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Fair Plan 7: Earth's Climate Future = Humanity's Choice

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Abstract

Earth's climate future is in the hands of humanity. If emissions of greenhouse gases remain unabated, Earth's climate will return to the climate of the Late Eocene, 35 million years ago, when sea level was 73 meters (240 feet) higher than today. Should that occur, many coastal cities around the world would be inundated. Moreover the Global Warming of this unabated Reference case will be comparable to the Global Warming from the Last Glacial Maximum 21,000 years ago to the beginning of the Holocene interglacial climate 11,000 years ago. However, this human-caused Global Warming would occur 50 times faster than that caused by nature. Alternatively, humanity can mitigate greenhouse-gas emissions to keep Global Warming below the 2˚C maximum adopted by the United Nations Framework Convention on Climate Change "to prevent dangerous anthropogenic interference with the climate system". This mitigation can either be done rapidly, as in the "80/50" Plan to reduce greenhouse-gas emissions 80% by 2050, or much more slowly, from 2020 to 2100, as in the Fair Plan to Safeguard Earth's Climate. The Fair Plan is a compromise between doing nothing, as in the Reference case, and rapidly reducing greenhouse-gas emissions, as in the 80/50 Plan. Regardless of the Plan chosen to reduce greenhouse-gas emissions to keep Global Warming below the UNFCCC limit of 2˚C (3.6˚F), it should not be tantamount to our saying to one of our planetary spacecraft, *Bon Voyage*, call us when you get to your planetary destination. Rather, as with our spacecraft, the chosen climate-change policy should be monitored throughout the 21st century and Midcourse Corrections made thereto as needed to keep our "Climate Spacecraft" on track to achieve its "Climate Target".

Keywords

Earth's Climate Future

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1. Introduction

To paraphrase Lewis Carroll in *Alice in Wonderland*:

"If you don't know where you are going, no road will take you there."

Humanity is grappling with the question: "To Act or Not on Climate Change?" There are "Naysayers"—generally conservatives, and "Aye-sayers"—generally liberals. The principal dichotomies for their so being—*The Great Climate Chasm*—are shown in **Table 1**.

The Great Climate Chasm is certainly not the first time that scientists and non-scientists have disagreed on a matter important to both. The archetype for this disagreement is the early 17th century contretemps between the Copernican conclusion that Earth is not the center of the Cosmos, but rather the Sun is [1]—the reinvention of the theory by Aristarchus of Samos (310-230 BC) ([2], p. 52)—and the Catholic Church's insistence that pagan Ptolemy (≈150 AD) [3] was correct—the Earth is the center of the Cosmos ([4], p. 156). This disagreement devolved onto Galileo in 1633 for his 1632 book [5] cleverly defending the Copernican theory (Codex 1181, Proceedings against Galileo Galilei [4], p. 156). As stated by Jacob Bronowski: "They (those in authority) believed that faith should dominate; and Galileo believed that truth should persuade" ([4], p. 156). The Inquisition trial of Galileo by the Church and his subsequent incarceration under house arrest in Arcetri (near Florence) for the final decade of his life, following the burning of Giordano Bruno at the stake in 1600 in Rome for his acceptance of the Copernicus-Aristarchus hypothesis of the Sun-centered cosmos, fostered the movement of science from Catholic (southern European) countries to Protestant (northern European) countries. It took the Church 300 years to right its wrong by "rehabilitating" Galileo ([2], p. 83), which was not an apology for its fallibility. The Church has remained unrepentant for its brutal execution of Giordano Bruno.

Climate Naysayers and some Climate Aye-Sayers are wrong—the Naysayers for wanting to do nothing forever, some Aye-Sayers for wanting to do too much too soon—We know not where we are going, so no road will take us there.

Here we propose a destination and a road thereto. We will do this by synthesizing the research findings of our 8 most-recent scientific papers [6]-[13].

By this exposition we hope to bridge *The Great Climate Chasm*, to forge agreement between Naysayers and Aye-sayers to: (1) begin the reduction in greenhouse-gas emissions no later than 2020, and (2) phaseout greenhouse-gas emissions over a sufficiently long time period to both: (a) safeguard Earth's climate, and (b) minimize the likelihood of economic *Future Shock*: "…the shattering stress and disorientation that we induce in individuals by subjecting them to too much change in too short a period of time" ([14], p. 2).

We are mindful of the difficulty of our enterprise. In his book "The Republican Brain: The Science of Why They Deny Science—and Reality" [15], Chris Mooney describes five coping mechanisms that individuals use to minimize their psychological discomfort, mechanisms that work to defeat acceptance of science by some people:

(1) *Cognitive Dissonance*: "…when the mind holds thoughts or ideas that are in conflict, or when it is assaulted by facts that contradict core beliefs, this creates an unpleasant sensation or discomfort—and so one moves to resolve the dissonance by bringing ideas into compatibility again." ([15], p. 28).

(2) *Motivated Reasoning*: Seeing what one wants to see ([15], p. 28).

(3) Confirmation *Bias*: "…give(ing) greater heed to evidence and arguments that bolster our beliefs and seek(ing) out information to reinforce our prior commitments." ([15], p. 32).

(4) *Disconfirmation Bias*: "…expend(ing) disproportionate energy trying to debunk or refute views and arguments that we find uncongenial, responding very defensively to threatening information and trying to pick it apart." ([15], p. 32).

Table 1. *The Great Climate Chasm*: Principal Dichotomies for Not Acting and for Acting on Climate Change.

Dichotomy	Not Act (Naysayers)	Act (Aye-sayers)
God v. Humanity	God Is in Charge of Climate, Not Humanity [52]	Humanity Must Be the Steward of God's Creation, Earth [38]-[40]
Nature v. Humanity	Changing Climate Is Due to Natural Variability [53] [54]	Changing Climate Is Due to Humanity [6] [55]
Economics v. Environment	It Costs Too Much Economically to Act [56]	It Costs Too Much Environmentally Not to Act [57]

(5) *Selective Exposure*: "How we sort ourselves into different information streams that reaffirm our core convictions…" ([15], p. 15).

These five psychological coping mechanisms can be summed up by the mid 20th century aphorism:

"My mind is made up. Don't confuse me with the facts."

But, as John Maynard Keynes is taken to have said:

"When the Facts Change, I Change My Mind. What Do You Do, Sir?"

As an example of such anti-dogmatism, about 25 years ago the lead author of this paper was a climate agnostic. After making the calculations of the Global Warming from 1990 through 2100 for 4 scenarios of future emissions for the first IPCC report in 1990 [16], Schlesinger and Ph.D. student Xingjian Jiang published the 1991 paper "Revised Projection of Future Greenhouse Warming" in *Nature* [17]. In this paper it was argued that studying the problem of Global Warming for 10 years before taking action posed only a small penalty = the ability to reduce the Global Warming in 2100 would be decreased by only 4%. *New York Times* reporter Bill Stevens wrote an article about this paper titled "Some Scientists See No Danger in a Decade's Delay in Curbs on Warming" [18]. In Steven's article then-Senator Al Gore commented: "The longer we wait, the harder the necessary actions become. He (Gore) said delay would be 'irresponsible' given the 'potential for disastrous consequences'." Subsequent research by the Climate Research Group at the University of Illinois at Urbana-Champaign and others taught the senior author of this paper that: (1) there is Global Warming, (2) it is due to humanity, and (3) it must be mitigated now.

So, Dear Reader, please "screw your courage to the sticking-place", subdue your psychological coping mechanisms, and keep your mind open to the evidence we present below.

We begin with our analysis of the observed record of global near-surface air temperature. This sets the stage for examining our Reference Case for future, unabated emission of greenhouse gases. We then consider the "80/50" Plan whereby it is proposed to reduce greenhouse—gas emissions 80% relative to a reference year by 2050. Finally we present our Fair Plan to Safeguard Earth's Climate. We conclude with a discussion of the need to make *Midcourse Corrections* to any chosen emission-reduction plan to keep it "on target".

2. Analysis of the Observed Global Temperature Record

Finding 1: The Earth has warmed by about 0.9˚C (1.6˚F) since 1850.

Figure 1 presents the observations of global-mean near-surface temperature departure compiled by the Hadley Centre (Exeter, England) and the Climate Research Unit of the University of East Anglia (Norwich, England) [19] (data points & black curve). There are three other such datasets, from NASA [20], NOAA [21] and the Japanese Meteorological Agency [22]. We analyzed the HadCRU dataset in our first 1994 Oscillation paper [23] and all four datasets in our 2012 Causes paper (Causes 2) [6]. Here we present only the HadCRU dataset because it begins in 1850, while the other three datasets begin later, in 1880, 1880 and 1893, respectively.

It can be seen in **Figure 1** that the temperature departures are negative in the early part of the record, and are positive in the later part of the record. This is because the temperature departures are from the average temperature for the 30-year period, 1961-1990. Why? Because temperature decreases with increasing altitude in the lowest layer of Earth's atmosphere—the troposphere—averaging temperatures from high-altitude stations with temperatures from low-altitude stations would produce a rather strange global-mean temperature. Accordingly, from the temperature data for each station is subtracted its 30-year average, 1961-1990, to produce the temperature departure for the station. The temperature departures from each station are then appropriately area weighted and averaged to obtain the global-mean near-surface temperature departure.

Figure 1 shows that the difference between the temperature departure at the end of the record in 2012 and the temperature departure at the beginning of the record in 1850 is about 0.9˚C (1.6˚F). We say "about" here because it is clear that there is a lot of variability in the record across this 162-year time period.

