



Social change to avert further climate change: defining the scale of change and principles to guide a new strategy

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The inability of the international community so far to materially affect the trend in anthropogenic emissions demonstrates the urgent need to formulate an effective response to the threat of climate change. We offer a detailed picture—disaggregated by country—of the social changes necessary to reduce the rate and risk of climate change. We recognize two broad types of social change—changes that either reduce energy intensity or reduce carbon intensity. Through the Kaya identity, we demonstrate that the current business as usual scenario expects a carbon concentration of approximately 660 ppm by 2100, which corresponds to a potentially catastrophic 4.9°C temperature increase. Through a low-carbon-emissions scenario built on principles used by the Center for Energy and Environmental Policy over the past 20 years, we show the social changes required to realize a hopefully sustainable 450 ppm carbon dioxide concentration with an equitable 3.3 ton/capita annual carbon emissions budget. We conclude that all members of the international community—even Non-Annex 1 members—face major and immediate challenges in any common effort to address climate change. Our analysis supports exploratory efforts for the formulation of menus of social change. As a preliminary basis for identifying such menus of social change, we suggest priority be given to bottom-up discourses that position the principles of sustainability, equity, development autonomy, and justice at the core of decision-making. © 2012 John Wiley & Sons, Ltd.

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INTRODUCTION

In 2011, the atmospheric concentration of carbon dioxide (CO₂) reached 390 ppm, 40% higher than its preindustrial 278 ppm level. After 17 meetings of the Conference of the Parties (COP-17) to the UN Framework Convention on Climate Change, the world's political and business leaders have found no means to materially affect the trend in anthropogenic emissions or atmospheric concentrations of CO₂. Indeed, the only proven 'tools' for deeply cutting emissions since 1992, when the UN Conference on Environment and Development began the international odyssey to find paths of cooperation

in lowering climate risk, are nation-state collapse (notably, the break up of the Soviet Union and the accompanying decline in its emissions and those of countries aligned with it) and the 'great recession' of 2008–present. These are hardly the approaches to a low-carbon future, which will enlist enthusiasm for the task of addressing arguably the greatest environmental challenge ever faced by human civilization.

Diverse reasons for international failure have been offered by many (including, e.g., Refs 1–4). No doubt there are accurate explanations, which may help us to understand why we have not succeeded. But obviously, the greater need is to understand how we can respond effectively to this threat. The research community has been less helpful in this task. Indeed, some work suggests we need to begin again with 'post-Kyoto' thinking.^{5–7}

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In this paper, we offer a detailed picture of the social changes necessary to reduce the rate and risk of climate change. The picture is drawn in a manner that can define social change of, broadly, two types—those that reduce carbon intensity of human activity (mostly, these are changes in the mix of energy sources to power societies around the world) and those that reduce energy intensity (mostly, i.e., changes in the rate of energy consumption by human beings in different parts of the world). The picture is highly aggregate and further research is required to define more clearly what each menu of human activity might include by region/country. But we hope it is a useful start.

In the conclusion to this paper, we discuss a new strategy that acknowledges, on the one hand, 18 years of international policy and market failure and, on the other, that we can describe only sketches for action. It is not a satisfactory definition of a new strategy but it is what we are able to present in the aftermath of nearly two decades of little or no social change.

METHODOLOGY FOR ESTIMATION OF FUTURE CO₂ CONCENTRATION LEVELS

Several models have been developed to estimate future CO₂ concentration levels, ranging in complexity from the sophisticated Atmosphere–Ocean General Circulation Models (AOGCMs) and Earth System Modeling of Intermediate Complexity to Simple Climate Models (SCMs).^{8,a} AOGCMs are considered to be the most comprehensive and are designed to provide the best representation of the climate system. They require large-scale computing capability and utilize among the largest, detailed data sets found in any field. By contrast, SCMs emulate AOGCMs but without the large data requirement and processing complexity.^{9,10} SCMs are computationally more efficient and can be used to project future climate change in response to different global greenhouse gas (GHG) emission scenarios. Such projections would be impractical with AOGCMs.^{9,11}

SCMs characterize the exchanges of CO₂ between the atmosphere, oceans, and terrestrial biosphere, where the latter two serve as primary sinks. One of the widely used SCM models is the Bern carbon cycle–climate model.^b The Bern model was used for CO₂ scenario calculations in the Intergovernmental Panel on Climate Change (IPCC) Second, Third, and Fourth Assessment Reports (see Refs 12–15). The mathematical representation of the Bern model is well documented (see Refs 16–19). The model can be represented by the following carbon budget equation:

represented by the following carbon budget equation:

$$\Delta p\text{CO}_{2,a} = F_{\text{fossil}} + F_{\text{land-use}} - F_{\text{as}} - F_{\text{ab}} \quad (1)$$

$\Delta p\text{CO}_{2,a}$ represents an annual change in global average CO₂ concentration (i.e., a change in partial pressure of CO₂). F_{fossil} is annual CO₂ emissions from fossil fuel combustion and cement production, $F_{\text{land-use}}$ is annual CO₂ emissions from land-use change. F_{as} and F_{ab} are the uptake of excess CO₂ by the ocean and the land biosphere, respectively. All units in Eq. (1) are expressed in ppm per year (1 ppm equals to 2.123 billion tons of carbon or 7.779 billion ton of CO₂).

Global F_{fossil} can be obtained from the Carbon Dioxide Information Analysis Center (CDIAC) of the Oak Ridge National Laboratory or from the U.S. Energy Information Administration.^{20,21} Global $F_{\text{land-use}}$ is also reported by CDIAC.²²

F_{as} can be expressed as a function of the global average gas exchange coefficient $K_g = (9.06 \text{ years})^{-1}$ and the difference in perturbations of partial pressures of air and surface ocean water ($\delta p\text{CO}_{2,a}$ and $\delta p\text{CO}_{2,s}$) from a preindustrial level (of 280 ppm):

$$F_{\text{as}} = K_g(\delta p\text{CO}_{2,a} - \delta p\text{CO}_{2,s}) \quad (2)$$

$\delta p\text{CO}_{2,a}$ and $\delta p\text{CO}_{2,s}$ can be written as:

$$\delta p\text{CO}_{2,a} = p\text{CO}_{2,a} - 280 \text{ ppm} \quad (3)$$

$$\delta p\text{CO}_{2,s} = p\text{CO}_{2,s} - 280 \text{ ppm} \quad (4)$$

In the mixed-layer pulse response function model, $\delta p\text{CO}_{2,s}$ can be as Joos et al.^{16,17} propose:

$$\begin{aligned} \delta p\text{CO}_{2,s} = & (1.5568 - 1.3993T_0 \times 10^{-2})\delta \sum \text{CO}_2 \\ & + (7.4706 - 0.20207T_0) \times 10^{-3}(\delta \sum \text{CO}_2)^2 \\ & - (1.2748 - 0.12015T_0) \times 10^{-5}(\delta \sum \text{CO}_2)^3 \\ & + (2.4491 - 0.12639T_0) \times 10^{-7}(\delta \sum \text{CO}_2)^4 \\ & - (1.5468 - 0.15326T_0) \times 10^{-10}(\delta \sum \text{CO}_2)^5 \end{aligned} \quad (5)$$

T_0 represents preindustrial global ocean surface temperature ($T_0 = 18.2^\circ\text{C}$). $\delta \sum \text{CO}_2$ is a perturbation in dissolved inorganic carbon in the surface ocean, which can be calculated from the following equation:

$$\delta \sum \text{CO}_2 = \frac{c}{hA_{\text{oc}}} \int_{t_0}^t F_{\text{as}}(t')r_s(t-t')dt' \quad (6)$$

h is the mixed-layer depth ($h = 75 \text{ m}$), A_{oc} is the global ocean area, and $A_{\text{oc}} = 3.62 \times 10^{14} \text{ m}^2$. The constant c is a conversion factor ($c = 1.722 \times 10^{17} \mu\text{mol m}^3/\text{ppm/kg}$) and r_s is the mixed-layer impulse

