How to distribute humanity's remaining carbon-dioxide budget

Peter Nightingale*

Fossil Free Rhode Island

(Dated: Tuesday 13th May, 2014)

This is a discussion document that works out how we might allocate the rest of humanity's carbon-dioxide budget with a modicum of fairness.

Contents

I. DISCLAIMER

This was written in haste. Not all numbers have been checked with sufficient care. In particular, there are issues such as the evaporation of the USSR, which make attributing total emissions to countries existing in 2010 problematic. Probably the effects of these problems is smaller than the intrinsic inaccuracies of the global emission numbers to begin

*Electronic address: nigh@pobox.com

with. I expect that future revisions will be small and that the current results are good enough for discussion of the principles. Once we get beyond that, somebody else should produce these numbers independently.

II. INTRODUCTION

The ideas presented here are based on a recent paper by Hansen et al. *Assessing "dangerous climate change": required reduction of carbon emissions to protect young people, future generations and nature.*[1] For a short version of this paper see Ref. 2. To sum up:

1. The global mean temperature change is determined directly by cumulative carbon emissions.[3]

2. Hansen *et al.*[1] base their predictions on

> A cumulative industrial-era limit of ∼500 GtC fossil fuel emissions and 100 GtC storage in the biosphere and soil would keep climate close to the Holocene range to which humanity and other species are adapted.[1]

The following simplifications make it very easy to reproduce the results presented in Ref. 1:

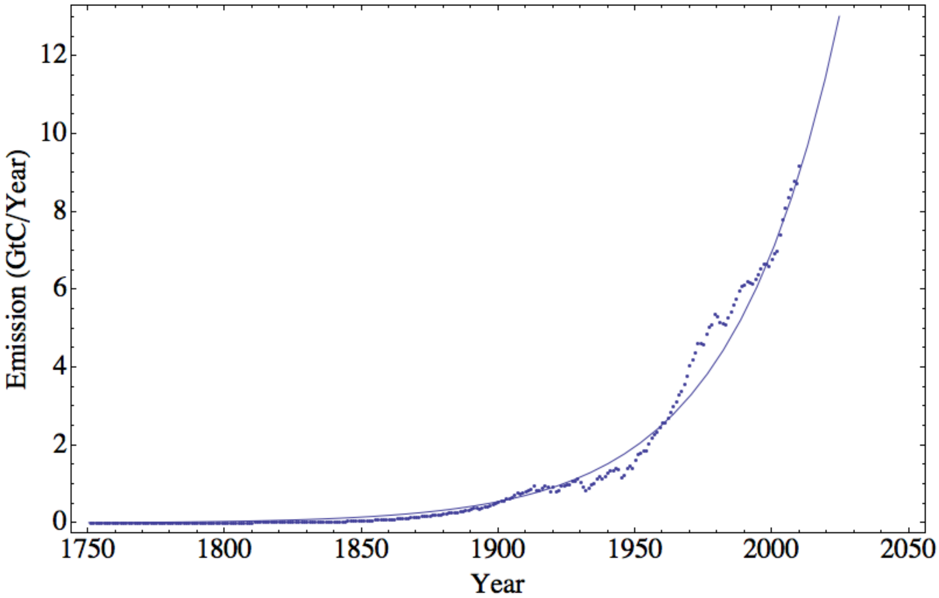
1. Roughly half of the CO_2 put into the atmosphere ends up in the biosphere and *v.v.*[4].

2. With this we can replace the assumption of Hansen *et al.*, namely "∼500 GtC fossil fuel emissions and 100 GtC storage in the biosphere," by a single number: a total global emission of 550 GtC.