Finding 2: There are natural variations in global temperature, three of which are quasi-predictable on a year-to-year basis, and there is other variability that is not predictable yearly, but which can be characterized by the 90% confidence interval of its Normal (Gaussian) probability distribution.

We have performed *detection analyses* of the HadCRU temperature record in both our Oscillation [23] and

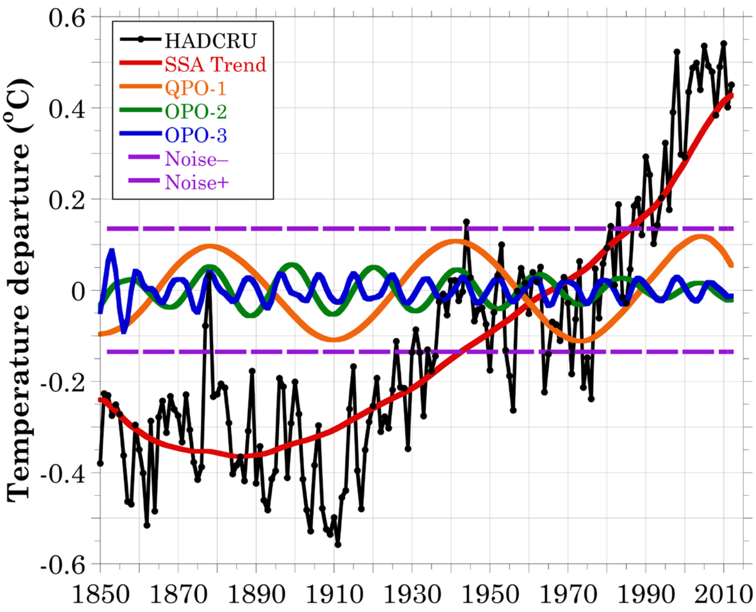

Figure 1. The observed global-mean near-surface temperature departure compiled by the Hadley Centre (Exeter, England) and the Climate Research Unit of the University of East Anglia (Norwich, England) [19] (data points & black curve). Singular Spectrum Analysis thereof finds a trend/oscillation (red line) and three Quasi-Periodic Oscillations that are quasi-predictable on a year-to-year basis (orange, green and blue curves). The remaining QPOs and stochastic noise can be represented by the 90% confidence interval for a Normal (Gaussian) probability distribution with zero mean and standard deviation of 0.11˚C (dashed purple lines).

Causes 2 papers [23]. *Detection analysis* determines what signals, if any, are in the data. To do this we use a modern form of signal analysis that was invented by Jean-Baptiste Joseph Fourier (1768-1830). (It is interesting to note that Fourier also wrote the first paper on the natural greenhouse effect in 1824 [24]). In classical Fourier analysis the time series shown in **Figure 1** would be projected onto trigonometric functions whose time-dependent amplitudes would be determined by the time series data. In modern Fourier analysis–Singular Spectrum Analysis (SSA), not only are the time-dependent amplitudes determined by the time series data, but so too are the functions onto which the time series data are projected [25]. This enhancement makes it possible to obtain statistically significant results with the modern Fourier method (SSA) that would not be statistically significant with the classical Fourier analysis.

Figure 1 shows that the HadCRU temperature data consist of: (1) a trend or oscillation (red curve); (2) three Quasi-Periodic Oscillations (QPOs, orange, green & blue lines) that are quasi-predictable on a year-to-year basis; and (3) other QPOs that are not predictable on a year-to-year basis but which, together with the residual stochastic variability, can be characterized by the 90% confidence interval of their Normal (Gaussian) probability distribution (band between the purple dashed lines) [10].

QPO-1 (orange curve) is the oscillation we discovered in our 1994 Oscillation paper [23]. It has a period of about 62.4 years and an amplitude of 0.11˚C. QPO-2 (green curve) has a period of about 21.0 years and an amplitude of 0.04˚C. QPO-3 (blue curve) has a period of about 9.1 years and an amplitude of 0.03˚C. There are additional QPOs that are not sufficiently regular to be quasi-predictable on an annual basis.

While SSA is a very powerful statistical tool, it is rather like a black box, obtaining all of its results at once and, thus, not providing a feeling for the data. Accordingly, we have analyzed the observed temperature record of **Figure 1** using the simplest statistical method, the Simple Moving Average (SMA). In SMA an average is taken over the first N (odd) data points of the time series and the result is placed at year (N+1)/2. Next the N-year window is moved forward one year, and the procedure is repeated. This is done to the end of the dataset. This procedure removes the variability with periods less than N years. It also "loses" the first and last (N–1)/2 data points. SMA is applied sequentially, step by step, from the largest N to the smallest N. In this way it is possible to sequentially see the signals that are in the dataset. We have done this in our Fair Plan 3 paper [7]. The results of the SMA are very close to those of SSA, the latter filling in the first and last (N–1)/2 data points "lost" by SMA. Thus, the simplest statistical tool, SMA, also reveals what is revealed in **Figure 1** by the most sophisticated statistical tool, SSA.

At this stage of the analysis, we cannot distinguish whether the red curve is a trend, created either by nature [26] or humanity, or an oscillation with a period at least twice that of the HadCRU dataset. To do so we must perform *attribution analysis*. But before doing so, we combine elements (1), (2) & (3) in **Figure 2** and compare the result with the observed temperature departures. The red curve therein is the sum of the trend/oscillation and QPOs 1, 2 and 3. The blue dashed lines are the red curve together with the 90% confidence interval of the Normal (Gaussian) probability distribution with a mean of zero and a standard deviation of 0.11˚C. It is seen that the *detection analysis* has successfully determined the signals in the HadCRU temperature data and that, therefore, there are no other signals therein.

Finding 3. The Global Warming is due to humanity, particularly due to the emission of greenhouse gases.

We now perform *attribution analysis* to determine whether the red curve in **Figure 1** is a trend–caused either by nature [26] or humanity, or an oscillation with a period at least twice the length of the HadCRU temperature record. To do this we could wait another 160 years to learn whether or not the red curve is an oscillation. But doing that would forgo humanity's ability to handle the Global Warming problem should the red curve not be an oscillation but rather a trend caused by humanity. Accordingly, we will now examine the *external radiative forcing*—the change in the net incoming radiation at the top of Earth's atmosphere—due to solar-irradiance variations and volcanoes, and due to humanity. A simple visual inspection of the former with the trend/oscillation (red curve) of **Figure 1** shows that they are not related. A similar inspection of the radiative forcing by humanity and the red curve of **Figure 1** shows they are very nearly the same. Recalling that the red curve in **Figure 1** excludes all the natural internal variability—the QPOs and stochastic noise—leads us to the conclusion that the red

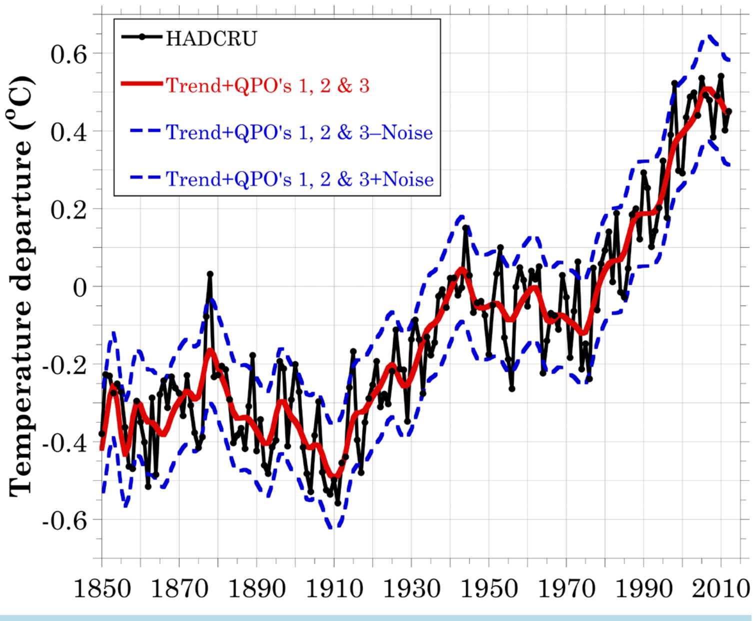

Figure 2. Reconstruction of the HadCRU observed temperature departures (dots and black curve) by the sum of the trend/oscillation and QPOs 1, 2 and 3 obtained by Singular Spectrum Analysis (red curve). The blue dashed lines are the red curve together with the 90% confidence interval of the Normal (Gaussian) probability distribution with a mean of zero and a standard deviation of 0.11˚C.

[1]An *Engineering-type Climate Model* reproduces the observed climate without explaining it. In this model quantities such as the ocean's upwelling velocity are prescribed rather than calculated. In contrast, a *Physics-type Climate Model*, such as a Global Climate Model (General Circulation Model), reproduces the observed climate by explaining it, that is, by simulating how it occurs. In this model quantities such as the ocean's upwelling velocity are calculated from "First Principles" (= fundamental Laws of Physics, e.g., Conservation of Mass, Conservation of Energy & Newton's Second Law of Motion, F = ma) rather than being prescribed.

curve in **Figure 1** is a trend, not an oscillation, a trend due to humanity, principally due to its emission of greenhouse gases. We will use our Engineering-type Climate Model[1] [27] to: (1) verify this conclusion, (2) estimate the climate sensitivity—the change in the equilibrium global-mean near-surface temperature due to the doubling of the preindustrial CO_2 concentration, and (3) determine the contributions to the observed Global Warming by: (a) the long-lived greenhouse gases (LLGHG's), (b) aerosols, (c) volcanoes, (d) QPO's, (e) stochastic noise and (f) other forcing.

