Review of INDC Analyses

Bruce Parker
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Summary

The "Intended Nationally Determined Contributions" (INDC) analyses that were examined (from Climate Action Tracker, Climate Interactive, and the MIT Joint Program on the Science and Policy of Global Change) are in very good agreement with the expected total emissions through 2030. As a result, the expected temperature increase by 2100 depended primarily on the year emissions peak and how fast emissions were expected to be reduced after the peak year. What is really lacking is an explanation of the assumptions and economic costs in terms that are relatively easy to understand.

Conclusions

What is not generally understood (or appreciated) is that most of the analyses of both the INDCs and our abilty to meet the "2° C challenge" rely on data provided in the IPCC's AR5, which itself relied on our understanding of climate science prior to 2011. Since then there have been significant improvements in our understanding of our climate, so many of the assumptions need to be examined in detail. The following lists some of these underlying assumptions and comments about each assumption:

1. Significant CO2 emissions will not be caused by feedbacks from a warming world.
   a. Over one-half of the UNFCCC's 1000 GTCCO2 budget could be taken up by such emissions this century
2. Sea level rise can be contained by limiting the temperature increase to 2° C.
   a. The ice sheets in Greenland and Antarctica are destabilizing much faster than anticipated and expectations for sea level rise by 2100 are being increased. In addition, over long periods of time, sea level rise will very like be at least 30 feet per degree C. It is doubtful that long-term catastrophic sea level rise can be prevented
3. The IPCC's AR5 included one pathway (RCP2.6) which was supposed to consistent with meeting the 2° C target, and RCP 2.6 calls for emissions in 2030 to about the same as in 2000.
   a. The 2030 emissions estimated in the INDCs are about 40% higher than 2000 emissions
4. We will be willing to pay "carbon capture and storage" (CCS) costs needed to meet the UNFCCC carbon budget. RCP 2.6 calls for significant CCS.
   a. "Under the IEA Energy Technology Perspectives 2012 2°C Scenario (2DS), CCS contributes one-sixth of total CO2 emission reductions required in 2050". Costs in 2050 were estimated to be about $400 Billion/year.
   b. There is very likely an upper limit as to how much we will be willing to pay, particularly since most of the costs of CCS provide no direct economic value but are needed solely to meet the temperature target
   c. Will the global politicians be willing to impose the necessary taxes to meet the 2° C challenge?
5. The "costs of inaction" will be much higher than the "cost of action"
   a. When looking at the "costs of action" for this century we should only include the incremental costs of a world with a 3-4° C temperature increase over that of a 2° C increase since the latter costs will be borne no matter what we do. While the "costs of action" will likely run well over $50 trillion by 2100 (with a significant portion of that having no real economic value), the "incremental cost of action" will likely be much less (one "Hurricane Katrina" per year after 2050 would cost only $10 trillion).
6. The 2° C target will be breached when atmospheric concentrations of CO2 exceed 450 PPM
   a. Current atmospheric concentrations for Kyoto gases already exceed 450 ppm CO2eq, while CO2 concentrations approach 400 ppm.
   b. To reach the 2° C target we may need to remove the equivalent of all greenhouse gas emissions emitted after 2014

(See www.ccdatacenter.org/documents/INDCAnalysis.PDF for additional information)

Background

The UNFCCC has settled on the need to limit future greenhouse gas emissions such that there will be a 66 percent chance that the temperature increase expected by 2100 will not exceed 2° C. Predicting the temperature increase by 2100 is very difficult as there are many factors – population growth, GDP growth, technological changes, investment decisions, market forces, vested interests, etc., not to mention the limited abilities of climate models to accurately predict the climate 85 years from now. Fortunately, there have been two major advances in the last several years which enables a much simpler analysis of problem - the UNFCCC derived an emissions budget which must be adhered to in order to limit the temperature increase (1000 GTCO2 after 2011) and most of the countries of the world have submitted estimates of their greenhouse gas emissions (Intended Nationally Determined Contributions or INDCs) through 2030. So it is now possible to develop a variety of simple emissions pathways to explore how (and if) the 2 °C target can be met – simply pick a peak emissions year, plan on reducing emissions at a specific rate, and capture and sequester any emissions that exceed the UNFCCC budget. With this approach the "window" for reaching the 2 °C target never technically closes – all we'll need to do is capture and sequester sufficient CO2 to meet the target no matter what the emissions are.

Analysis

The graphs below show some of the data analyses that were done based in the greenhouse gas emissions specified in the INDCs. The following table summarizes the results.

	Greenhouse Gas Emissions (GTCO2e)													
			Emissions			Cum. Emissions								
			2010	2025	2030	2012-2025	2012-2030	2012-2100	Temp Incr.	Atmos CO2	Atmos CO2e	%GHG for CO2	Climate Sens.+	Temp Incr if CS = 3.0*
	INDCs													
1	Climate Action Tracker	Pledges	47.3	52.6	53.8	713	980	4154	2.7				2.60	3.2
2	Climate Interactive	INDC Strict (2-4.6)	50.7	57.2	57.6	802	1089	6230	3.5	675	860	78	2.75	3.8
3	Climate Interactive	3.5 Pathway	50.6	56.7	57.5	780	1065	6153	3.5				2.75	3.8
4	MIT Joint Program	PERSP. - 2015	48.6	55.0	56.0	735	998	5764	3.7				3.00	3.7
	2 Degree Pathway													
5	Climate Action Tracker	2C consistent	46.7	34.3	28.4	569	722	1374	1.7				2.40	2.1
6	Climate Interactive	2 deg Pathway (1.1-2.7	50.7	55.5	53.9	792	1065	2737	2.0	475	480	99	2.20	2.7
7	Climate Interactive	2.0 Pathway (50% chance)	50.6	56.2	55.7	744	1024	2888	2.0	470			2.20	2.7
	IPCC AR5 with GWP from SAR		48.6											
	IPCC AR5 with GWP from AR5		51.9											
	+ - Climate sensititity for a doubling of CO2 and assuming that 75% of GHG emissions are CO2													
	* - The expected temperature increase if it turns out that the climate sensitivity is 3.0													
	To get 2 degrees of warming with a climate sensitivity of 3.0 a maximun of 1100 GTC can be emitted													

Table 1 - Summary of INDC analyses
(Data for this table is available at www.ccdatacenter.org/documents/GHGAnalysis.xlsx)

The UNFCCC estimated total CO2 emissions through 2030 based on the INDCs. (See section "D. UNFCCC "below. The section includes a table of "CO2 Emissions to meet 2 degree C target (and associated CDR costs)", which is uses different peak years (2025 and 2030), a linear emissions reduction to 0 emissions, and CDR to remove the "overshoot" emissions. The table includes a separate computation for taking feedbacks from a warming world into account).