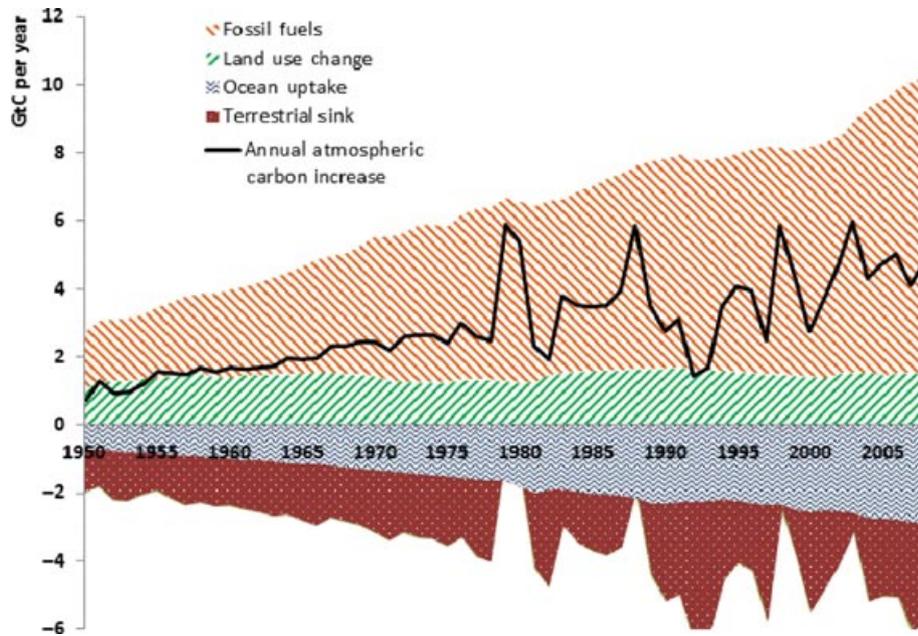


FIGURE 1 | The Global Carbon Budget from 1950 to 2008. Data Source: Emissions are from Ref 20. Land-use change flux data are from Ref 22. Annual atmospheric increase of carbon is from CDIAC database. Ocean-to-atmosphere flux and the residual terrestrial sink were calculated by CEEP based on the Bern model described above.

TABLE 1 | Global Carbon Budget (GtC per Year)

	1990–1999		2000–2005		1990–2008
	IPCC AR4 ¹	CEEP ²	IPCC AR4 ¹	CEEP ²	CEEP ²
Atmospheric increase	3.2	3.2	4.1	4.2	3.5
1. Emissions (fossil + cement)	6.4	6.4	7.2	7.3	7.0
2. Net ocean-to-atmosphere flux	–2.2	–2.3	–2.2	–2.6	–2.5
3. Net land-to-atmosphere flux	–1.0	–0.9	–0.9	–0.5	–1.0
3a. Land-use change flux	1.6	1.6	n.a. ³	1.5	1.5
3b. Residual terrestrial sink	–2.6	–2.5	n.a. ³	–2.0	–2.5

¹From Ref 24.

²Using the Bern model, the CEEP estimates can be compared in detail with the Second, Third, and Fourth Assessment Reports of the IPCC. Because each report built a baseline for different time period, comparisons in the table are reported for concurring estimation periods for AR4.

³Data not available.

response, which can be obtained from the following equation:

$$\begin{aligned}
 &\text{For } 0 \leq t \leq 2 \text{ years: } r_s(t) = 0.12935 \\
 &\quad + 0.21898 \exp(-t/0.034569) \\
 &\quad + 0.17003 \exp(-t/0.26936) \\
 &\quad + 0.24017 \exp(-t/0.96083) \\
 &\quad + 0.24093 \exp(-t/4.9792) \\
 &\text{For } t \geq 2 \text{ years: } r_s(t) = 0.022936 \\
 &\quad + 0.24278 \exp(-t/1.2679) \\
 &\quad + 0.13963 \exp(-t/5.2528) \\
 &\quad + 0.089318 \exp(-t/18.601) \\
 &\quad + 0.037820 \exp(-t/68.736) \\
 &\quad + 0.035549 \exp(-t/232.30)
 \end{aligned} \tag{7}$$

where t is the time elapsed from the initial release of carbon to the ocean.

The final variable in Eq. (1) is F_{ab} . It is often defined as a residual terrestrial sink, and it is the least understood variable in the carbon budget equation^{23,24}

Using the Bern model and data for fossil fuels, cement production, and land-use change from the CDIAC database, the global carbon budget for 1950–2008 was estimated by researchers of the Center for Energy and Environmental Policy (CEEP) (see Figure 1).

The obtained values were compared with the IPCC’s Fourth Assessment report (see Denman et al.²⁴) and very close results were found (see Table 1).

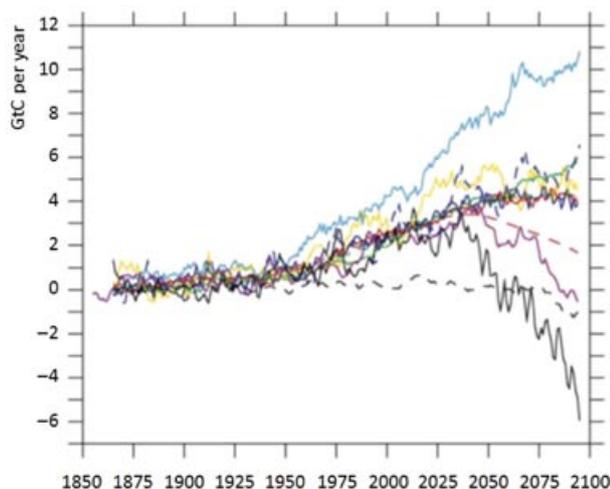


FIGURE 2 | Estimated and projected terrestrial carbon sink. (Reprinted with permission from Ref 27. Copyright 2006, American Meteorological Society.)

Major sources of carbon emissions (notably emissions from fossil fuels, cement production, and land-use change) can be modeled on the basis of well-defined social, economic, and policy assumptions. But in addition to these ‘societal’ factors, forecasts of future CO₂ concentration require modeling of emissions uptake by oceans and land (i.e., terrestrial sink). While significant challenges exist, ocean uptake can be assessed through SCMs. There is a larger uncertainty over the terrestrial sink mechanism. The terrestrial sink has large year-to-year variability, with its volume ranging from 0.3 to 5 GtC per year.^{25,26} Based on past observations, it is evident that the terrestrial sink has increased over time.^{27,28} During the past three decades, Gurney and Eckels²⁸ estimate that the terrestrial sink increased by an average of 0.057 GtC per year. The increase is mostly attributed to photosynthetic proficiency of the earth’s terrestrial vegetation under higher atmospheric carbon concentration.^{25,26}

Future volumes of the terrestrial sink are difficult to predict. However, it is understood that future increases in the terrestrial sink would be limited and in the next few decades it will most likely level off and might decline afterwards.^{15,26,29,30} Figure 2 presents projections of the future terrestrial sink. From the 11 models assessed by Friedlingstein et al.,²⁹ most show that natural carbon store will gradually increase from its current 2.5 GtC per year and will level off at around 5 GtC per year by the end of the century. These models assume atmospheric CO₂ concentration at the end of the 21st century within the range of 700–1000 ppm.