Figure 3 presents the four radiative forcings due to humanity: (1) LLGHG's (green curve), (2) aerosols (blue curve), (3) tropospheric ozone (orange curve) (O_3), and (4) land-use changes (black curve). It can be seen that the radiative forcings due to LLGHG's and tropospheric ozone are each positive and the radiative forcings due to aerosols and land-use changes are each negative. It is evident that the total radiative forcing due to humanity is dominated by the radiative forcing due to LLGHG's.

Figure 4 presents the radiative forcing due to humanity (red curve), the sun and volcanoes (blue curve), and their sum (total, dashed black curve). The radiative forcing due to humanity shows a distinct trend while the radiative forcing by the sun and volcanoes does not. The trend in the total radiative forcing is due to the trend in the radiative forcing due to humanity. Comparing the SSA temperature trend in **Figure 1** with the radiative forcings in **Figure 4** shows that the observed Global Warming is not due to the sun and volcanoes.

Figure 5 presents the simulated global-mean temperature departures for radiative forcing by: (a) the sun and volcanoes (blue curve) and (b) humanity, the sun and volcanoes (total, dashed black line), in comparison with the SSA temperature departure trend of **Figure 1** (red curve). It is seen that the simulated global-mean temperature departures for radiative forcing by the sun and volcanoes bears no resemblance to the SSA temperature departure trend. In contrast, the simulated global-mean temperature departures for radiative forcing by humanity, the sun and volcanoes bears good resemblance to the SSA temperature departure trend. This is borne out by the coefficient of determination shown in **Table 2** for the HadCRU temperature dataset (leftmost column). For the radiative forcing by the sun and volcanoes, $R^2 = 0.05$; while for the radiative forcing by humanity, the sun and volcanoes, $R^2 = 0.84$. Similar coefficients of determination are obtained for the three other temperature datasets. From this we conclude that the trend in the observed global-mean near-surface temperature is not due to an oscillation with a period at least twice the length of the observational record, nor is it due to a trend caused by nature. Rather, the trend in the observed global-mean near-surface temperature is due to humanity.

Figure 6 shows the contributions of the long-lived greenhouse gases (LLGHGs, red bar), aerosols (blue bar), volcanoes (purple bar), QPOs (orange bar), stochastic noise (brown bar) and other (green bar) to the observed HadCRU temperature increase of 0.92˚C (black bar) from 1850 to 2010. There are three warming factors—

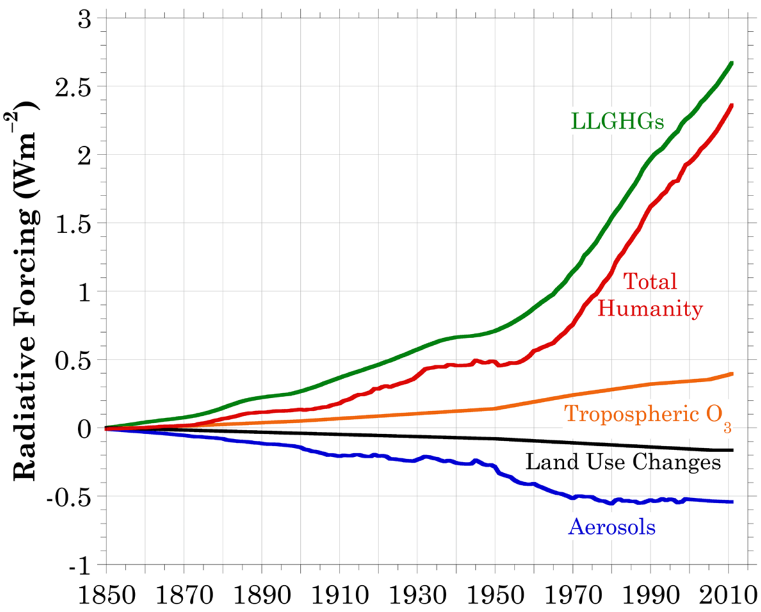

Figure 3. The total radiative forcing by humanity (red curve) due to: (1) Long-lived greenhouse gases (LLGHG's; green curve), (2) aerosols (blue curve), (3) tropospheric ozone (orange curve), and (4) land-use changes (black curve).

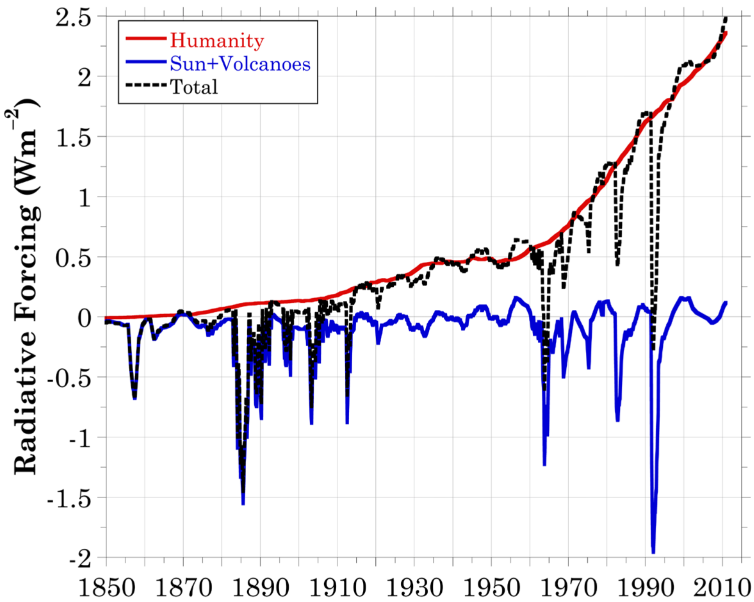

Figure 4. Radiative forcing due to humanity (red curve), the sun and volcanoes (blue curve), and their sum (total, black dashed line).

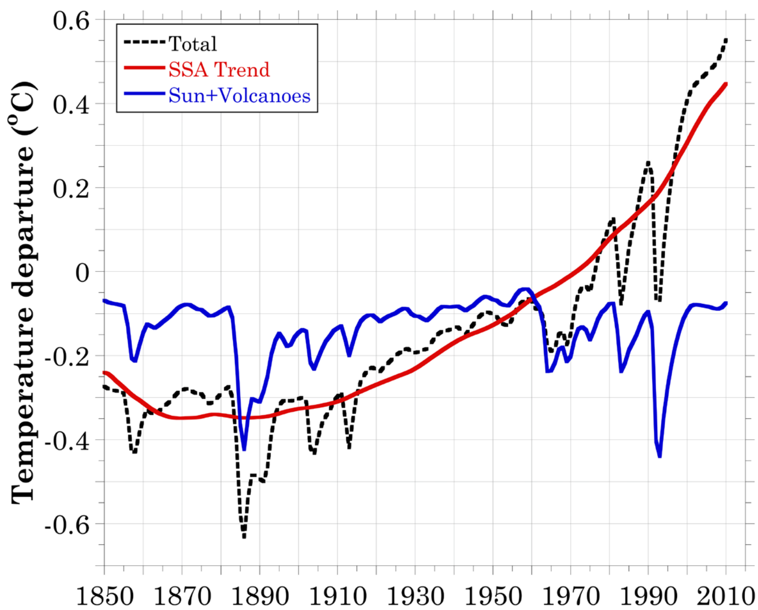

Figure 5. The simulated global-mean temperature departures for radiative forcing by: (a) the sun and volcanoes (blue curve) and (b) humanity, the sun and volcanoes (total, dashed black line), in comparison with the SSA temperature departure trend of **Figure 1** (red curve).

LLGHGs, QPOs and stochastic noise—and three cooling factors—aerosol, volcanoes and other—albeit the other is essentially zero, meaning that there is nothing unexplained in the overall warming. Clearly, the overall warming is due to the long-lived greenhouse gases, with the other positive and negative factors essentially cancelling each other. Accordingly, the Global Warming of the HadCRU observed temperatures from 1850 to 2010 is not due to a long-period oscillation or a natural trend, rather it is due to humanity. The same finding is found for the other three observed temperature datasets. Global Warming is due to humanity, not nature.

The values of the climate sensitivity—the change in the equilibrium global-mean near-surface temperature

Table 2. Climate sensitivity ΔT_{2x} and the coefficient of determination R^2 between the SSA-determined temperature trend for the four observed temperature datasets with the temperature changes simulated for: (a) solar and volcanic radiative forcing, and (b) total radiative forcing due to humanity, the sun and volcanoes.