III. GLOBAL EMISSIONS

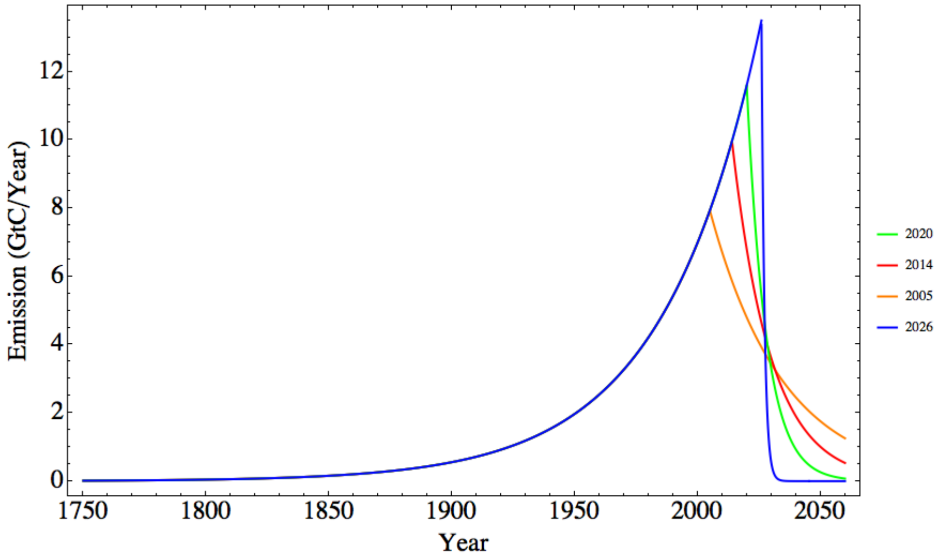
Estimates of total carbon dioxide emissions from the beginning of the Industrial Revolution are available from CDIAC[5]. As demonstrated by Fig. 1, the data can be represented as an exponential growth curve. (For mathematical details see Eqs. 1 and 2 in the Section V A in the appendix.)

FIG. 1: Global CO_2 emissions in gigatons of carbon per year: data[5] with exponential fit



The curve shown in Fig. 1 is used to define what is meant by "continuing business as usual" beyond 2010 as far as global fossil fuel emissions are concerned. The numbers in Fig. 2 and Table I show some possible scenarios assuming a cut of emissions by the same percentage each year of what's left that year after continuing business as usual until the year listed on the left. The percentage is determined by that year and by the 550 GtC target mentioned in Section III. These estimates agree with those in Ref. 1 where available.

FIG. 2: Global CO_2 emissions scenarios consisting of business as usual until a certain year followed by fixed rate of yearly reduction; (1) 2006: 3% — orange; (2) 2014: 6% — red; (3) 2020: 12% — green; (4) 2026: 81% — blue. The total emission for each curve is represented by the area under the curve. It is equal to 550 GtC in each case.



The total CO_2 emission is represented in Fig. 2 by the area under the curve. This area is the same for all four curves. As a consequence, longer continuation of business as usual is followed by a steeper decline. The blue curve is very close to the "cold turkey" limit of continuing business as usual until the bitter end.

TABLE I: Global emissions: business as usual until the year in the left column followed by percentage cut each following year. Note: 100% means business as usual followed by cold turkey in 2027.