Sitch et al.³⁰ have estimated change in terrestrial uptake under the IPCC’s high-emissions (A1FI) and low-emissions (B1) scenarios. Under the high-emissions scenario, terrestrial uptake is highly variable across different models ranging from a 3 GtC increase above the current level to a decrease of 3 GtC. For the low-emissions scenario, the terrestrial sink for all models remains near the current levels. Following the above-mentioned projections,^{29,30} we assume that under the business as usual (BAU) scenario, carbon uptake from land would increase from 2.5 GtC per year to 5 GtC by 2100, and under the CEEP’s low-carbon scenario, the residual sink will remain at 2.5 GtC for the analysis period.

The BAU Scenario for Carbon Emissions From Fossil Fuels

In its First Assessment Report published in 1990, the IPCC produced several long-term GHG emissions scenarios. In 1992, the body released a suite of global scenarios (IS92), which covered GHG emissions under a wide range of population, economy, technology innovation, and policy assumptions. In 2000, in the preparation of its Third Assessment Report, the IPCC published the Special Report on Emissions Scenarios (SRES). The SRES initiative gathered input from science and other expert communities worldwide. The report contained 40 scenarios, which were created by six modeling teams. These scenarios were grouped into four ‘storylines’ referred to as ‘families’. These storylines and associated scenario families captured the range of physical impacts associated with alternative assumptions about global social, technological, economic, and policy trends.³¹

The A1 scenario family describes a future with rapid economic growth and global population that peaks in mid-century and declines thereafter. Its subgroups map changes in the world energy system—a fossil intensive path (A1FI), a path with increasing reliance on nonfossil energy sources (A1T), or a path with a balanced mix of fossil and nonfossil sources (A1B). Under the A2 scenario family, economic growth is regionally concentrated and population increases throughout the 21st century. The B1 scenario family describes a world with rapid change in economic structures, toward a service and information economy, and with the same population trends as in the A1 scenario. The B2 scenario family emphasizes local solutions for economic, social, and environmental sustainability, where the global population continually grows but at a rate lower than trends in A2. In the B2 family, intermediate levels of economic development coincide with less rapid and more

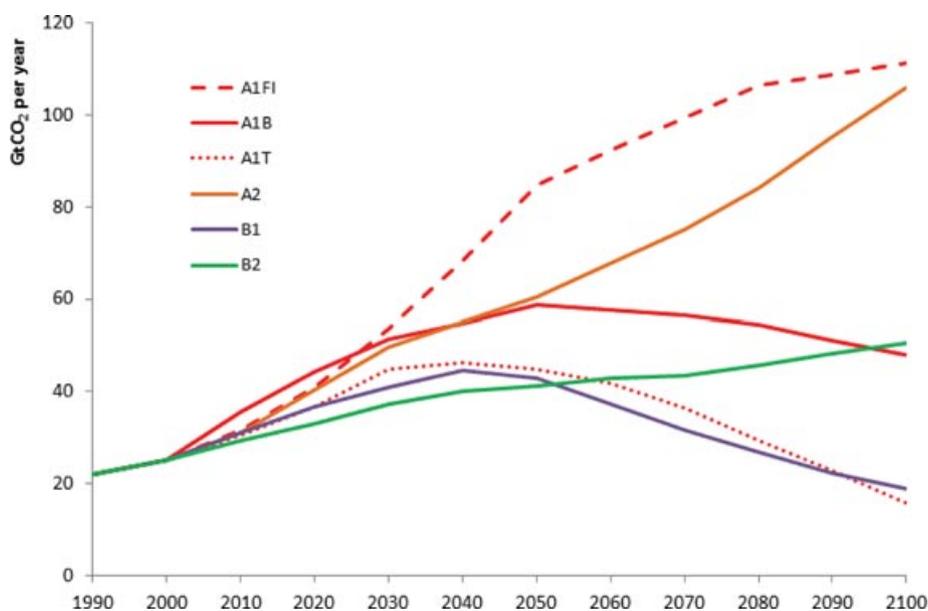


FIGURE 3 | Carbon dioxide emissions from fossil fuels under SRES Scenarios. (Reprinted with permission from Ref 37. Copyright 2000, Cambridge University Press.)

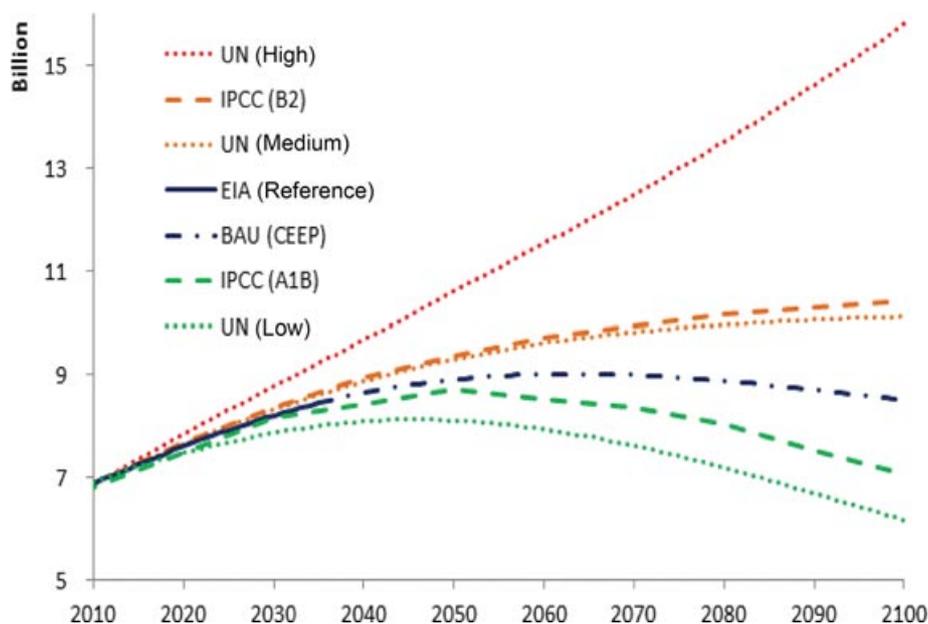


FIGURE 4 | Global population projections. Data Sources: Refs 21,31,33,34.

diverse technological change than in the A1 and B1 storylines.³¹

The IPCC report highlighted six scenarios across the story lines: A1FI, A1T, A1B, A2, B1, and B2.³¹ Figure 3 shows CO₂ emission from fossil fuels under the six highlighted SRES scenarios.