Quantity	Observational Dataset			
	HadCRU [19]	NASA [20]	NOAA [21]	JMA [22]
ΔT_{2x} (˚C)	1.61	1.45	1.99	2.01
R^2, Simulated ΔT due to Solar & Volcanoes with SSA Trend	0.05	0.04	0.02	0.03
R^2, Simulated ΔT due to Humanity & Solar & Volcanoes with SSA Trend	0.84	0.94	0.92	0.90

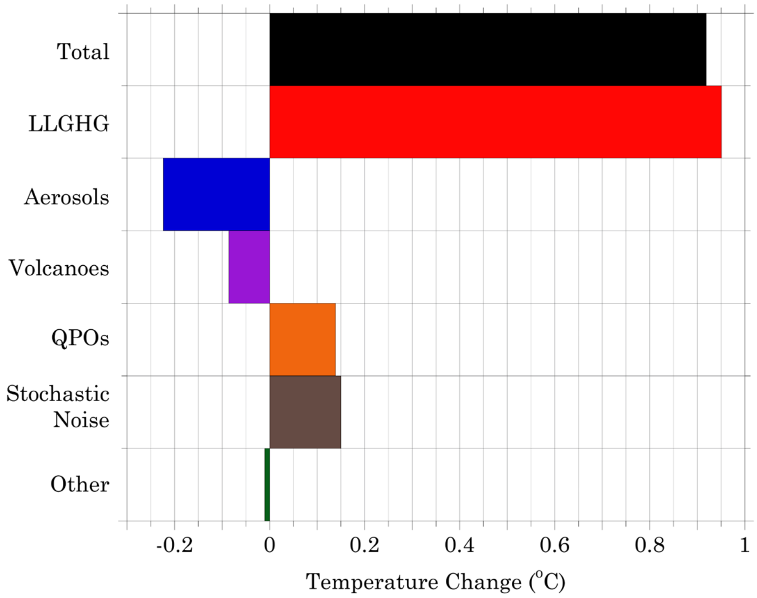

Figure 6. Contributions of each factor to the observed HadCRU temperature increase from 1850 to 2010.

due to the doubling of the preindustrial CO_2 concentration—obtained in our Causes 2 paper [6] for each of the four datasets using the total radiative forcing shown in **Figure 4** are shown in **Table 2**. These values range from 1.45˚C to 2.01˚C which are on the low side of the estimates that have been published since the so-called Charney report in 1979 [28]. This is not bad news, as some seem to think. Rather, as we shall see below, a smaller value of climate sensitivity gives humanity more flexibility to deal with the problem of anthropogenic global warming. But suppose future research revises the value of climate sensitivity upwards while we have based our climate-change policy on a lower value of climate sensitivity? The answer to this question is *Midcourse Corrections* to the policy. We shall return to this issue in our Conclusions.

Let us now look to Earth's climate future. We begin with the case that humanity unabatedly burns all the fossil fuel—coal, oil and natural gas—that Mother Nature has provided humanity.

3. No Emissions Reduction = the Reference Case

Finding 4. The unabated emission of greenhouse gases will return Earth's climate to that of the Late Eocene, 35 million years ago. Sea level then was 73 meters (240 feet) higher than today's sea level.

Figure 7 shows the emission of carbon dioxide (CO_2) for the Reference Concentration Plan 8.5 (RCP-8.5) greenhouse gas (GHG) emission scenario [29], which we take as our Reference case. This is the way the world would likely emit GHGs if either there were no consequent climate change or if we were completely ignorant-thereof. The RCP-8.5 was developed at the International Institute for Applied Systems Analysis in Laxenburg, Austria, to be one of four emission scenarios developed for the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) [30]. RCP-8.5 is the highest of these scenarios and leads to a radiative forcing of about 8.5 $W \cdot m^{-2}$ in 2100.

The emission of CO_2 under RCP-8.5 is shown by the red curve in **Figure 7**. The Reference case from 2101 through 2500 is the Extended Concentration Pathway 8.5 (ECP-8.5) [31]. Thereafter, through 3000, the emission rate is kept equal to its value in 2500. The CO_2 emission rises from about 37 billion tonnes of carbon dioxide per year (Gt CO_2/year) in 2010 to 106 Gt CO_2/year in 2100, remains essentially constant until 2150, and then decreases to 7.3 Gt CO_2/year in 2300, where it remains essentially constant throughout the remainder of the millennium.

We have used the simple carbon-cycle model of the Center for International Climate and Environmental Research—Oslo (CICERO) [32] to calculate the CO_2 concentrations from the CO_2 emissions (**Figure 8**). It should

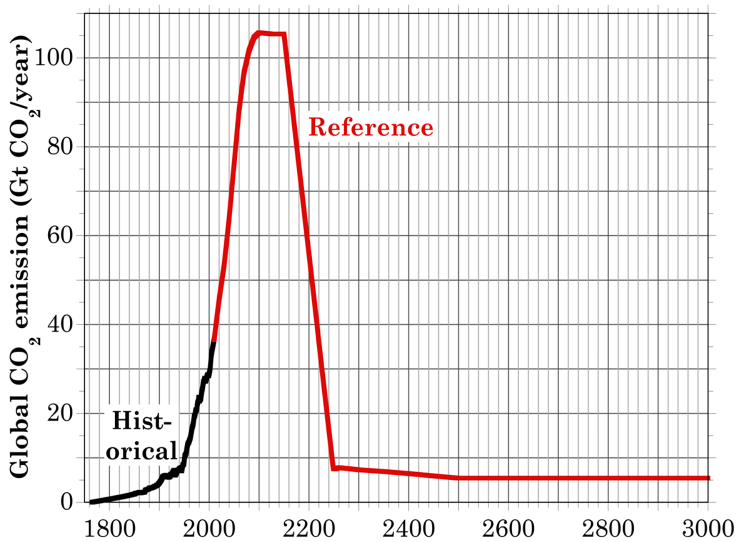

Figure 7. Historical (black curve) and future CO_2 emissions for the Reference case (red curve).

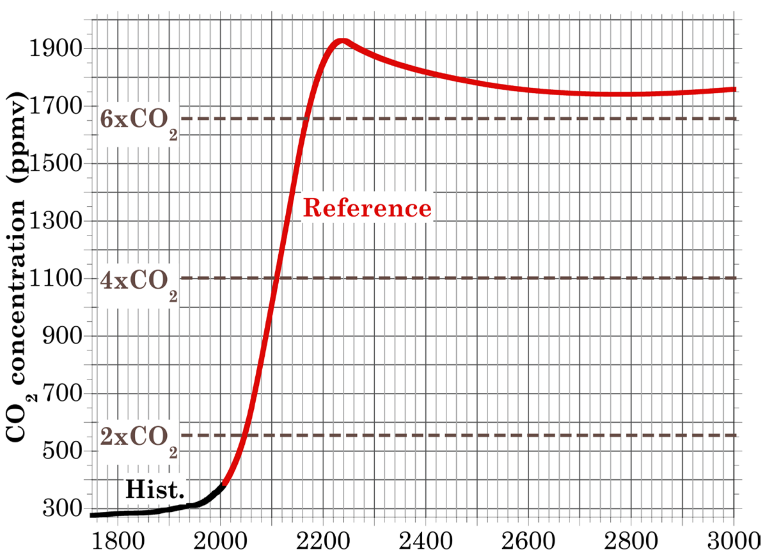

Figure 8. Historical (black curve) and future CO_2 concentrations for the Reference case (red curve). Two, four and six times the preindustrial CO_2 concentration are shown by the dashed brown lines.

be noted that this model does not include the positive ocean-CO_2-solubility/temperature feedback whereby the fraction of emitted CO_2 removed from the atmosphere by the ocean decreases with increasing temperature. Thus, *ceteris paribus*, our calculated CO_2 concentrations are underestimates of those with this positive feedback included.

Figure 8 shows the CO_2 concentration for the Reference case rises to 1928 ppmv in 2237 and then, as a result of the natural sinks (see FP6 [13]), decreases to about 1750 ppmv over the last 400 years of the third millennium, that is, more than six times the preindustrial concentration of 277 ppmv.

A CO_2 concentration of 1750 ppmv is about 500 ppmv larger than the CO_2 concentration was during the Late Eocene, 35 million years ago. Then there was no ice on Earth and sea level was 73 meters (240 feet) higher than at the beginning of the Industrial Revolution. Some of the coastal cities of the World that would be inundated by a sea-level rise of 66 meters (216 feet), based on a study by the National Geographic Society [33], are listed in **Table 3**. Clearly, this is an outcome that humanity should not create by continuing its unabated emission of greenhouse gases.

Finding 5. The human-caused Global Warming of the Reference case over the next two centuries will be comparable to, but 50 times faster than, the nature-caused Global Warming from the Last Glacial Maximum climate 21,000 years ago to the start of the Holocene interglacial climate 11,000 years ago.

We have used our engineering-type climate model to calculate the temperature change for the increasing CO_2 concentration shown in **Figure 8** and for the 39 other radiative forcing factors of the Reference case listed in **Table 4**. We have done this for each of the four estimated values of climate sensitivity shown in **Table 2**.

The expected value of the change in global-mean near-surface temperature is shown in **Figure 9**, taken as the arithmetic average of the four simulated temperature changes. In 2054 the Global Warming for the Reference case exceeds the 2˚C (3.6˚F) limit adopted by the UN Framework Convention on Climate Change (UNFCCC) "to prevent dangerous anthropogenic interference with the climate system" [34] and increases to 5.3˚C (9.5˚F) in 2240 where it remains for the remainder of the third millennium. This human-caused future Global Warming is comparable to the nature-caused past Global Warming from the Last Glacial Maximum climate of the Wisconsin ice age about 21,000 years ago to the succeeding Holocene interglacial climate 11,000 years ago [35] (page 435). Thus the human-caused future warming of the Reference case, if unabated, would be 50 times faster than the nature-caused past Global Warming from the last Ice Age to its successor non Ice Age.

Table 3. Some of the world's cities inundated by a sea-level rise of 66 meters (216 feet). These data are based on a study by the National Geographic Society [33].