Notes

1. The UNFCCC estimated that the total carbon budget is about 1000 GTC from 1870 to 2100, with 515 GTC being used through 2011. With only about 80% being available for greenhouse gas emissions, the "post 2011" carbon

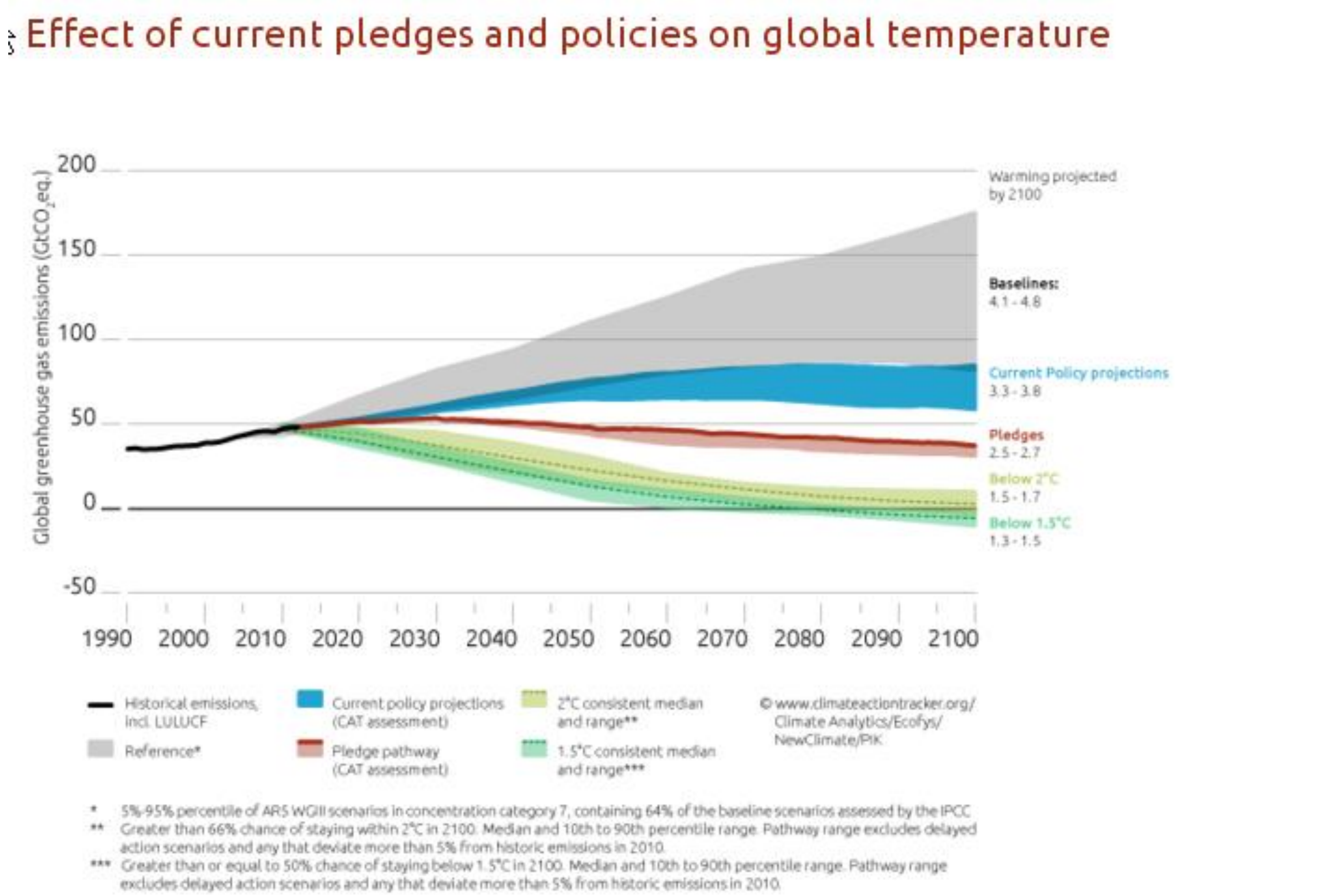
budget is about 388 GTC (485*.8) and the carbon dioxide budget is about 1422 GTCO2 (388 * 3.664). If the climate sensitivity is about 3, that budget will increase temperatures by about 2.15 degrees C. If the climate sensitivity is about 3, the budget would need to be reduced by about 300 GTCO2e, and total emissions through 2030 will have used up almost the entire budget.

2. Note the different values for 2010 emissions – this could very well be caused by organizations using different values for the global warming potential (GWP) – see bottom rows of the above table
3. The four "INDC" analyses are in very good agreement with the expected total emissions trough 2030. Taking the different GWPs into account, a reasonable estimate for cumulative emissions through 2030 is about 1050 GTCO2e. So if the emissions through 2030 match the projected INDC emissions about 75% of the total post-2011 carbon budget will have been used. This agrees very closely to the analysis done by the UNFCCC for carbon dioxide emissions (See section "D. UNFCCC" below)
4. Given that the analyses are fairly close, the temperature increase by 2100 depends primarily on the year emissions peak and how fast emissions can be reduced after the peak year (and these assumptions drive the temperature estimates of the various analyses)
5. The "Climate Action Tracker – Pledges" scenario (#1) is the only one of these INDC analyses that has emissions being reduced after 2030
6. The "Climate Action Tracker – 2C Consistent" scenario (#5) has 2030 emissions about one-half that of the INDCs for 2030 - an indication as to how far off of the 2°C path we are
7. The "Climate Interactive 2 Degree Pathway (50% chance)" (#7) also show us how very difficult to meet the 2 degree C target. For example,
   a. It only provides a 50% chance
   b. Emissions decline 3.5-4.4% annually after peaking
   c. Total emissions from India, with over four times the US population, would be significantly less than those from the US - very unlikely
8. None of the analyses in the table above include the expected emission-equivalents from feedbacks from a warming world (see "F. Feedback Factors" below) or the amount of carbon dioxide that needs to be removed by various CDR processes (see "G. Sequestration" below)
9. None of the analyses include the expected costs:
   a. The investment costs for the BAU scenario
   b. The investment costs for the "pledges" or "2 degree pathway"
   c. The mitigation costs for the various pathways (b-a)
   d. Expected "CO2 overshoot" and corresponding CDR costs (perhaps $400 Billion/year in 2050– see section "G. Sequestration" below)
   e. Total expected costs for the scenario
10. A reasonable "upper bound" as to how fast greenhouse gas emissions can realistically be reduced is very hard to come by. Since emissions are currently increasing about two percent per year, a three percent per year reduction requires a five percent change from "business as usual". Given the energy needs of the developing world and the unwillingness of the developed world to make really significant cuts in their emissions, even obtaining a three percent reduction seems optimistic