From Figure 3, it is possible to group these scenarios as ‘high-emissions’ (A1FI and A2), ‘low-emissions’ (A1T and B1), and ‘moderate-emissions’

scenarios (A1B and B2). The IPCC has not assigned any weight on its scenarios in terms of likelihood. For policy impact analysis, it is useful to build a BAU scenario, which can represent a baseline for estimating emission reduction targets. In building our BAU scenario, we used a combination of medium-emission scenarios A1B and B2. For this task, CO₂ emissions from fossil fuel burning were disaggregated using the Kaya identity,⁶ which can be represented by the

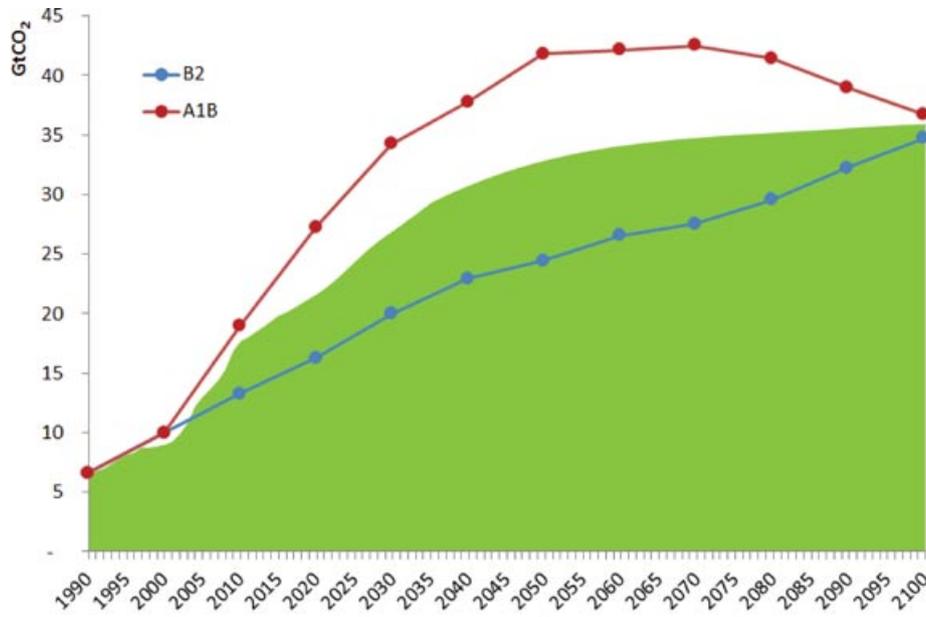


FIGURE 5 | CO₂ emissions for major Non-Annex 1 countries under the CEEP’s BAU scenario.

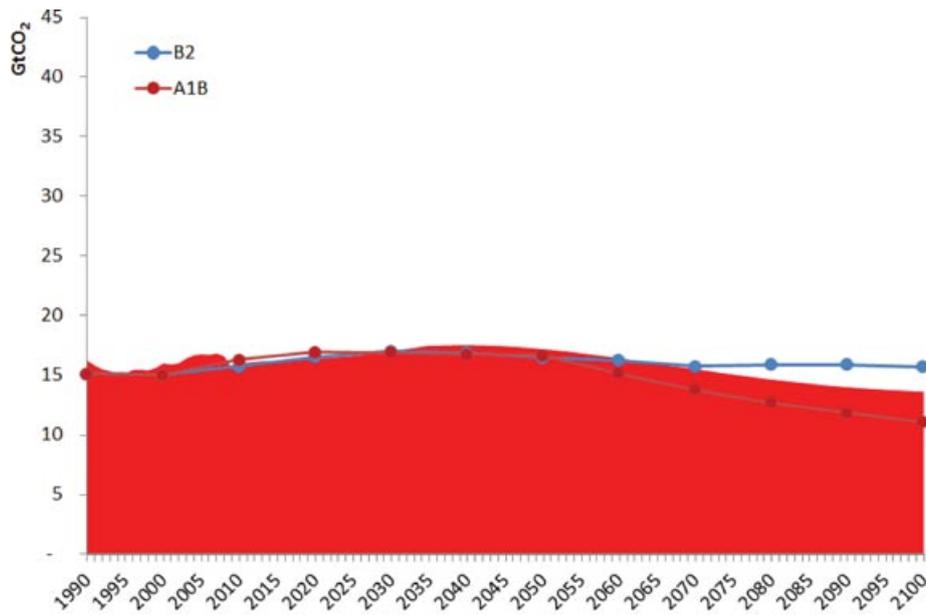


FIGURE 6 | CO₂ emissions for Annex 1 countries under the CEEP BAU scenario.

following formula:

$$C = \frac{C}{E} \frac{E}{GDP} \frac{GDP}{POP} POP \quad (8)$$

where C is annual carbon emissions, E is primary energy consumption, GDP is gross domestic product expressed in constant dollars through market exchange rates or purchasing power parity,^d and POP is pop-

ulation. $\frac{C}{E}$ represents the carbon content in energy supply, $\frac{E}{GDP}$ is the world economy’s energy intensity, and $\frac{GDP}{POP}$ represents global per capita income. Change in carbon emissions is the combined result of these three factors. Equation (8) can be also represented in a double logarithmic form:

$$\ln(C) = \ln\left(\frac{C}{E}\right) + \ln\left(\frac{E}{GDP}\right) + \ln\left(\frac{GDP}{POP}\right) + \ln(POP) \quad (9)$$

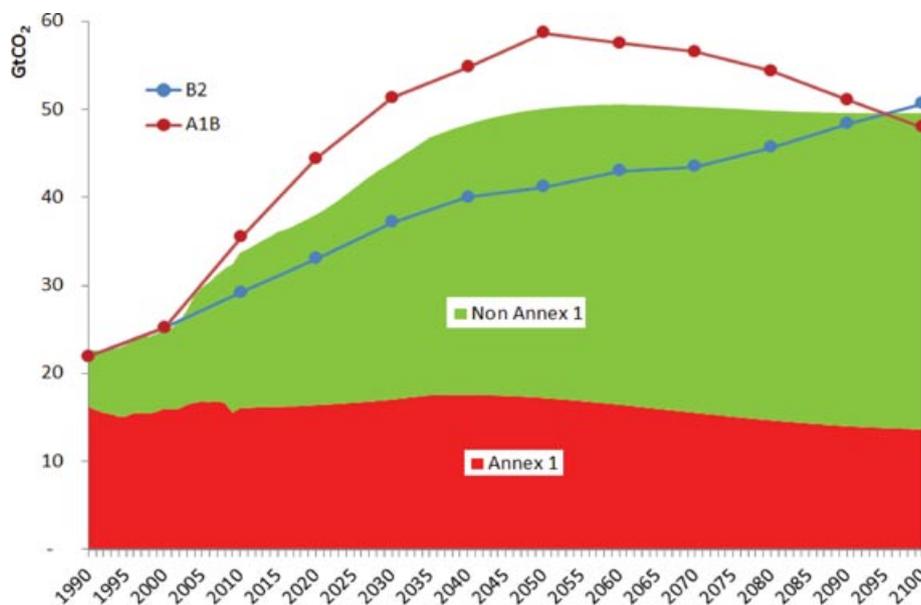


FIGURE 7 | Global CO₂ emissions from fossil fuels under the CEEP BAU scenario.

From Eqs. 8 and 9, it is clear that a projection of future carbon emissions requires assumptions regarding future demographic, social–economic, and technological change.

The IPCC did not forecast carbon emissions for individual countries. Instead, the SRES menu provides emissions projections for four regional groups: (1) Organisation for Economic Co-operation and Development (OECD) countries; (2) Economies in Transition (includes Russia and other ex-Soviet republics and Eastern Europe); (3) Asia (includes China and India); and (4) Latin America, Africa, and Middle East.⁹ Thus, SRES scenarios cannot be directly used for building disaggregated emissions projections for major economies such as the United States, OECD Europe, Japan, China, India, and Russia. To address this limitation, at first, we use the US Energy Information Administration's (EIA) recent projections covering carbon emissions from fossil fuels from 2010 through 2035 for these countries.³² EIA projections prove to be a compatible choice because the global CO₂ emissions path in the EIA forecast lies between A1B and B2 scenarios for the period of 2010–2035 (see Figure 7).