Region	Coastal Cities Inundated
North America & Gulf of Mexico	Cancún, Veracruz, Havana, Houston, New Orleans, Miami, Tampa, Charleston, Norfolk, Washington, D.C., New York, Boston, San Diego
Western Europe	London, Brussels, Amsterdam, Copenhagen, Stockholm, Helsinki, St. Petersburg, Tallinn, Riga
Mediterranean & Black Seas	Venice, Istanbul, Odessa
Red Sea & India	Baghdad, Doha, Dubai, Karachi, Mumbai (Bombay), Kolkata (Calcutta)
Southeast Asia	Dhaka, Yangon (Rangoon), Bangkok, Kuala Lumpur, Jakarta, Singapore, Phnom Penh, Ho Chi Minh City
East Asia	Manila, Hong Kong, Shanghai, Beijing, Seoul, Tokyo
South America	Lima, Asuncion, Montevideo, Rio de Janeiro
Africa	Dakar, Freetown Monrovia, Lagos, Luanda, Maputo, Dar es Salaam
Australia & New Zealand	Perth, Adelaide, Melbourne, Sydney, Brisbane, Auckland, Wellington

Table 4. Radiative-forcing factors.

Greenhouse Gases	Aerosols	Other
CO_2, CH_4, N_2O, CFC11, CFC12, CFC113, CFC114, CFC115, CCl4, CH3CCl3, HCFC22, HCFC141b, HCFC123, HCFC124, HCFC142b, HCFC225ca, HCFC225cb, HCFC134a, HCFC125, HCFC152a, CF4, C2F6, SF6, H1211, H1301, H2402, CH3Br, HFC23, HFC143a, HFC32, HFC227, HFC245, C6F14, Tropospheric O_3	SO_2, Black carbon, Organic carbon	Solar irradiance variations, volcanoes, land-use changes

Finding 6. Humanity lives on a unique planet—"This Island Earth"—a Genesis world.

Earth is a unique planet, at least for trillions of miles in Space.

Figure 10 shows the temperatures of the planets of the Solar System. Two planets—Mercury and Venus—are too hot for life to exist there. Five planets—Mars, Jupiter, Saturn, Uranus and Neptune—and the now-dwarf planet—Pluto—are too cold for life to exist there. Life in the Solar System is possible only on "This Island Earth"—a *Genesis World*.

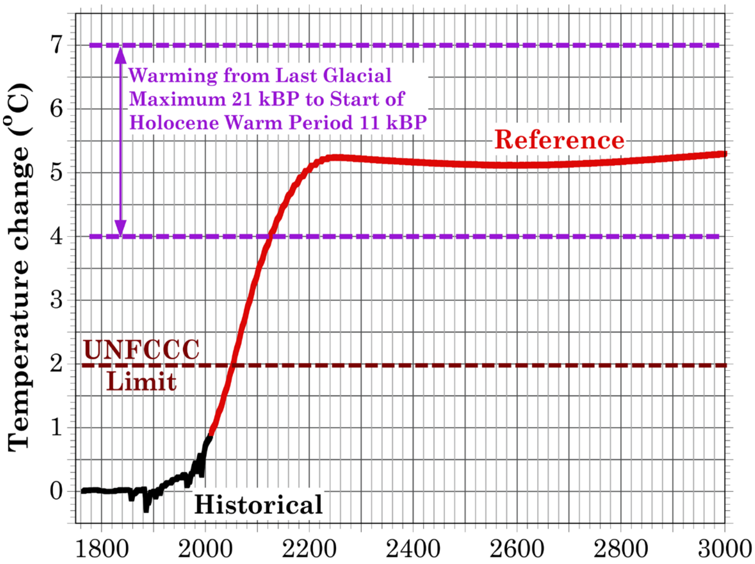

Figure 9. The change in global-mean near-surface temperature (Global Warming) from 1765 through 3000: Historical (black line) and Reference case (red line). The UN Framework Convention on Climate Change (UNFCCC) limit of 2˚C (3.6˚F) is shown by the dashed brown line. The estimated warming from Last Glacial Maximum 21,000 years before present (kBP) to the start of the Holocene warm period 11 kBP ([35], p. 435) is shown by the dashed purple lines.

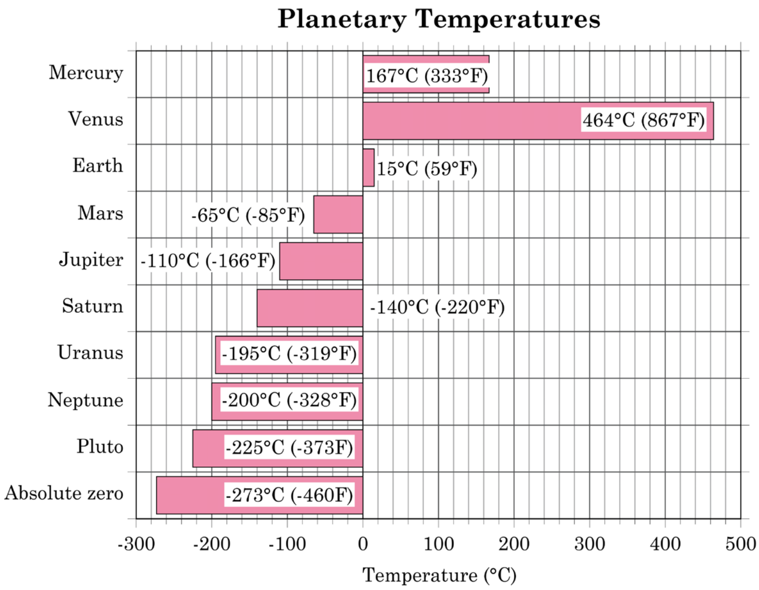

Figure 10. Temperatures of the planets of the Solar System. Source of data: NASA Planetary Fact Sheet [58].

The nearest star other than the Sun (*Sol*), the red-dwarf star *Proxima Centauri*, is 4.2 light years distant from Earth, that is, 25 trillion miles away. At the speed of the Voyager 1 spacecraft, which has departed the Sol(ar) System and is now travelling at 35,000 miles per hour relative to Earth, it would take humanity 80,000 years to reach *Proxima Centauri*.

There may be a planet orbiting another of the three stars of the Centauri system, the K-type main-sequence, orange-dwarf star *α Centauri B* [36], a planet within the so-called "Habitable Zone"—the region wherein liquid water can exist.

The Habitable Zone for *Sol* is the region between Venus and Mars. However, neither Venus nor Mars has liquid water on its surface. Why? Because being in the Habitable Zone is only a necessary condition for the existence of surface liquid water and life. Another necessary condition, and the one that is less well known and appreciated, is that a planet must have the right amount of greenhouse gases in its atmosphere. Of course both these necessary conditions are predicated on a planet's having water molecules.

The atmosphere of Venus has too much greenhouse gas—90 Earth atmosphere's worth of CO_2—with an enormous greenhouse effect of 506˚C (911˚F), almost twice as hot as your home oven can get, hot enough to melt lead! The atmosphere of Mars has too little greenhouse gas—1/160 of an Earth atmosphere's worth of CO_2—with a miniscule greenhouse effect of merely 2˚C (4˚F). Only Earth's atmosphere has the right amount of natural greenhouse gases—water vapor, CO_2 and ozone—with a greenhouse effect of 33˚C (59˚F), to be habitable.

Thus humanity's home planet is "This Island Earth" [37]—a Genesis World—remote from any other habitable world for at least 25 trillion miles and likely much farther. This remarkable reality means that humanity must take care of its one-and-only home planet, "This Island Earth". Humanity must be the Steward of *Genesis Planet Earth* [38]-[40].

Accordingly, we now turn our attention to two scenarios that mitigate the greenhouse-gas emissions of the Reference case: the 80/50 Plan and the Fair Plan to Safeguard Earth's Climate.

4. The 80/50 Plan

In the 80/50 Plan, greenhouse-gas emissions are reduced by 80% relative to a reference year by 2050. It appears that the "causality chain" for the 80/50 Plan is from the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4 (AR4) to the European Council to the EUCO2 80/50 project. According to the latter:

"The European Commission's ambitious objective manifests the intention to reduce the global CO2 emissions by 50% compared to 1990, by the year 2050. Only this can ensure that the average global warming does not exceed 2 degrees centigrade. This requires the industrialised countries to reduce their emissions by 80%, in order to compensate for the lower mitigation capacities of the developing countries, due to the backlog demands of their national economies." [41]

This notion appears on page 7 of the Presidency Conclusions–Brussels, 29/30 October 2009 of the European Council:

"The European Council calls upon all Parties to embrace the 2˚C objective and to agree to global emission reductions of at least 50%, and aggregate developed country emission reductions of at least 80-95%, as part of such global emission reductions, by 2050 compared to 1990 levels; such objectives should provide both the aspiration and the yardstick to establish mid-term goals, subject to regular scientific review. It supports an EU objective, in the context of necessary reductions according to the IPCC by developed countries as a group, to reduce emissions by 80% - 95% by 2050 compared to 1990 levels." [42]

This notion apparently arose from Table SPM.5 "Characteristics of post-TAR stabilization scenarios" (Category A.1) of the Summary for Policymakers of the Fourth Assessment Report (AR4) of Working Group 3 (WG3) of the Intergovernmental Panel on Climate Change (IPCC) [43], and Table 3.10 (Class I) and Figure 3.38 of Chapter 3 of AR4 of IPCC WG3 [44]. These tables show that to limit global warming to 2.0˚C - 2.4˚C requires emissions reductions below 2000 values of 85% - 50% in 2050.

The 80/50 Plan has been proposed as the emissions reduction plan for the United States in H.R.5271, the Healthy Climate and Family Security Act of 2014 [45]. The 80/50 Plan was also implicit in the emissions reduction cited in the White House press release of 11 November 2014 about the U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation [30].