Year	%
2006	3
2008	4
2010	5
2012	5
2014	6
2016	7
2018	9
2020	12
2027	100

IV. USA EMISSIONS

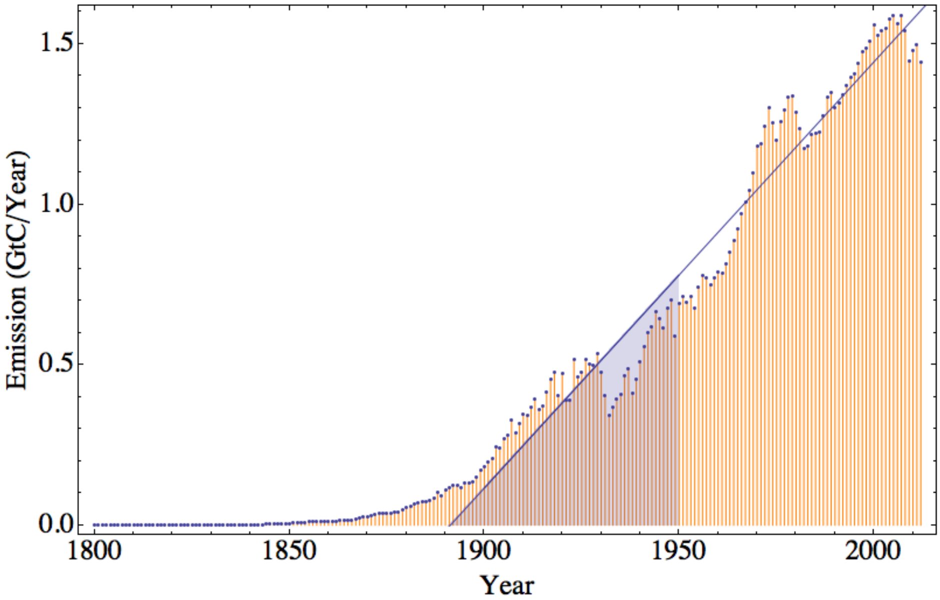
Fig. 3 shows the emissions of the USA.[6]. The orange hatched area represents the total amount of carbon dioxide the USA has put into the atmosphere. As mentioned in the introduction in Section II, the total mass of carbon-dioxide humanity can store safely in the atmosphere without creating catastrophic climate change is about 550 gigatons – only carbon is included in count.

The blue triangle represents the total amount the USA is entitled to according to a strict constructionist interpretation of the following:

> We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty, and the Pursuit of Happiness. That to secure these rights, Governments are instituted among Men, deriving their just powers from the consent of the governed;

Of course, the USA shares its status of carbon debtor nation with the rest of the industrialized world.

FIG. 3: USA CO_2 emissions in gigatons of carbon per year data[6, 7] with linear fit through the data since 1900. The area of the blue triangle represents the total carbon emissions the USA is entitled to according to the principle that all people are equal.



The solid line is used to extrapolate and to give meaning to what is meant by "business as usual." The percentages listed in Tab. II represent various schemes of cutting USA emissions. Obviously, given the fact that the USA has already spent the fraction to which it is entitled, as is the case for the rest of the industrialized world, none of them can be characterized as fair. The various values of the quantity G, the Gini coefficient, represent a quantitative measure of the degree of unfairness: $G = 0$ represent a fully egalitarian distribution and $G = 1$ represents the other extreme in which the winner has all. Values of $G > 0$ can be viewed as the equivalent of the unfairness representative of banana republic.

TABLE II: USA emissions: business as usual until the year listed in the left column. The three right-most columns are the percentage cuts in each subsequent years according to scenarios with different Gini coefficients. Note: 100% means business as usual followed by cold turkey.

Year	$G = 0.4$	$G = 0.45$	$G = 0.5$
2006	12	7	5
2008	16	8	5
2010	24	9	6
2012	46	12	7
2013	100	13	7
2014		15	8
2016		21	10
2018		37	12
2020		100	17
2022			26
2024			53
2025			100

Finally, Tab. III contains the outcome of the various schemes outlined above. The table shows the fraction p of the world population living in the countries listed in the left-most column. Columns under the headings $e_{0.4}$, $e_{0.45}$, and $e_{0.5}$ show the outcomes of the various mitigating emission mentioned above. The column of the right-most represents the fraction of the cumulative carbon emission if inequality is maintained at its current level.

TABLE III: Percentage of major players of in the global carbon casino. Their fraction of the world population is p. Total global final emissions fractions are $e_{0.4}, e_{0.45}, e_{0.5}$ associated with various Gini coefficients. The left most column represents the situation as of 2010.

Country	p	$e_{0.4}$	$e_{0.45}$	$e_{0.5}$	$e_{0.62}$
USA	4	19	20	22	27
China	18	12	12	11	10
India	16	7	6	5	3

V. APPENDIX

A. Global emission growth

The data in Fig. 1 can be represented by

$$c_{\text{global}}(t) = 9.00\, e^{0.025(\frac{t}{\text{year}} - 2010)}\,\text{GtC/year}. \tag{1}$$