We have already reached about 1° C and are likely committed to at least 2.0° C based on the CO2 and other greenhouse gases already in our atmosphere, according to a 2014 MIT report (see "H. Greenhouse Gas Concentrations and Climate Implications" below). So not exceeding 2.0° C (let alone 1.5° C, as many are advocating), likely means that CO2 equivalent of all of the greenhouse gases put in the atmosphere from now on will eventually need to be captured and sequestered. If emissions peak in 2025 (it will likely be later) and can be reduced at 3 percent per year (which is likely faster that it can be realistically done) then total GHG emissions after today will be about 1650 GTCO2e (see section D below – total CO2 emissions would be about 1240 GTCO2, and adding about 1/3 to cover other GHG emissions gives a total of about 1650 GTCO2e to sequester). At $30/ton CO2 (which is likely too low) the total cost would be about $82 trillion dollars. And this does not take into account the costs of mitigation and sequestering the CO2 from natural emissions (e.g., from thawing permafrost) caused by positive feedbacks from a warming world –see section "F. Feedback Factors" below).

Data Sources

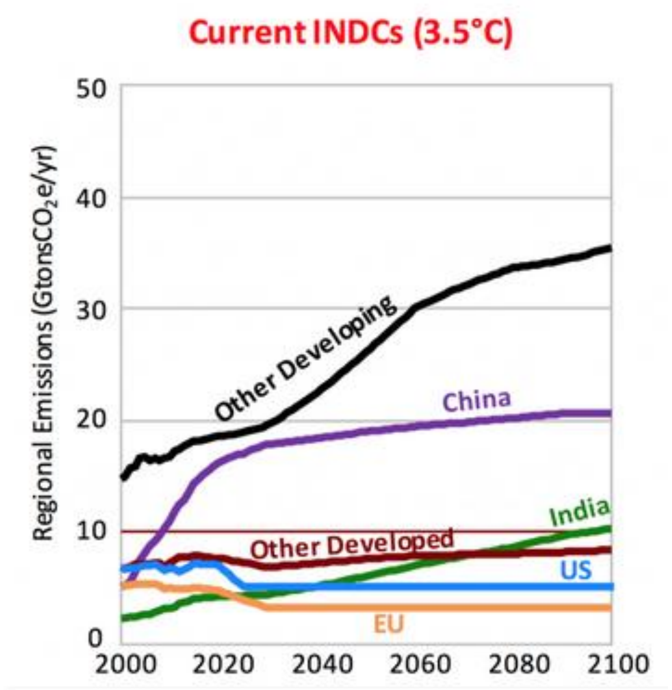
A. Climate Action Tracker

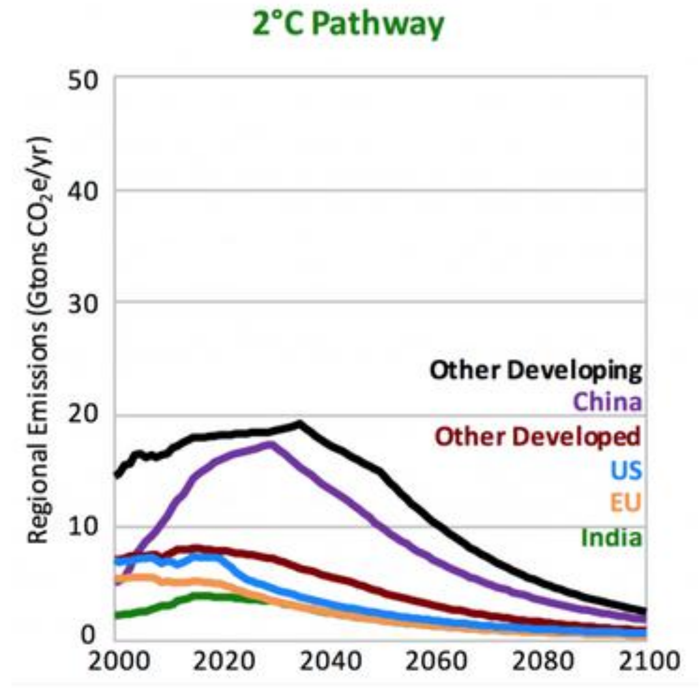


Data for these scearios is available in a spreadsheet from the Climate Action Tracker web site

B. Climate Interactive (https://www.climateinteractive.org/analysis/video-how-could-paris-climate-talks-ratchet-up-to-success/)