EIA projections report fossil fuel emissions for major countries (e.g., the United States, Japan, China, and India) and regions (e.g., OECD Europe, Africa, and Middle East). However, the EIA forecast covers only 25 years. To project carbon emissions from fossil fuels beyond 2035 for individual countries, we utilized relations presented in Eq. 9 above. For pop-

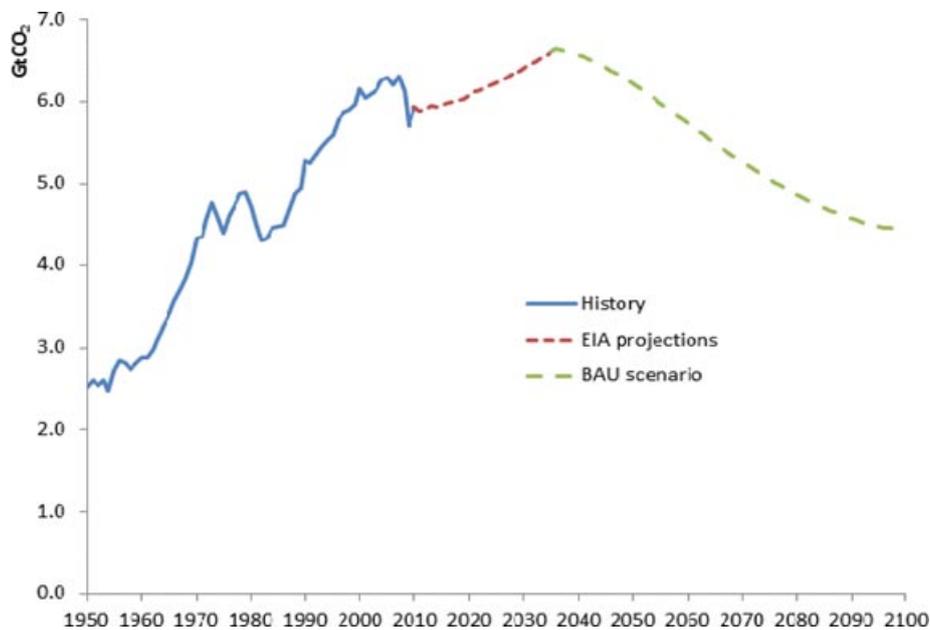
ulation projections, global population values under A1B and B2 were converted to logarithmic form. These two values were summed and divided by 2 to get an average. The results were converted back to normal values using an exponential function. To obtain population projections for selected countries and regions, population forecasts by the United Nations' Population Office for its medium- and low-population scenarios³³ were then used to conform with the average A1B and B2 population projections. For comparison, please see Figure 4.

For carbon intensity (C/E), energy intensity (E/GDP), and per capita income (GDP/POP), we used a similar methodology. At first, we converted values to logarithmic form for both the A1B and B2 scenarios. After taking an average of these values, resulting values were converted back using an exponential function. This process was repeated for the four groups used by IPCC to build its SREC storylines. Obtained average values for per capita income, energy intensity, and carbon intensity (all expressed in logarithmic form) were used to project carbon emissions for individual economies (resulting values for 2100, after the US EIA projections for 2035 were plotted—see Table 2).

CO₂ emissions for Non-Annex 1 countries, Annex 1 countries, and a combined global emissions total are presented in Figures 5, 6, and 7, respectively. Individual emission profiles for each major economy (i.e., the United States, OECD Europe, Japan, China, India, and Russia) are presented in Figures 8–13.

TABLE 2 | Key Parameters for CEEP's BAU Scenario Development for Major Economies

	CO ₂ Intensity (g/MJ)			Energy Intensity (MJ/\$)			\$2005)		
	2010	2035	2100	2010	2035	2100	2010	2035	2100
United States	54.70	52.38	29.30	7.79	4.68	2.88	42.57	65.98	113.03
OECD Europe	48.75	43.02	29.30	5.46	4.02	2.88	27.97	42.48	113.03
Japan	49.67	43.29	29.30	4.80	4.61	2.88	36.02	46.91	113.03
Russia	51.74	46.65	26.78	34.97	19.88	4.26	6.44	15.07	86.06
Other Annex 1	52.76	48.09	28.04	13.98	9.13	3.57	12.44	23.21	99.54
China	74.87	66.56	30.39	28.80	14.16	3.36	2.85	9.84	63.16
India	76.56	70.19	30.39	20.50	11.59	3.36	1.01	2.93	45.11
Other Non-Annex 1	54.79	51.87	25.82	14.94	9.62	4.19	2.81	5.49	43.41

**FIGURE 8** | U.S. CO₂ emissions under the CEEP BAU Scenario.

Figures 14 and 15 show per capita CO₂ emissions for major Annex 1 and Non-Annex 1 economies.

Land-Use Change

As noted earlier, land-use change^f is a major factor influencing atmospheric carbon storage, as well as emissions. The IPCC estimates carbon emissions from land-use change to fall within a range of 0.5–2.7 GtC per year with 1.6 GtC being the mid-point.³⁵ CDIAC estimates carbon emissions at 1.4–1.5 GtC per year (see Ref 22). The IPCC's SRES estimate of carbon emissions from land-use change in 2010 is within the range of 0.8–1.2 GtC per year, and future estimates widely vary among six scenarios (see Figure 16). However, all SRES scenarios project a decline in carbon emissions from land-use change after 2030.

The International Energy Agency (IEA) in its World Energy Outlook³⁶ also makes assumptions

regarding future net emissions from the land-use change. According to IEA projections, emissions from land-use change will decline from 1.42 GtC in 2009 to 1.17 GtC in 2020 and further decline to 0.52 GtC by 2035 (an average of 0.035 GtC reduction per year during 2009–2035). If emissions from this source would continue to decline at the same rate, it will virtually disappear as a net carbon source by 2050. Half of the SRCC scenarios also show land-use change emissions become negative after 2050. For our analysis, we use IEA projection rate for land-use change, and we assume emissions will decline after 2035 by 0.035 GtC per year until 2050 when net emissions from land-use change will be zero.

Carbon Concentration

Combining projected data for carbon emissions from fossil fuels, land-use change, and the terrestrial sink

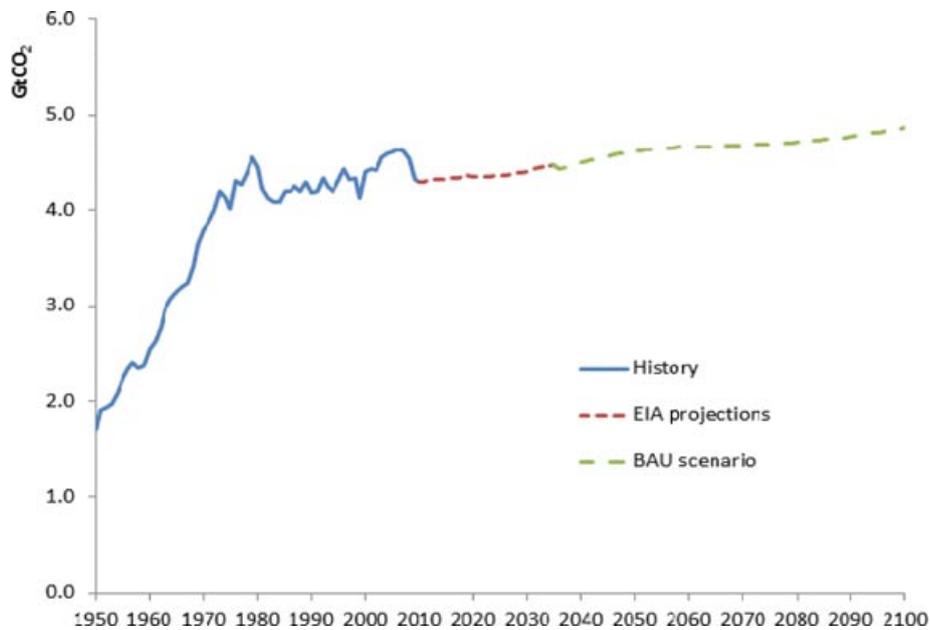


FIGURE 9 | OECD Europe's CO₂ emissions under the CEEP BAU scenario.