This expression was obtained by a least squares fit, followed by a slight adjustment of the normalization constant so that the integral from $-\infty$ to year 2011 reproduces

$$\int_{-\infty}^{2011\,\text{year}} c(t)\,dt = 365\,\text{GtC}, \tag{2}$$

the CDIAC estimate of 2010 cumulative emissions.[5]

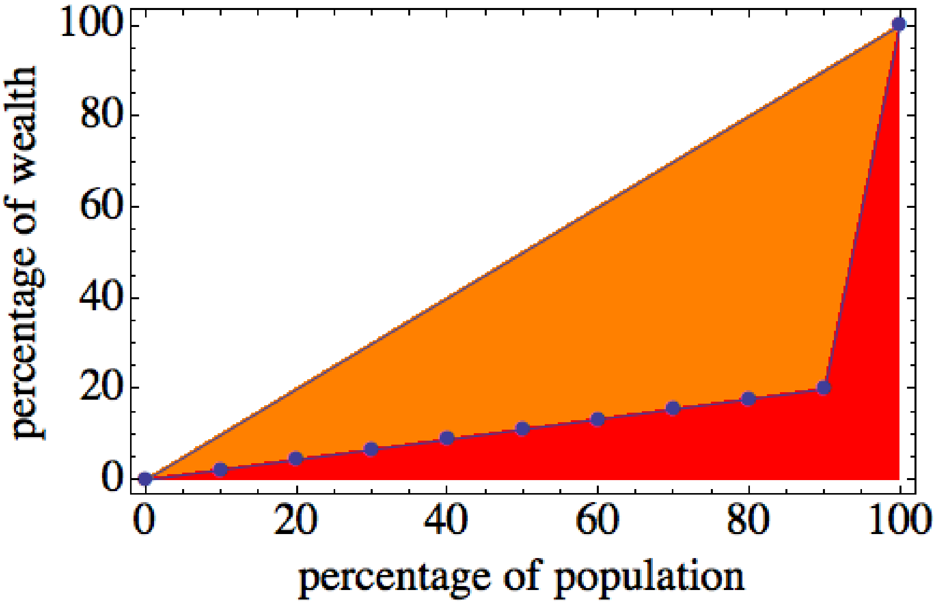
B. Lorenz curves and Gini coefficients

C. Quantifying inequality: a simple example

Suppose there is a "population" of ten people. They collectively own a wealth of \$100. The nine at the bottom equally share \$20, and the one at the top owns the remaining \$80 Line the population up so that wealth increases or stays the same from left to right. Pick a person on that line and find the fraction of the population to the left of and including that person and the fraction of the total weal the these people collectively own. This produces the blue dots in Fig. 4.

If wealth were distributed equally, the blue dot would all fall on the diagonal, the top border of the orange triangle. The orange triangle would vanish in this case. The area of the orange triangle is a measure of inequality. It varies between 0 and $\frac{1}{2}$. The Gini coefficient G is defined to be twice the area of the orange triangle. The line connecting the blue dots is called the Lorenz curve. It shows that 90% of the population owns 20% of the wealth in this example; the $G = 0.7$ in this case.

FIG. 4: Definition of the Gini coefficient: twice the area of the orange triangle. Perfect equality: orange triangle vanishes. Complete inequality: the red triangle vanishes. In this example $G = 0.7$