1. Graphs from the above Web page – the 3.5 and 2.0 °C scenarios

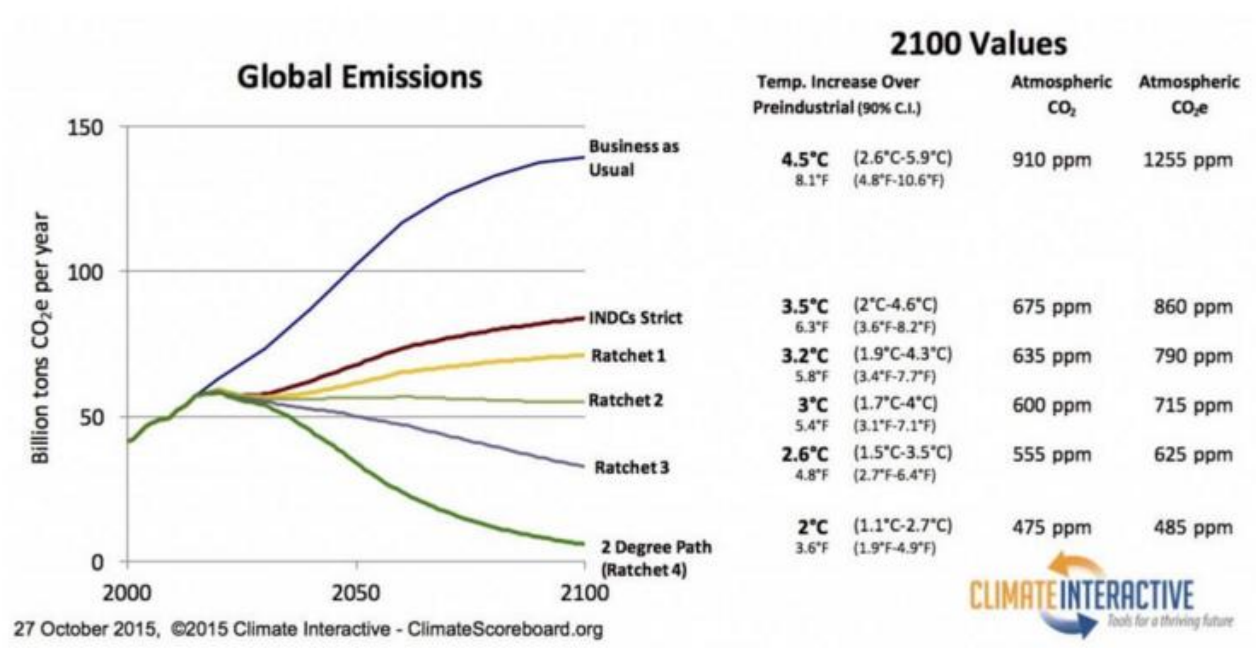




No progress after 2030 EU 40% below 1990 by 2030 US 26% below 2005 by 2025 Other Developed – rise just a bit after 2030 China – CO2 peaks 2030 but other GHGs continue to increase India – No net change in emisssions pathway due to pledges Other develpoing – Emissions reductions relatove to BAU, rate slows but growth continues Total emissons 2012-2100 – 6153 GTCO2e	Developed countries peak 2020-2025 Developing countries peak 2030-2035 Emissions decline 3.5-4.4% annually after peaking 50% chance of meeting 2° C increase Total emissons 2012-2100 –2,888 GTCO2e

Data for these scenarios was not available from the Web page, so estimates for some of the years was obtained by estimating the emissions bases on the graph and then computing the total about by assuming a linear change between each pair of years. (Note that the results are very similar to the "INDC Strict" and "2 degree pathway" "ratcheting scenarios" – see below

2. The “ratcheting” scenarios



GHG Emission and totals from Climate-Scoreboard-Output-27Oct2015-to-share.xlsx

BAU	INDC Strict	Ratchet 1	Ratchet 2	Ratchet 3	2 deg Pathway
9333	6230	5635	4993	4188	2737

C. MIT Joint Program on the Science and Policy of Global Change - ENERGY & CLIMATE OUTLOOK PERSPECTIVES FROM 2015

August 2015 http://globalchange.mit.edu/files/2015%20Energy%20%26%20Climate%20Outlook.pdf

"With emissions stable and falling in Developed countries, on the assumption that the Paris pledges made at COP21 are met and retained in the post-2030 period, future emissions growth will come from the Other G20 and developing countries."

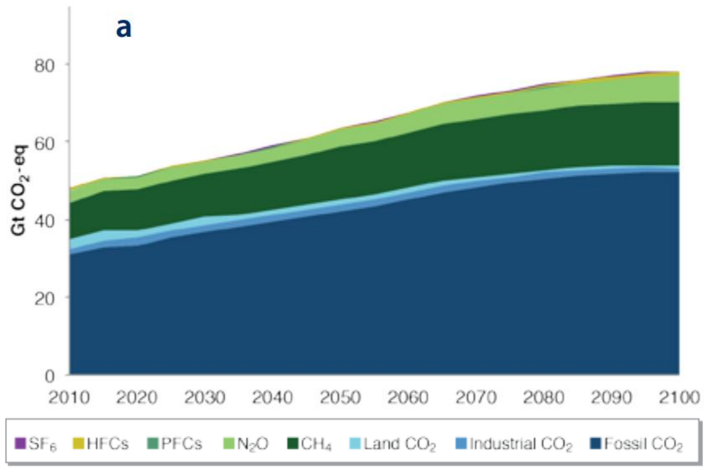


Figure 14. (a) Global greenhouse gas emissions

2011 Emissions - 49; "linear 2100"emissions – 82

Total emissions 2012-2100 – 5764 GTCO2e

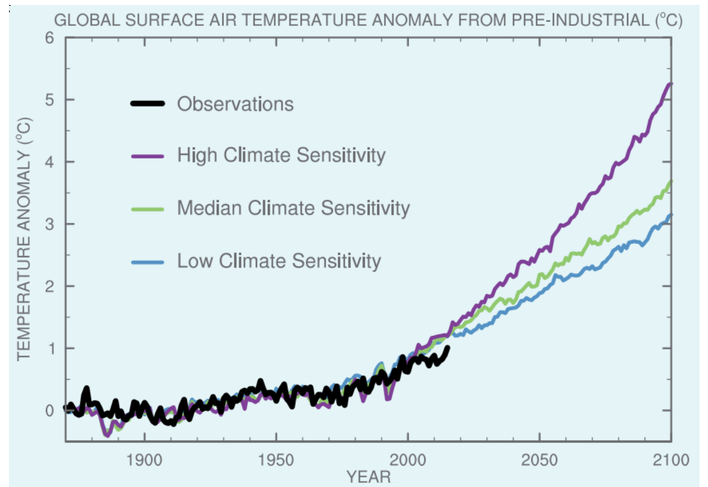


Figure 19. Global mean temperature and precipitation changes from the 1860–1880 mean

"We choose three values of climate sensitivity (CS) that correspond to the 5th percentile (CS=2.0°C), median (CS=2.5°C), and 95th percentile (CS=4.5°C) of the probability density function that were jointly estimated with the ocean heat uptake rate."

Temperature increases - 3.1, 3.7, 5.2

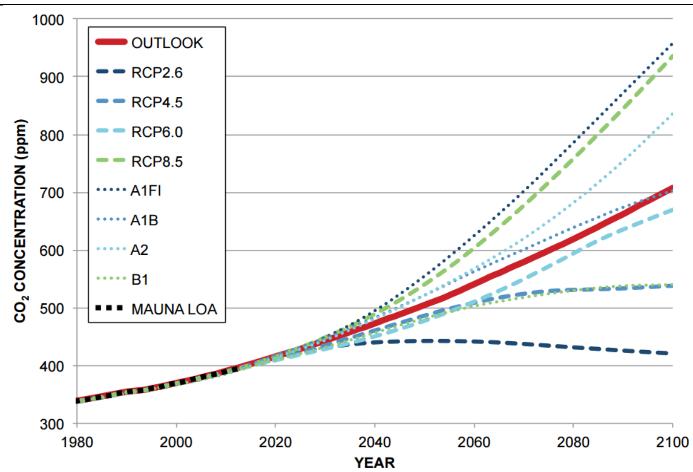


Figure 17. Projected CO_2 concentrations (ppm).