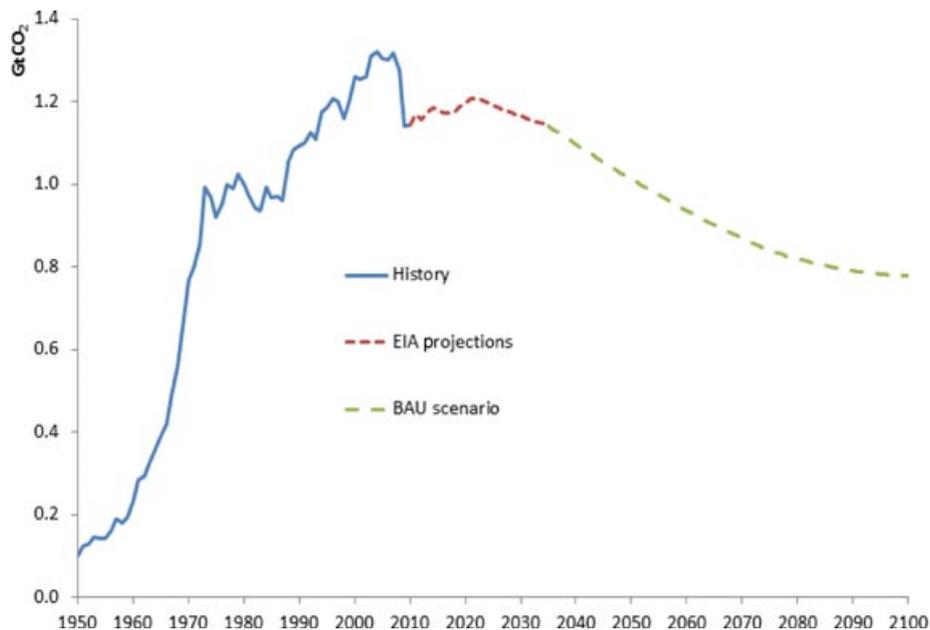


FIGURE 10 | Japan's CO₂ emissions under the CEEP BAU Scenario.

and applying the Bern model methodology (described above) to the data we reported above, an atmospheric carbon concentration profile was obtained—see Figure 17.

From Figure 17, it is clear that our BAU scenario expects a continuously growing annual release rate of carbon and a carbon concentration of approximately 660 ppm by 2100. Even if carbon concentration sta-

bilized at 660 ppm, based on the findings reported in IPCC assessments, this level of carbon concentration would correspond to 855 ppm when other GHGs are included in CO₂ equivalent. At this level of concentration, the IPCC reports a research consensus that global mean temperature increases by 4.9°C above its preindustrial level (see Table 3). A temperature increase of such a magnitude could be catastrophic. To

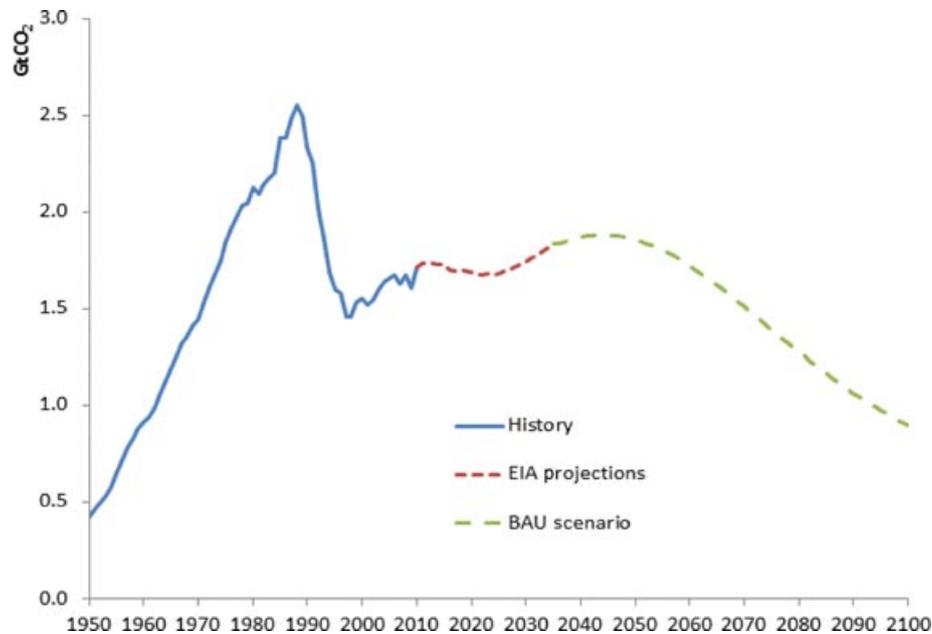


FIGURE 11 | Russia's CO₂ emissions under the CEEP BAU Scenario.

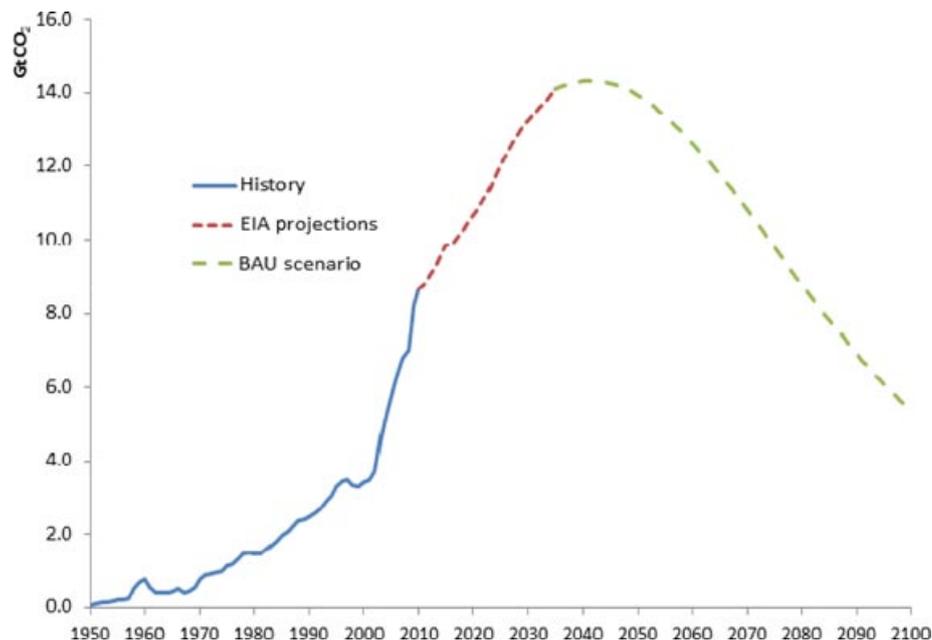


FIGURE 12 | China's CO₂ emissions under the CEEP BAU scenario.

avoid this, global carbon emissions from the energy sector should follow a significantly different path than the BAU case.