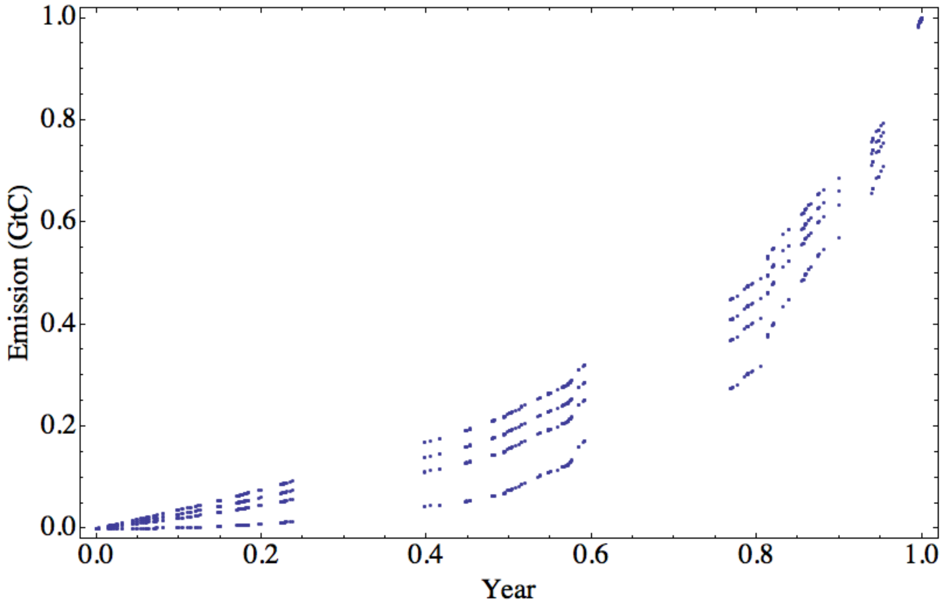
In Fig. 5 the bottom set of points represents the contributions of various nations to the carbon dioxide put into the atmosphere as of 2010[5]. The bottom curve has a Gini coefficient of 0.62.. The other three curves are hypothetical redistribution curves corresponding to Gini coefficients of 0.5, 0.45, and 0.4.

Singer and Fei[8] put the meaning of these Gini coefficients in context:

> Naturally, all existing societies fall somewhere between these two extremes, with relatively egalitarian countries like Denmark at around 0.25, and less egalitarian countries like the US and Turkey closer to 0.4.

As we'll see, humanity has missed the boat on being able to restore fairness to a level of with a Gini coefficient of $G = 0.4$.

FIG. 5: Global Lorenz curves for CO_2 national cumulative emissions up 2010 with CIDIAC data[5]. Bottom curve$G = 0.62$; other curves represent slightly more equitable distributions $G = 0.5, 0.45$, and 0.5.



D. USA emission growth

The data in Fig. 3 in during the last century can be represented by

$$c_{\text{USA}}(t) = [1.58 + 0.013(\frac{t}{\text{year}} - 2010)]\,\text{GtC/year}. \tag{3}$$

Data up to and including 2010 are from CDIAC.[6] Data for 2011 and 2012 are from the U.S. Energy Information Administration.[7]

[1] J. Hansen, P. Kharecha, M. Sato, V. Masson-Delmotte, F. Ackerman, D. J. Beerling, P. J. Hearty, O. Hoegh-Guldberg, S.-L. Hsu, C. Parmesan, et al., PLoS One (2013), URL http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0081648.

[2] J. Hansen, P. Kharecha, M. Sato, V. Masson-Delmotte, F. Ackerman, D. J. Beerling, P. J. Hearty, O. Hoegh-Guldberg, S.-L. Hsu, C. Parmesan, et al., PLoS One (2013), URL http://www.columbia.edu/~jeh1/mailings/2013/20131202_PopularSciencePlosOneE.pdf.

[3] H. D. Matthews, N. P. Gillett, P. A. Stott, and K. Zickfeld, Nature **459**, 829 (2009), URL http://www.nature.com/nature/journal/v459/n7248/abs/nature08047.html.

[4] J. Hansen, P. Kharecha, and M. Sato, Environmental Research Letters **8**, 011006 (2013), URL http://stacks.iop.org/1748-9326/8/i=1/a=011006.

[5] CDIAC, Carbon Dioxide Information Analysis Center (2010), URL http://cdiac.ornl.gov/ftp/ndp030/CSV-FILES/global.1751_2010.csv.

[6] CDIAC, Carbon Dioxide Information Analysis Center (2010), URL http://cdiac.ornl.gov/ftp/ndp030/CSV-FILES/nation.1751_2010.csv.

[7] U. S. EIA, U.S. Energy Information Administration (2013), URL http://www.eia.gov/todayinenergy/chartdata/US_annual_carbon_emissions.csv.

[8] P. Singer and T. Fei, project-syndicate.org (2013), URL http://tinyurl.com/nx9mxr3.