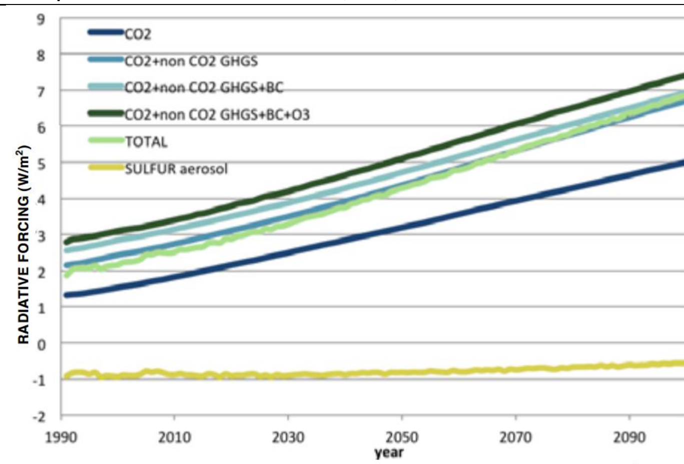


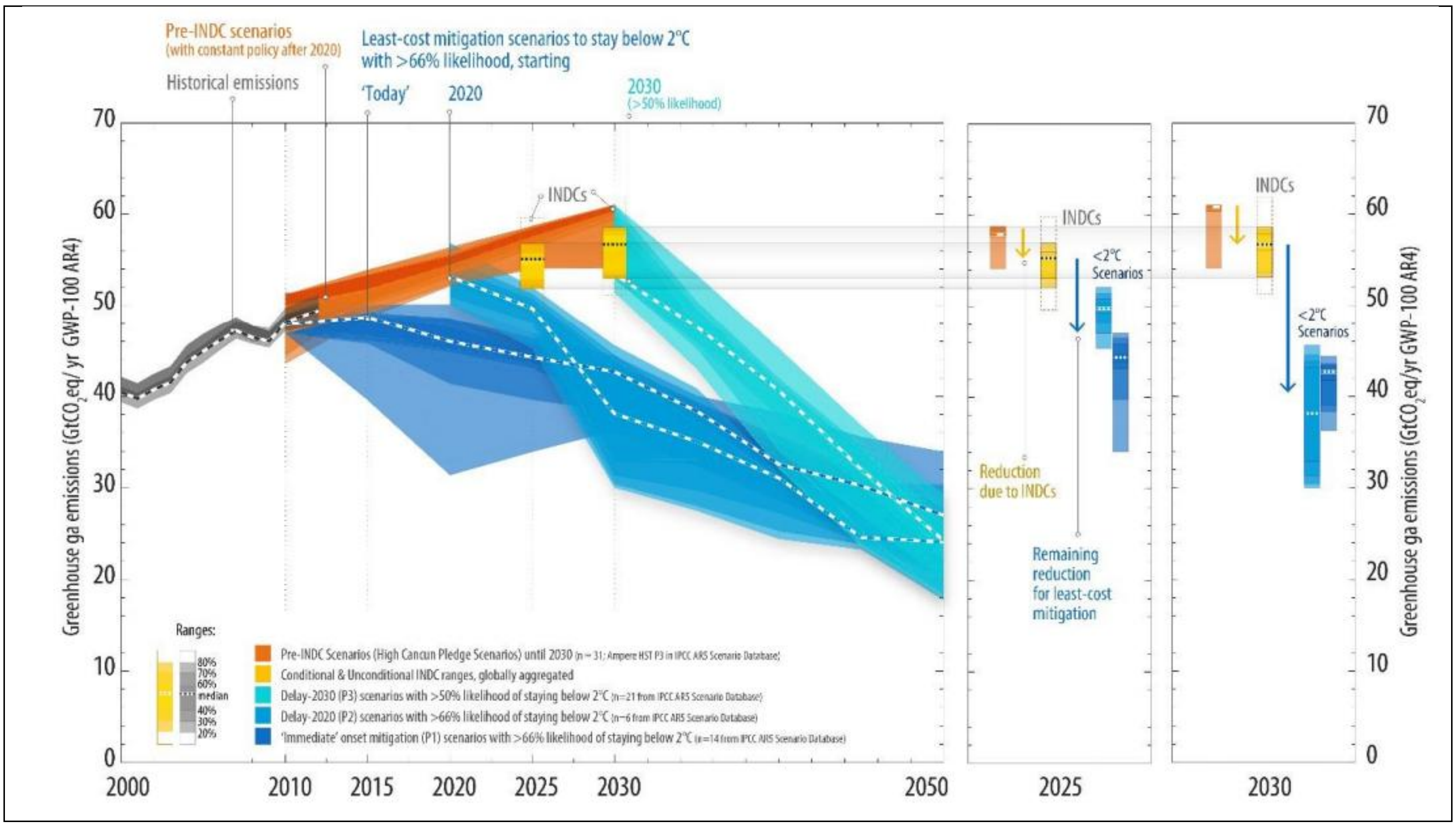
Figure 18. Projected greenhouse gas (GHG) radiative forcing (W/m^2).

D. UNFCCC

http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf

The UNFCCC did not forecast emissions beyond 2030, but the following provides some guidance from which "reduction scenarios" can be developed.

> "33. The implementation of the communicated INDCs is estimated to result in aggregate global emission levels[7] of 55.2 (52.0 to 56.9)[8] Gt CO2 eq in 2025 and 56.7 (53.1 to 58.6) Gt CO2 eq in 2030. The global levels of emissions in 2025 and 2030 were calculated by adding the estimated aggregate emission levels resulting from the implementation of the communicated INDCs (41.7 (36.7 to 47.0) Gt CO2 eq in 2025 and 42.9 (37.4 to 48.7) Gt CO2 eq in 2030) to the levels of emissions not covered by the INDCs. [9] Aside from various uncertainties in the aggregation of the INDCs, these ranges capture both unconditional and conditional targets. Global cumulative CO2 emissions after 2011[10] are expected to reach 541.7 (523.6– 555.8) Gt CO2 in 2025 and 748.2 (722.8– 771.7) Gt CO2 in 2030."
>
> "42. Given the fact that GHGs are long-lived in the atmosphere and therefore cumulative emissions determine the impact on the climate system, higher emissions in the early years (compared with least-cost trajectories) would necessitate greater and more costly emission reductions later on in order to keep the global mean temperature rise below the same level with the same likelihood. According to the AR5, the total global cumulative emissions since 2011 that are consistent with a global average temperature rise of less than 2 °C above pre-industrial levels at a likely (>66 per cent) probability is 1,000 Gt CO2. Considering the aggregate effect of the INDCs, global cumulative CO2 emissions are expected to equal 54 (52–56) per cent by 2025 and 75 (72–77) per cent by 2030 of that 1,000 Gt CO2. [18]"



CO_2 Emissions to meet 2 degree C target (and associated CDR costs)

- Based on a peak year (2025 or 2030) and a linear reduction to 0
- CDR is used to remove the "overshoot" emissions
- The table includes a separate computation for taking feedbacks from a warming world into account (See Section G below – 440GTCO_2e is a suggested “mean” for emissions from permafrost this century , so the number used below - 400 - is likely low as it also includes other feedbacks)

