO2 Emissions budget about 115 GTC (P66 for IPCC results)			
	Units		Notes
Original Estimate			
Target Temperature	°C	1.5	
Climate Sensitivity		2.6	
Emissions			
CO2	GTC	114	
CH4	Mt	280	
N2O	Mt	950	
Adjustments			
NonCO2 Emissions			
CH4	Tg	103	Surface Waters[1]
CH4	Mt		Other
N2O	Mt		
Climate Sensitivity			
Climate Sensitivity adjustment			
CO2 Emission Equivalents (GTC)			
IPCC report feedbacks	GTC	30	
CO2	GTC		Amazon changes to savannah
Peat	GTC		
Soils	GTC		
Permafrost	GTC		
Forests	GTC		
CH4 - 25% add'l forcing	GTC	36	=(5.1 GTC/10 Mt CH4)* 280 * 0.25
CH4 - Additional emissions	GTC	64	=(5.1 GTC/10 Mt CH4)* 100 * 1.25
N2O	GTC	0	Additional emissions
Climate Sensitivity	GTC	0	
Total Adjustments	GTC	130	
Adjusted Carbon Budget	GTC	-16	(Adjusted anthropogenic CO2 budget)

1. A recent report found that freshwaters emit at least 103 Tg of CH_4 per year.
2. Another recent article reported that a recent IPCC report underestimated the radiative forcing of methane by 25%.

US Responsibility

- Because of "embodied" emissions, US CO_2 emissions have not declined significantly in the last 20 years
- We cannot deny significant additional fossil fuel emissions to people in other countries who would like to have our standard of living
- According to the IPPC, historical CO_2 emissions have been about 2230 GTCO2. If another 800 GTCO2 can be added (to keep the total temperature increase well below 2°), then the total CO_2 emissions budget is about 3000 GTCO2.
- Historic US emissions have been about 25% of global emissions, or about 550 GTCO2. If US emissions decline from about 5 GTCO2 to zero in 40 years, our total will be about 650 GTCO2.
- US has about 4.25 percent of the world's population, and we'd be using 22% of the total world budget
- Assuming the "polluter's pay" principle, what is the US's "fair share" of the total budget?
- Historical US emissions are about 17% of the 3000 GTCO2 total budget. So if our "fair share" is anything less than 17% we would need to capture and sequester *at least* all future emissions.
- If future US emissions are 100 GTCCO2 and capture and sequestration costs are $100/Ton CO_2, then the US would need to spend at least $10 Trillion (about 1/2 of the total US debt) on "negative emission technologies" in the next 40 years