Finding 7. If the post-2100 global greenhouse-gas emissions of the 80/50 Plan are kept at their 2100 values, Global Warming will be stabilized only for the 21st century; thereafter Global Warming increases

continuously throughout the 3rd millennium.

In the 80/50 Plan we examine here, global greenhouse-gas emissions are reduced by 80% relative to a reference year—taken here to be 2020—by 2050 and are then held constant throughout the remainder of the 21st century as shown by the blue curve in **Figure 11** for CO_2 emissions. Thereafter the global CO_2 emissions are kept at their 2100 value.

The CO_2 concentration for the 80/50 Plan, shown by the blue curve in **Figure 12**, remains approximately constant throughout the 21st century, with a mean value of 463 ppmv. Indeed, as explained above, it is because of this near constancy of the CO_2 concentration throughout this century that the 80/50 Plan has been proposed. But if the global CO_2 emission of the 80/50 Plan is continued beyond the 21st century at its value in 2100, the CO_2 concentration ceases to remain constant and instead increases throughout the millennium to 834 ppmv in year 3000, nearly three times the preindustrial value.

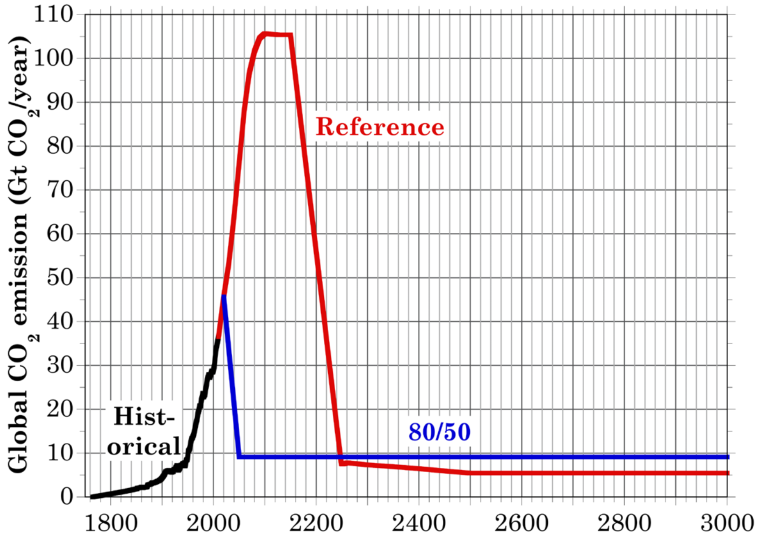

Figure 11. Historical (black curve) and future CO_2 emissions for the Reference case (red curve) and 80/50 Plan (blue curve).

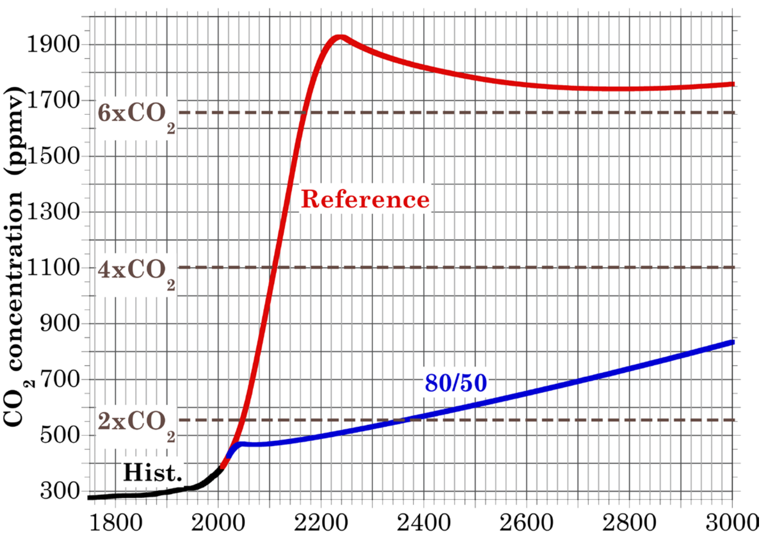

Figure 12. Historical (black curve) and future CO_2 concentrations for the Reference case (red curve) and 80/50 Plan (blue curve). Two, four and six times the preindustrial CO_2 concentration are shown by the dashed brown lines.

The Global Warming for the 80/50 Plan, shown by the blue curve in **Figure 13**, decreases from 1.45˚C (2.61˚F) in 2048 to 1.31˚C (2.36˚F) in 2087. As shown in FP6 [13], this decrease in Global Warming is due to: (1) the rapid decrease in methane emission from 2020 to 2050, (2) the 8.7 ± 1.3 year lifetime of methane in the Earth's atmosphere [46] (page 541), both of which cause a rapid decrease in the methane concentration, and (3) methane's high global-warming potential—72 on a 20-year timescale [46] (Table 2.14, page 212). The Global Warming for the 80/50 Plan increases throughout the remainder of the millennium, exceeding in 2596 the 2˚C (3.6˚F) limit adopted by the UNFCCC "to prevent dangerous anthropogenic interference with the climate system" [34], and rises to 2.7˚C (4.8˚F) in year 3000.

5. Fair Plan to Safeguard Earth's Climate

Finding 8. A Fair Plan to Safeguard Earth's Climate has been crafted that reduces the emissions of greenhouse gases much more slowly than the 80/50 Plan and keeps Global Warming below the 2˚C (3.6˚F) maximum Global Warming chosen by the UN Framework Convention on Climate Change (UNFCCC) "to prevent dangerous anthropogenic interference with the climate system".

As stated in the Introduction, Climate Naysayers want to do nothing forever about climate change while some Climate Aye-Sayers want to do too much too soon. Following the Climate Naysayers leads to the Reference case; following the Climate Aye-sayers leads to the 80/50 Plan.

The Reference case of unabated emissions returns Earth's climate back to that of the Late Eocene when sea level was 73 meters (240 feet) higher than today. The human-caused Reference case causes Global Warming that is comparable in size to the nature-caused Global Warming between the Last Glacial Maximum 21,000 years ago and the start of the Holocene Interglacial 11,000 years ago. The human-caused Global Warming of the Reference case occurs 50 times faster than that nature-caused Global Warming. Climate Aye-sayers will not accept the Reference case of the Climate Naysayers.

The 80/50 Plan controls Global Warming through the 21st century but thereafter, if emissions are kept at their 2100 value, Global Warming resumes and exceeds the UNFCCC's 2˚C (3.6˚F) limit within two centuries. Moreover, as shown below, the 80/50 Plan reduces emissions faster than they need to be reduced to stay beneath the 2˚C (3.6˚F) UNFCCC limit. Climate Naysayers will not accept the 80/50 Plan of the Climate Aye-sayers.

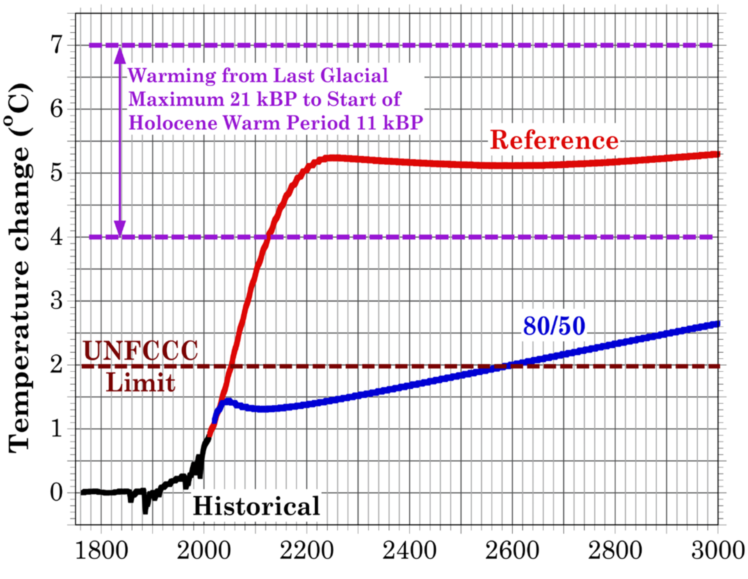

Figure 13. The change in global-mean near-surface temperature (Global Warming) from 1765 through 3000: Historical (black line), Reference case (red line) and 80/50 Plan (blue curve). The UN Framework Convention on Climate Change (UNFCCC) limit of 2˚C (3.6˚F) is shown by the dashed brown line. The estimated warming from Last Glacial Maximum 21,000 years before present (kBP) to the start of the Holocene warm period 11 kBP ([35], p. 435) is shown by the dashed purple lines.

Is this impasse hopeless or is there a middle ground where Climate Naysayers and Climate Aye-sayers can reach a compromise? In 2011 we attempted to craft such a compromise plan, the Fair Plan to Safeguard Earth's Climate. The Fair Plan [9] was designed to satisfy three objectives:

Objective 1: The cumulative trade-adjusted CO_2 emissions by the developing countries equal the cumulative trade-adjusted CO_2 emissions by the developed countries. Trade-adjusted emissions mean the emissions incurred by country A to export goods and/or services to country B are debited to country B, not country A.

Objective 2: The maximum global warming above preindustrial temperature does not exceed the 2˚C (3.6˚F) chosen by the United Nations Framework Convention on Climate Change (UNFCCC) "to prevent dangerous anthropogenic interference with the climate system" [34].

Objective 3: The phaseout of CO_2 and other greenhouse-gas emissions is begun as late as possible in the 21st century and proceeds at the slowest possible pace, consistent with Objectives 1 and 2, to minimize the disruption of the global economy.