Many in the climate research field agree that temperature increases of 2°C above the preindustrial level could significantly increase sea level and lead to major biodiversity losses (see Refs 37–39). To avoid a temperature increase above 2°C, GHG

concentrations should not exceed 450 ppm CO₂-eq (this level approximately corresponds to 350 ppm of CO₂, see Table 3). As we have already surpassed this level (the current CO₂ concentration is approximately 390 ppm), stabilization of GHGs at this low level would be extremely difficult and might necessitate negative emissions.^{g,38,40–43} According to 177 scenarios reviewed by the IPCC,³⁸ only six (ones with

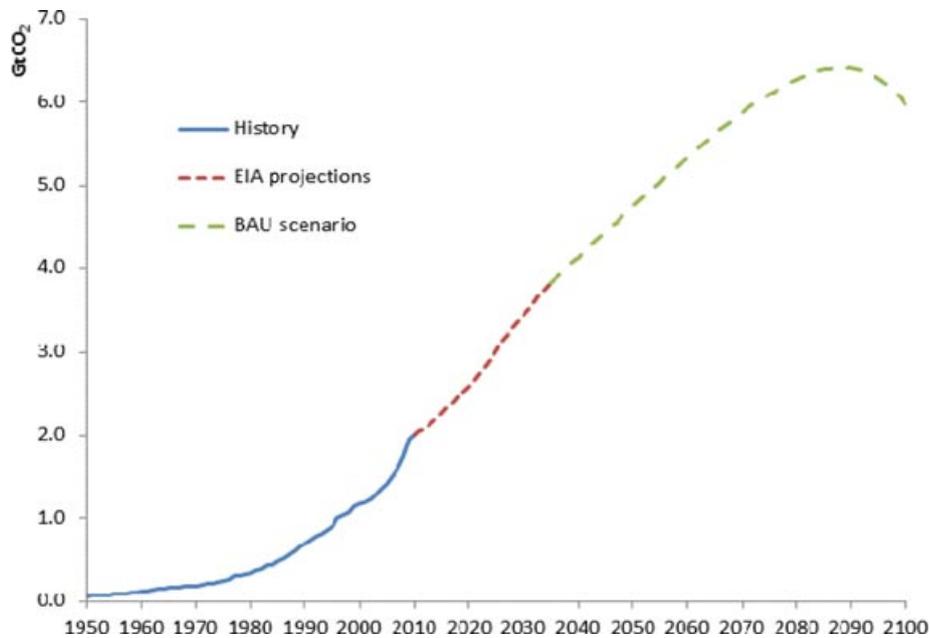


FIGURE 13 | India's CO₂ emissions under the CEEP BAU scenario.

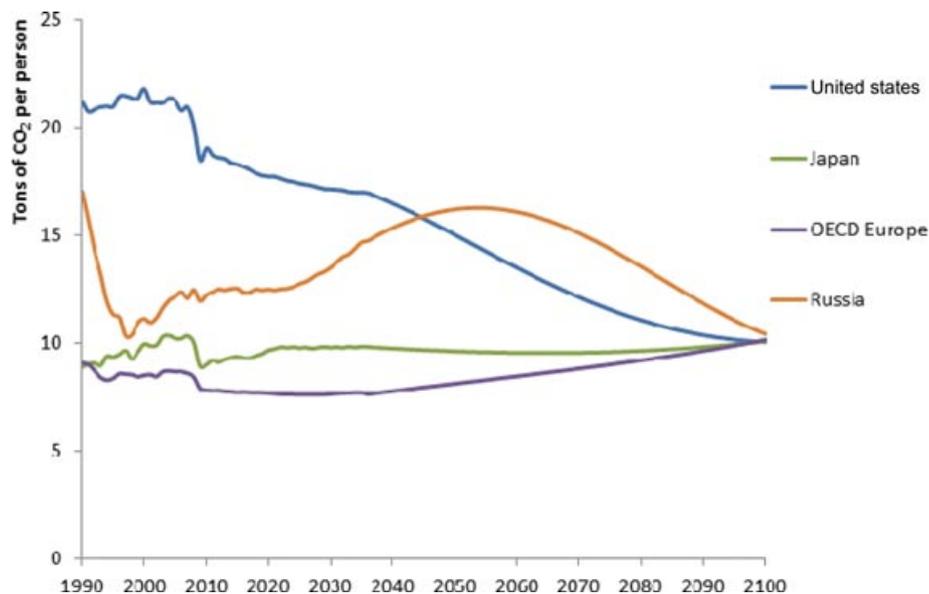


FIGURE 14 | Per capita CO₂ emissions for major Annex 1 countries under the CEEP BAU Scenario.

the most costly and restrictive policies) can stabilize CO₂ concentration below 400 ppm. These scenarios require immediate reductions in GHG emissions, and even then it is likely that we will exceed 2°C above the preindustrial level (see Table 3). Even with the Copenhagen Accord, which has explicitly set a target not to exceed global average temperature above 2°C (which was later officially adopted in the Cancun Agreements), there is no indication that the world's major economies are actually plan-

ning to take emission paths that would achieve this goal.^{44–46}

Most of the mitigation scenarios reviewed by IPCC³⁸ foresee CO₂ stabilization in the 485–570 ppm range. Similarly, different emissions reduction scenarios analyzed by the International Model Comparison Project focus on the 450–550 ppm range.⁴⁷ Stabilization scenarios modeled by The U.S. Climate Change Science Program⁴⁸ targeted a 450–750 ppm range of CO₂ concentration. Stern,⁴⁹ using economic analysis

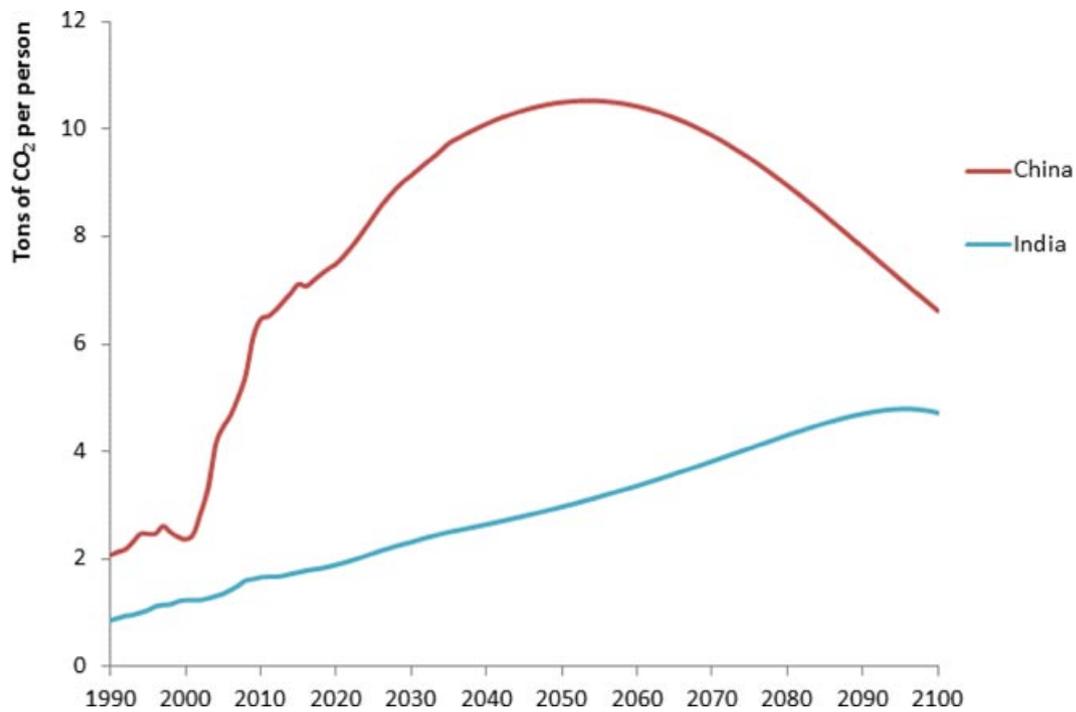


FIGURE 15 | Per capita CO₂ emissions for major Non-Annex 1 countries under the CEEP BAU scenario.