Starting Values														
Peak Year	2025	2025	2025	2025	2025	2025	2025	2030	2030	2030	2030	2030	2030	2030
Emissions In Peak Year	41.95	41.95	41.95	41.95	41.95	41.95	41.95	43.09	43.09	43.09	43.09	43.09	43.09	43.09
Emissions Through Peak Year	541.7	541.7	541.7	541.7	541.7	541.7	541.7	750	750	750	750	750	750	750
Total Budget	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Remaining Budget	458.3	458.3	458.3	458.3	458.3	458.3	458.3	250	250	250	250	250	250	250
Computations to Meet the 2 Degree C Target														
Reduction %/Year	4.58	4.00	3.50	3.00	2.00	1.00	0.50	8.62	5.00	4.00	3.00	2.00	1.00	0.50
Total Emissions	1000	1066	1141	1241	1591	2639	4737	1000	1181	1289	1468	1827	2905	5059
CO_2 Removed by CDR	0	66	141	241	591	1639	3737	0	181	289	468	827	1905	4059
Other GHG removed by CDR+	0	22	47	80	197	546	1244	0	60	96	156	275	634	1352
Number of Years	22	25	29	33	50	100	200	12	20	25	33	50	100	200
Zero Year	2047	2050	2054	2058	2075	2125	2225	2042	2050	2055	2063	2080	2130	2230
Emission Reduction/Year	1.9	1.7	1.5	1.3	0.8	0.4	0.2	3.7	2.2	1.7	1.3	0.9	0.4	0.2
Estimated Costs of CDR														
CDR Cost/Ton CO_2	50	50	50	50	50	50	50	50	50	50	50	50	50	50
CDR Costs (Trillions of $)	0.0	4.4	9.4	16.1	39.4	109.3	249.1	0.0	12.1	19.2	31.2	55.1	126.9	270.5
Estimated Temperature Increase if No CDR														
Total Anthropogenic Emissions	1000	1066	1141	1241	1591	2639	4737	1000	1181	1289	1468	1827	2905	5059
Temp increase by 2100 if no CDR	2.00	2.05	2.11	2.19	2.45	3.15	4.15	2.00	2.14	2.23	2.36	2.62	3.30	4.26
Computations Which Include Emission-Equivalent Feedbacks														
Emission Equivalent From Feedbacks	400	400	400	400	400	400	400	400	400	400	400	400	400	400
CO_2 to be removed by CDR	400	488	588	721	1187	2585	5381	400	641	785	1024	1503	2939	5811
CDR Costs (Trillions of $)	20.0	24.4	29.4	36.1	59.4	129.3	269.1	20.0	32.1	39.2	51.2	75.1	146.9	290.5
Total CO_2 Emission Equivalent	1400	1488	1588	1721	2187	3585	6381	1400	1641	1785	2024	2503	3939	6811
Temp increase by 2100 if no CDR	2.31	2.38	2.45	2.54	2.86	3.66	4.57	2.31	2.49	2.59	2.75	3.06	3.83	4.62

+Once the 2 degree C target is reached the carbon equivalent of all GHG emissions needs to be captured and sequestered

Since other green house gases are about one-third of the CO_2 emissions, CO_2 CDR must be increased by one-third

E. Thoughts on CDR Financing

Given a realistic CO_2 emissions scenario and a realistic carbon budget, the sequestration costs between now and 2100 will be many tens of trillions of dollars (and very likely over $50 trillion).

Money spent on removing CO_2 from the atmosphere provides no net economic benefit in the "normal economic sense" as it does not build "useful" infrastructure (roads, buildings, etc) and provides no revenue stream (or return on investment). Even though the money spent on the "energy production side" of a BECCS power plant does provide a "normal economic" investment, the money spent to capture and sequester the CO_2 does not.

Governments are expected to contribute $100 billion annually to the UNFCCC's Green Climate Fund, half of which will be used for mitigation and half for adaptation. It will be a "stretch" to even come close to this level of financing, and that level of funding is far short of what is needed for sequestration.

It is generally assumed that private financing will play major role in funding the Green Climate Fund as there are insufficient public funds available. Because there is no "return on investment" for spending on CDR, it is highly unlikely that private financing will provide any money for CDR projects. Because minimal private financing will be available for CDR projects, the only source of funding is likely the public sector. But with current global tax revenues at about $8 trillion per year, the required public sector funding would represent about 10% of total tax revenue.

Greenhouse gas emissions need to be brought under control BEFORE global warming feedbacks start contributing significantly to the Earth's temperature, as an additional equivalent amount of CO_2 wound then need be sequestered, driving the costs even higher.

The need for funds for CDR will be competing with the costs for sea level rise, ocean acidification, an aging population, poverty reduction, etc.

Bio-energy carbon capture and storage (BECCS) is the least expensive carbon dioxide removal (CDR) technique, but will likely play a minimal role in removing excess CO_2 from the atmosphere. BECCS cannot be realistically deployed at sufficient scale to sequester really significant quantities of CO_2 before 2100. Since costs for other techniques for sequestration are greater that costs for BECCS, $300/Ton C seems to be a reasonable lower bound on average CDR costs.

With almost no economic benefit from spending money on CDR, it would be nearly impossible to have an enforceable global treaty that would commit countries to spend the necessary $1 trillion per year. So no country would have an incentive to fund CDR projects.

Incremental spending on CDR projects does not make economic sense – unless there is a reasonable expectation that sufficient funds could be committed to CDR so that CO_2 levels could be reduced to below that needed to avoid disruptive climate change, it's hard to image that any meaningful investments will be made in CDR.

There a maximum amount that society could be realistically expected to be willing to pay for CDR. That maximum amount is almost certainly less than expected costs of the CDR expenditures that would be needed

No politician will ever recommend spending significant dollars "today" on CDR, so costs will always be passed on to future generations

F. Feedback Factors

"It [(permafrost melt)] was first proposed in 2005. And the first estimates came out in 2011." Indeed, the problem is so new that it has not yet made its way into major climate projections, Schaefer says." …"None of the climate projections in the last IPCC report account for permafrost," says Schaefer. "So all of them underestimate, or are biased low." … "It's certainly not much of a stretch of the imagination to think that over the coming decades, we could lose a couple of gigatons per year from thawing permafrost," says Holmes…. But by 2100, the "mean" estimate for total emissions from permafrost right now is 120 gigatons, say Schaefer. http://www.washingtonpost.com/news/energy-environment/wp/2015/04/01/the-arctic-climate-threat-that-nobodys-even-talking-about-yet