In the Fair Plan to Safeguard Earth's Climate, the emission of greenhouse gas $(GHG)_i$ in year y is

$$E_{j,i}(y) = E_{Ref,i}(y)\cdot I_j(y);\ y \ge y_S;\ j = AB, nAB;\ i = 1,34; \tag{1}$$

where y_s is the start year of the phaseout of emissions, and AB and nAB are the so-called Annex B (Developed) Countries and non-Annex B (Developing) Countries [47]. The 34 GHGs included are listed in **Table 4**, together with the three aerosols that are phased out together with the GHGs, and three other radiative-forcing factors.

The emission intensity for AB countries is

$$I_{AB}(y) = \begin{cases} 1-\left(\dfrac{y-y_S}{D}\right), & y = y_S,\cdots,y_E \\ 0, & y > y_E \end{cases} \tag{2}$$

where y_E is the end year of the phaseout of emissions, and $D = y_E - y_S$ is the duration of the phaseout in years.

The emission intensity for nAB countries is

$$I_{nAB}(y) = \begin{cases} 1-\left(\dfrac{1-aD^3}{D}\right)(y-y_S) - a(y-y_S)^3, & y = y_S,\cdots,y_E \\ 0, & y > y_E \end{cases} \tag{3}$$

In our original Fair Plan paper (FP1) [8], we prescribed $y_S = 2015$ and $D = 50$ years. In our second Fair Plan paper (FP2) [9], we examined: (1) $y_S = 2015$ to 2030 in 5-year increments for $D = 50$ years (**Figure 14**), and (2) $D = 50$ to 100 years in 10-year increments for $y_S = 2020$ (**Figure 15**).

Figure 14 shows that as y_S is delayed from 2015 to 2030, the emissions intensity for non-AB countries flattens out and approaches the emissions intensity for AB countries. Because of this, as y_S is delayed from 2015 to 2030, the emissions-intensity trajectory for developing countries must become more aggressive in the early years of the Fair Plan, while becoming less aggressive during its later years. We found that the maximum global temperature increases as y_S is delayed from 2015 to 2030, and for $y_S > 2020$ exceeds the UNFCCC's 2˚C limit for the climate sensitivity needed to reproduce the NOAA temperature observations, which is the largest estimated climate sensitivity estimated in our Causes 2 paper [6] (**Table 2**). Accordingly we chose $y_S = 2020$. This is also the starting year chosen by the UNFCCC [48].

Figure 15 presents the GHG emissions intensity for AB and non-AB countries for phaseout periods of 50, 60, 70, 80, 90 and 100 years, each for a starting year of 2020. It can be seen that as the phaseout period increases, the emissions-intensity curve for the non-AB countries flattens out and approaches the straight line of the emissions-intensity curve for the AB countries. The two curves are almost indistinguishable for the phaseout period of 90 years. For the phaseout period of 100 years, the emissions-intensity curve for the non-AB countries lies below the emissions-intensity curve for the AB countries. This occurs because by the end of the 100-year phaseout period, the Reference case emissions for the non-AB countries greatly exceed the Reference case emissions for the AB countries. This argues for a short phaseout period rather than a long phaseout period.

How long a phaseout period can be chosen and still meet the UNFCCC's 2˚C maximum-warming threshold?

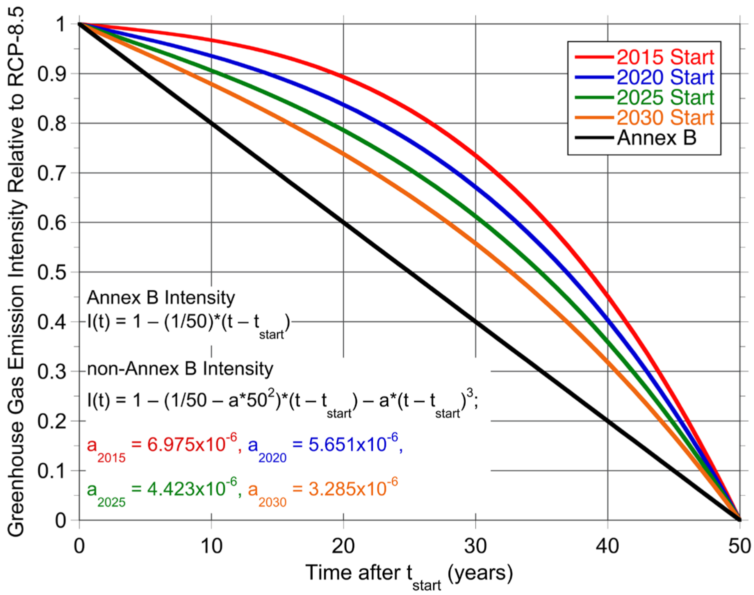

Figure 14. The greenhouse-gas emissions intensity for Annex B (black line) and non-Annex B (non-black curves) countries relative to the Reference case for the 50-year phaseouts of 2015-2065, 2020-2070, 2025-2075 and 2030-2080.

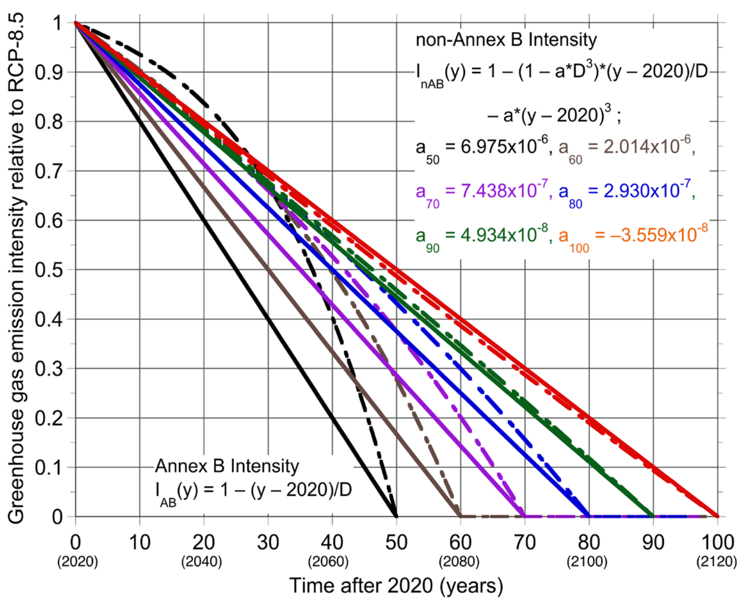

Figure 15. The greenhouse-gas emissions intensity for Annex B (solid) and non-Annex B (dashed) countries relative to the Reference case for phaseout periods of 50 years (black), 60 years (brown), 70 years (purple), 80 years (blue), 90 years (green) and 100 years (red).

We estimated this in FP2 [9] from the dependence of the cumulative CO_2 emissions on phaseout period and the dependence of the maximum global warming on cumulative emissions, the latter for the HadCRU results for the 50-year phaseout beginning in 2015, 2020, 2025 and 2030. We found that a 2˚C maximum warming would occur for global cumulative emissions of 2321 Gt CO_2, and that this would occur for a phaseout period of 78.3 years. Accordingly, we chose a phaseout period of 80 years, that is, from 2020 to 2100.

Figure 16 presents the emissions trajectories for the AB countries (black curves) and the nAB countries (red curves) for both the 80-year phaseout period (solid curves) and 50-year phaseout period (dashed curves) of the original Fair Plan of FP1 [8]. It can be seen that the increase in phaseout period from 50 to 80 years increases: (1) the cumulative emissions from 1667 to 2362 Gt CO_2; (2) the peak emission slightly, from 19.1 Gt CO_2/year to 21.7 Gt CO_2/year for AB, and from 29.09 Gt CO_2/year to 29.12 Gt CO_2/year for nAB; and (3) the year of peak emission from 2015 to 2030 for AB, and from 2042 to 2053 for nAB. Thus the number of years from peak emission to zero emission increases from 50 years to 70 years for AB, and from 23 years to 47 years for nAB. Accordingly, the increase in phaseout period from 50 to 80 years allows an increase in peak emission for AB, and an increase in the duration of increasing emission for both AB and nAB. It also allows a much more gradual phaseout of emissions for both AB and nAB.

The global annual CO_2 emissions for the Fair Plan are shown in **Figure 17** (green curve), together with the global annual CO_2 emissions of the Reference case (red curve) and 80/50 Plan (blue curve). The CO_2 emissions

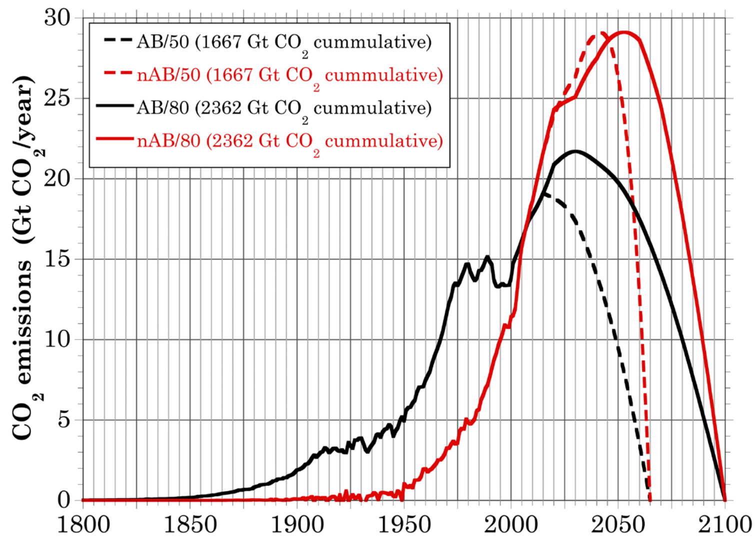

Figure 16. The CO_2 emissions trajectories for Annex B (black curves) and non-Annex B (red curves) countries for the 80-year phaseout period (solid) in comparison with the 50-year phase out period (dashed), both starting in 2020.

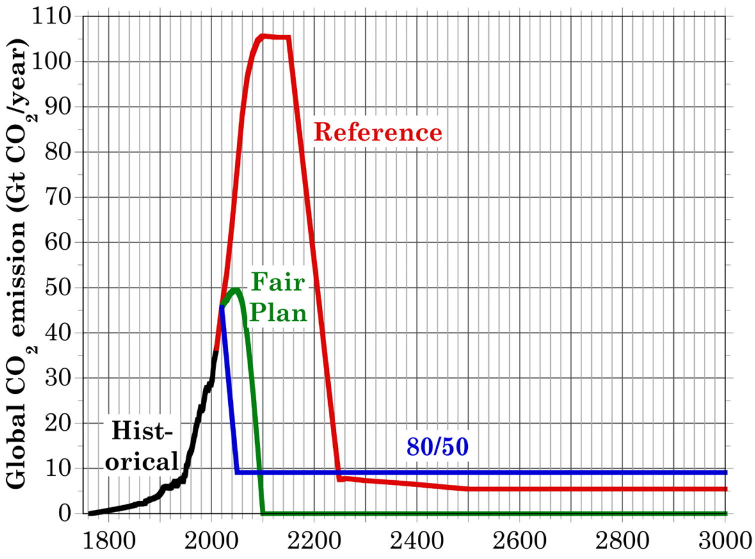

Figure 17. Historical (black curve) and future CO_2 emissions for the Reference case (red curve), 80/50 Plan (blue curve) and the Fair Plan (green curve).

for the Fair Plan increase slowly from 45.6 Gt CO_2 in 2020 to 49.5 Gt CO_2 2046, and thereafter decrease to zero in 2100.

Figure 18 shows the CO_2 concentration for the Fair Plan (green curve), together with the CO_2 concentrations of the Reference case (red curve) and 80/50 Plan (blue curve). The CO_2 concentration for the Fair Plan rises to 612 ppmv in 2087, a bit more than twice the preindustrial CO_2 concentration of 554 ppmv, and then decreases to 406 ppmv by the end of the third millennium.

The Global Warming for the Fair Plan is shown in **Figure 19** (green curve), together with the GW for the

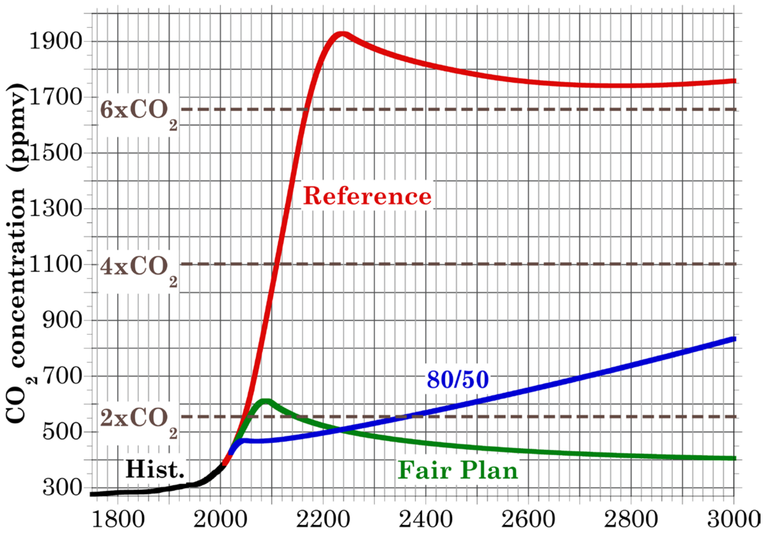

Figure 18. Historical (black curve) and future CO_2 concentrations for the Reference case (red curve), 80/50 Plan (blue curve) and Fair Plan (green curve). Two, four and six times the preindustrial CO_2 concentration are shown by the dashed brown lines.

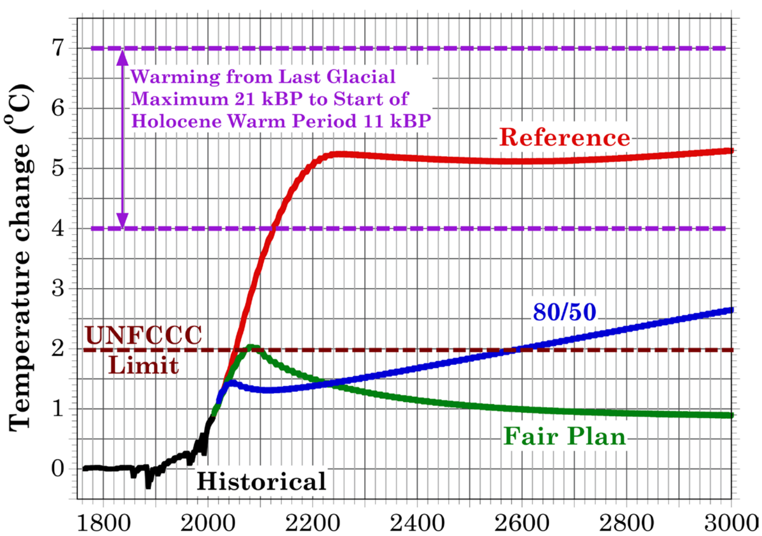

Figure 19. The change in global-mean near-surface temperature (Global Warming) from 1765 through 3000: Historical (black line), Reference case (red line), 80/50 Plan (blue curve) and Fair Plan (green curve). The UN Framework Convention on Climate Change (UNFCCC) limit of 2˚C (3.6˚F) is shown by the dashed brown line. The estimated warming from Last Glacial Maximum 21,000 years before present (kBP) to the start of the Holocene warm period 11 kBP ([35], p. 435) is shown by the dashed purple lines.

Reference case (red curve) and 80/50 Plan (blue curve). The GW for the Fair Plan peaks at 2.04˚C (3.7˚F) in 2082, just above the 2˚C (3.6˚F) UNFCCC limit, and decreases throughout the remainder of the millennium to 0.9˚C (1.6˚F) in year 3000. Accordingly we believe that the Fair Plan to Safeguard Earth's Climate is superior to the 80/50 Plan.

6. Conclusions

Finding 9. Regardless of which Plan is chosen such that Global Warming does not exceed the 2˚C (3.6˚F) maximum Global Warming chosen by the UN Framework Convention on Climate Change (UNFCCC) "to prevent dangerous anthropogenic interference with the climate system", Midcourse Corrections should be made as needed to achieve the climate target.

As written in the **Introduction**:

"If you don't know where you are going, no road will take you there."

In this paper we have presented two roads to take us there = reduce greenhouse-gas emissions to prevent Global Warming from exceeding the 2˚C (3.6˚) limit adopted by the UN Framework Convention on Climate Change "to prevent dangerous anthropogenic interference with the climate system".

One road—the 80/50 Plan—takes us there in 30 years, from 2020 to 2050. The other road—the Fair Plan to Safeguard Earth's Climate—takes us there in 80 years, from 2020 to 2100. It is humanity's choice whether or not to safeguard Earth's climate, and if so, how.

It may seem reasonable to try to find the "optimum plan" to achieve the UNFCCC objective of keeping Global Warming below 2˚C (3.6˚F). However, as François-Marie Arouet—a.k.a. Voltaire—correctly noted: "Le mieux est l'ennemi du bien" = "The best is the enemy of the good". What is essential now is to BEGIN to reduce emissions of greenhouse gases, no later than 2020, as documented in FP2 [9].

Regardless of the policy selected to begin by 2020, it must be re-evaluated periodically and Midcourse Corrections made thereto as needed. We and our colleagues have made this point about sequential adaptive decision making multiple times during the past quarter century, for example in [49]-[51].

As an analog, think of our now 9-year-old *New Horizons* mission to Pluto and the Kuiper belt beyond (!) Did we launch the *New Horizons* spacecraft toward Pluto and then in effect say *Bon Voyage*, call us when you get there and we will then receive your data? No, of course not. We tracked *New Horizons*, compared her position to where she needed to be to get to Pluto, and made Midcourse Corrections thereto as needed to guide her safely within 12,875 km (8000 miles) of Pluto on Bastille Day (14 July) 2015.

We must do likewise with the "New Horizons spacecraft" of our climate-change policy so that it reaches our "Pluto target" of not exceeding the 2˚C maximum global warming adopted by the UNFCCC at COP16 in Cancun in December 2010.

Evaluations of the need for such Midcourse Corrections should be made at least once per decade throughout the 21st century.

As a concrete example, recall that Objective 3 of the Fair Plan was to choose its start year y_s and duration D to be as late and long as possible, consistent with Objectives 1 and 2, this to maximize the likelihood of buy-in by all parties in the UNFCCC. Suppose however that future observations indicate that climate sensitivity is larger than the values used herein, shown in **Table 2**, which were estimated in our Causes 2 paper [6]. Then a Midcourse Correction can be made to the emissions intensity of the Fair Plan, shown in Equations (1)-(3), to keep the climate-change trajectory on target.

If this we do not do, then humanity will have abrogated its responsibility to be a Good Steward of our one-and-only *Genesis Home Planet*, *This Island Earth*.

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