Feedback/Factor	Carbon Store Size	Range of Likely Emission Values/Temperature Changes
Albedo Changes		
Arctic Ocean	Already .27 W/M^2, with pollution reducing the amount[7]	
		.3-1.3 w/m[8,9]
Retreating snowline		1.3 w/m[8,9]
Tundra greening		
Land use changes		
Other?		
CO2 Emissions		
Permafrost	1,600	.4-.6°F by 2100[1] 190 GTC by 2200[2] 250 GTC[3] by 2100
Peat Bogs	270 to 370[4]	100-220[5]
Methane Hydrates	5,000 to 20,000[3,6]	
Other Soils		
Tropical Forests	86 GTC (Amazon)	
Temperate Forests		US forests will change from a sink to a source later this century
Other?		
Atmosphere	820 GTC	
Anthropogenic Emissions	515 GTC	(through 2011)
Fossil Fuel Reserves	760 GTC	1.6°C if all reserves burned
1. http://nca2014.globalchange.gov/report/our-changing-climate/melting-ice .4-.6°F		
2. http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt264.pdf		
3. http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf		
4. globalcarbonproject.org/global/pdf/pep/Limpens.2008.Peatlands& Carbon.BiogeosciencesDiscus.pdf		
5. http://thinkprogress.org/climate/2015/01/13/3610618/peat-wetlands-global-warming/		
6. http://www.killerinourmidst.com/methane and MHs2.html		
7. http://www.nasa.gov/press/goddard/2014/december/nasa-satellites-measure-increase-of-sun-s-energy-absorbed-in-the-arctic		
8. http://www.esrl.noaa.gov/gmd/co2conference/posters_pdf/jones1_poster.pdf		
9. http://arctic-news.blogspot.com/2012/07/albedo-change-in-arctic.html		

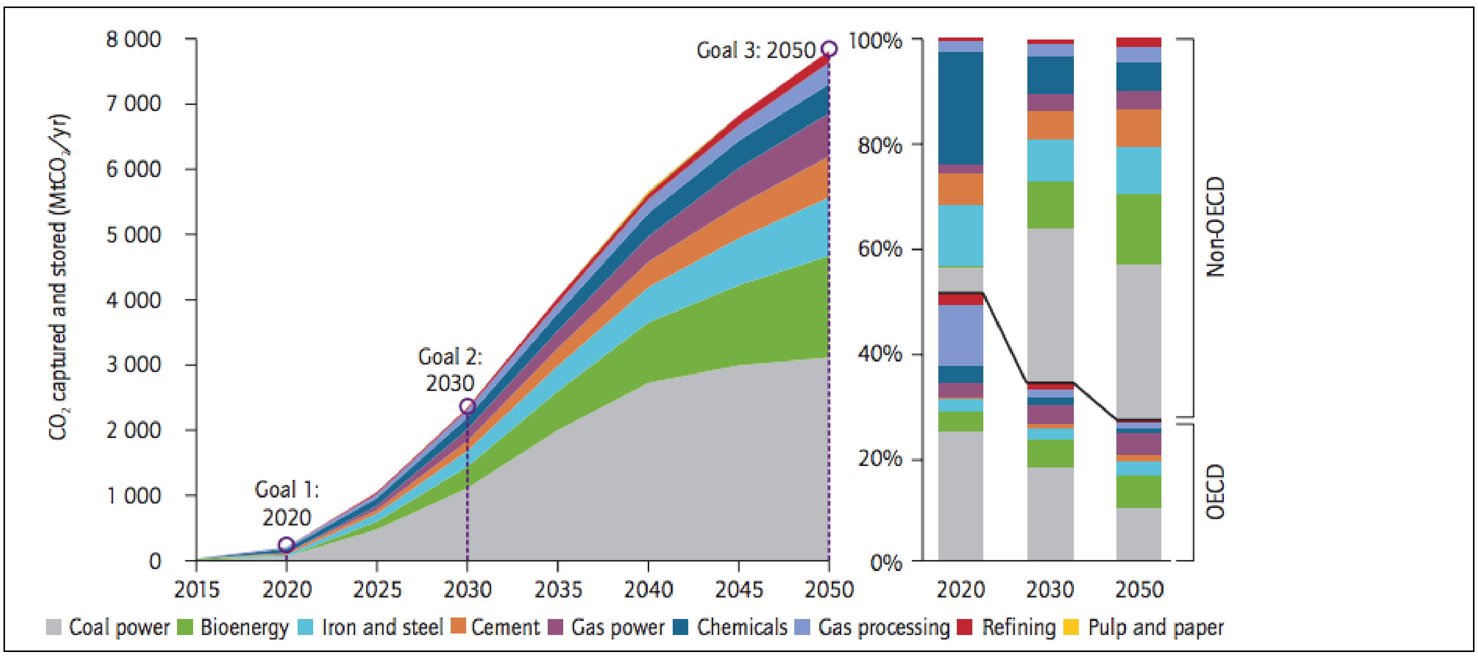
Table F1 – Feedback Factors

G. Sequestration

Carbon capture and storage (CCS) technologies can capture up to 90 percent of carbon dioxide (CO2) emissions from a power plant or industrial facility and store them in underground geologic formations. Since the incremental cost of capturing the other 10 percent of emissions is so high, if fossil fuel power plants are to stay in operation in a “net zero emissions” world, significant amounts of CO2 will have to be sequestered by other means. (Fossil fuel power plants with CCS cannot be used to sequester CO2 already in the atmosphere.) The technologies for both capture and storage are unproven at the scale that will be needed.

According to the IEA (https://www.iea.org/publications/freepublications/publication/technology-roadmap-carbon-capture-and-storage-2013.html - 2013), CCS is a critical component of meeting the 2°C target. They project that CCS will need to be used to sequester 50 MTCO2/year by 2020, 2,000 MTCO2/year by 2030, and almost 8,000 MTCO2/year by 2050.

- “Under the IEA Energy Technology Perspectives 2012 2°C Scenario (2DS), CCS contributes one-sixth of total CO2 emission reductions required in 2050, and 14% of the cumulative emissions reductions through 2050 against a business-as-usual scenario (6DS).”
- “Governments and industry must ensure that the incentive and regulatory frameworks are in place to deliver upwards of 30 operating CCS projects by 2020 across a range of processes and industrial sectors.”
- “CCS is not only about electricity generation. Almost half of the CO2 captured between 2015 and 2050 in the 2DS, is from industrial applications (45%).”
- “Given their rapid growth in energy demand (70% by 2050), the largest deployment of CCS will need to occur in non-Organisation for Economic Co-operation and Development (OECD) countries.”



It is likely that the 2020 goal will be met, but the majority of the current CCS plants use the captured CO2 for enhanced oil recovery and hence can capture the CO2 for a profit. But ramping up for the 2030 goal will be problematic as the average “energy penalty” is expected to be about 29 percent ("The energy penalty of post-combustion CO2 capture and storage" Jan 2009) and there will not be a way to recover the costs. For the US, the expected levelized cost of electricity in 2020 is $94/mwh for conventional coal and $144 for advanced coal with CCS. Since 1 MWH of coal produces about 1 metric ton of CO2, the CO2 capture costs are about $50/ton. Therefore the CCS capture costs are expected to be about $400 billion per year in 2050 *assuming that anthropogenic emissions can be mitigated at the rate necessary to meet the IPCC carbon budget and that there are not significant natural emissions from permafrost melt, peat bogs, etc.* (both very unlikely)

H. Greenhouse Gas Concentrations and Climate Implications

Greenhouse Gas Concentrations and Climate Implications

To meet the temperature and GHG concentrations goals discussed broadly amongst nations, global emissions need to peak very soon, if not immediately. Many analyses have focused on the target of 450 parts per million (ppm) as the limit for avoiding temperature increases of 2°C. Current atmospheric concentrations for Kyoto gases[4] (**Figure 16**) already exceed 450 ppm CO_2-eq, while CO_2 concentrations approach 400 ppm. When all major GHGs, including CFCs, are included, concentrations are currently above 480 ppm, as shown in Figure 16, labeled *CO_2-eq (IPCC)*. The use of chlorofluorocarbons (CFCs) has been almost entirely phased out under the Montreal Protocol because they destroy protective ozone in the stratosphere. While new CFCs are not being produced and emitted, concentrations will remain in the atmosphere for a very long time because their lifetimes are thousands of years. The seasonal cycle of concentrations, due largely to strong CO_2 effects of northern hemisphere vegetation, is smoothed to show the underlying trend (for details, see Huang et al. [2009], from which Figure 16 is updated). Note that CO_2-eq concentrations do not use GWPs as they are intended to show the relative radiative effect of concentrations at a point in time, rather than over their expected lifetime in the atmosphere (see **Box 4**).

Even though we have exceeded the 450 ppm level we have not yet seen warming of 2°C. Two important reasons are: (1) the offsetting cooling effect of sulfate aerosols (airborne particles), which is not included in Figure 15; and (2) due to the inherent inertia in the climate system, it will take decades to see most of the warming to which we are already committed. There have been strong efforts to control sulfate emissions in wealthier countries to reduce the source of acid precipitation, and because the aerosols are considered a health hazard. Sulfate aerosols remain in the atmosphere for only a few days to a week or so; if they were controlled worldwide, concentrations would fall almost immediately, and their substantial cooling effect would no longer mask GHG warming. Inertia in the climate system may spare us some of the warming for some decades, but not forever. Thus, there is little comfort in the fact that we have exceeded 450 ppm CO_2-eq without seeing a large impact on global temperature.

The implications of our emissions projections are that CO_2 concentrations approach 750 ppm by 2100 with no sign of stabilizing (**Figure 17**). The figure also shows the four Representative Concentration Pathways (RCP) scenarios (van Vuuren et al., 2011) in dashed lines, the scenarios A1FI, A1B, A2 and B1 from the special

Box 4.

CO_2-equivalent Concentrations of GHGs

As discussed in Box 3, GWPs provide an approach to aggregate emissions because, in part, the lifetimes of the gases in the atmosphere differ. CO_2-eq concentrations of gases are calculated differently—in the case of concentrations, we know the concentration of the gas (historically, or the predicted level in a particular future scenario). CO_2-eq concentrations are calculated by multiplying the instantaneous radiative forcing by the atmospheric concentration of the gas at any point in time. This metric is less subject to uncertainties because of lifetimes and feedbacks, and is intended to show how important different gases are in terms of the forcing they are causing at any given time.

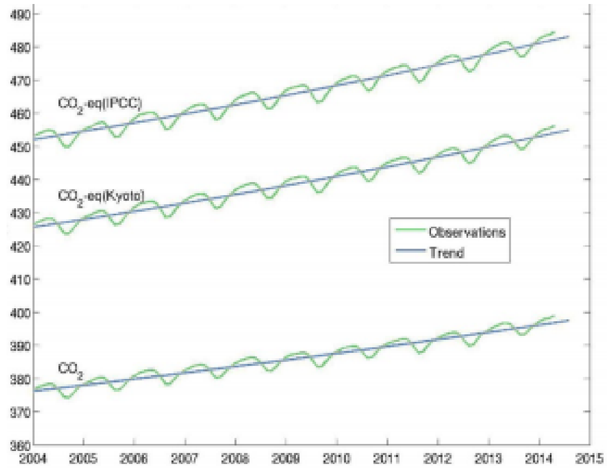


Figure 16. Current greenhouse gas (GHG) concentrations.

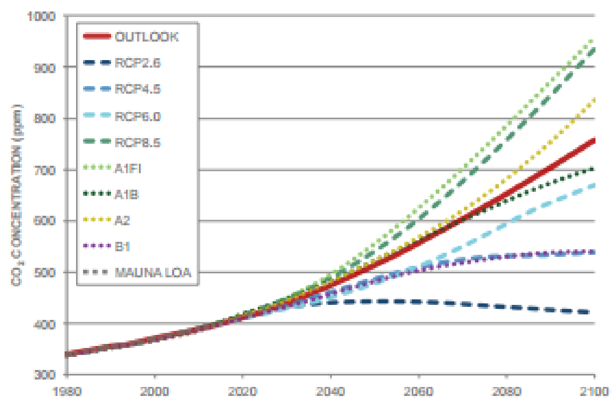


Figure 17. Projected CO_2 concentrations.

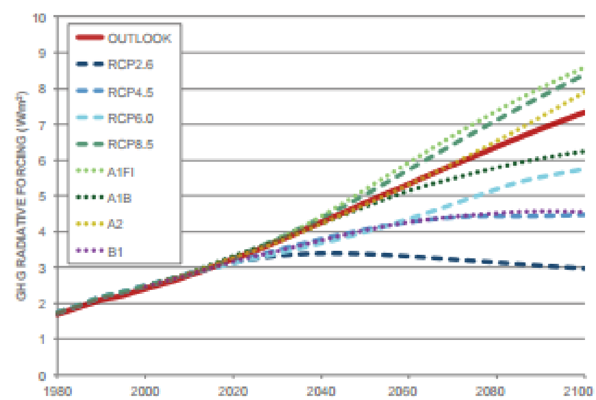


Figure 18. Projected greenhouse gas (GHG) radiative forcing.

[4] We refer to Kyoto gases to denote those included in the emission targets specified under the Kyoto Protocol.

http://globalchange.mit.edu/files/2014%20Energy%20%26%20Climate%20Outlook.pdf