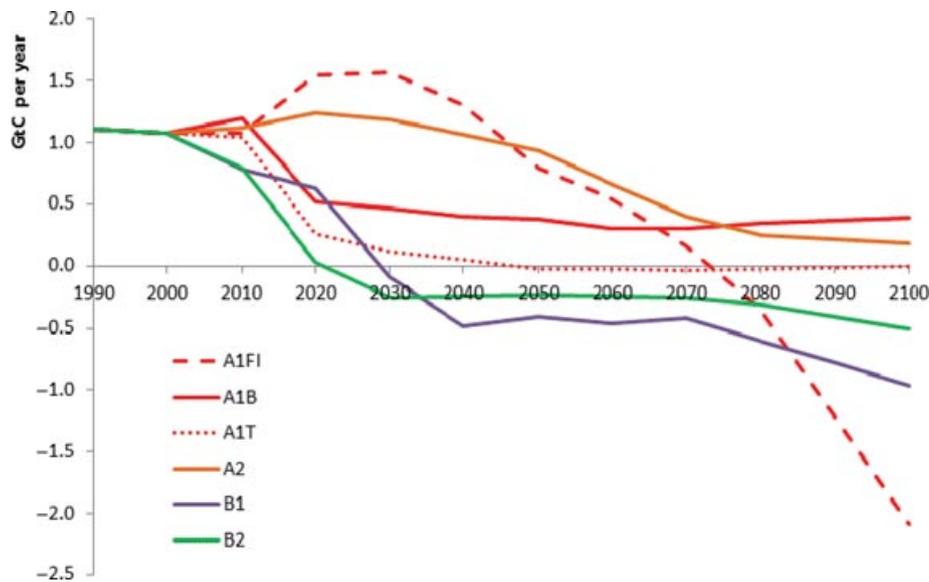


FIGURE 16 | Carbon emissions from land-use change under SRES scenarios. Data Source: Ref 31.

techniques, came to the conclusion that to avoid the most harmful consequences of climate change, GHG concentrations should not exceed 550 ppm CO₂-eq (this level approximately corresponds to 450 ppm CO₂, see Table 3). On the basis of this background, we modeled a low-carbon-emissions scenario (CEEP’s LCES) targeting a stabilized CO₂ concentration of 450 ppm by 2100. This scenario is discussed in detail below.

The CEEP’s LCES

To stabilize CO₂ concentration at 450 ppm, emissions from fossil fuels must peak in this decade and then rapidly decline (see Ref 38). The key question from a policymaker’s perspective is what emissions trajectory would different countries need to take to achieve this level of carbon concentration. One way to set an emission path was suggested by our previous works (see Refs 50–52). We have proposed to allocate an

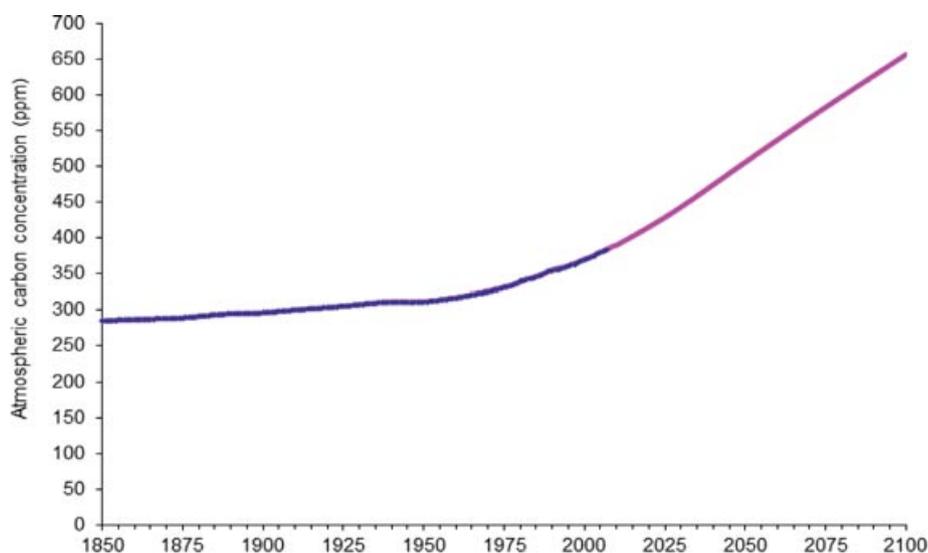


FIGURE 17 | Atmospheric carbon concentration under the CEEP BAU scenario.

TABLE 3 | Impact of Carbon Concentration on Global Mean Temperature Increase

Category	Additional Anthropogenic Radiative Forcing (W/m ²)	CO ₂ Concentration (ppm)	CO ₂ -eq Concentration (ppm)	Number of Scenario Studies	Peak Year for CO ₂ Emissions	Global Mean Temperature Increase Above Preindustrial at Equilibrium, Using 'Best Estimate' Climate Sensitivity (°C)
I	2.5–3.0	350–400	445–490	6	2000–2015	2.0–2.4
II	3.0–3.5	400–440	490–535	18	2000–2020	2.4–2.8
III	3.5–4.0	440–485	535–590	21	2010–2030	2.8–3.2
IV	4.0–5.0	485–570	590–710	118	2020–2060	3.2–4.0
V	5.0–6.0	570–660	710–855	9	2050–2080	4.0–4.9
VI	6.0–7.5	660–790	855–1130	5	2060–2090	4.9–6.1

equal volume of annual carbon emissions per person for each country at their 1990 population levels. The sustainable level of carbon emissions was calculated at 3.3 tons per person (at 1990 population levels) (see Ref 52). To achieve the LCES carbon concentration target, it was assumed that Annex 1 countries would start their rapid decline by 2015, and Non-Annex 1 countries would follow this path from 2020.

Using the population and GDP per capita assumptions from the CEEP's BAU scenario and modifying energy intensity to expect Annex 1 countries to make a greater effort in this factor^b, we have built a LCES. Initially, we solved for the carbon intensity by country or country group, which would be consistent with this scenario. Using the Kaya Identity, Eqs (8) and (9) given above, we solved for the resulting carbon intensities for 2100 (see Table 4).

CEEP's LCES has an architecture similar to model runs in IPCC's category III group (see Table 3). According to the IPCC (Ref 38: 203–206), stabilization costs for this type of scenario would amount up to

6.5% of world GDP in 2100. We assumed that these costs should be primarily borne by Annex 1 countries. Considering the income share of the Annex 1 group in global GDP, the proportion of the group's GDP required to meet the LCES target is 21%. This is reflected in the lower forecasted per capita GDP of these countries compared with the CEEP's BAU case (see Table 4). By contrast, forecasted per capita GDP for Non-Annex 1 countries is identical in the BAU and LCES scenarios, an intentional effort to improve the equity characteristics of the LCES.

Table 4 indicates that even with the United States., OECD Europe and Japan enjoying the same economic level of development, different effort levels would be required by them to meet the LCES CO₂ emissions budget of 3.3 tons per person at 1990 population levels. With other factors from the Kaya identity fixed, each country or region meets the budget by altering its CO₂ intensity factor, compared with the BAU. In the Annex 1 group, this solution set indicates that the United States would need to reduce the

TABLE 4 | Key Parameters in CEEP's LCES for Major Economies

	CO ₂ Intensity in 2100 (g/MJ)		Energy Intensity in 2100 (MJ/\$)		Population (Million)		Per Capita GDP in 2100 (Thousand \$2005)	
	BAU	LCES	BAU	LCES	1990	2100	BAU	LCES
United States	29.30	9.45	2.88	2.30	250	425	113.03	89.08
OECD Europe	29.30	15.38	2.88	2.30	477	498	113.03	89.08
Japan	29.30	21.75	2.88	2.30	124	91	113.03	89.08
Russia	26.78	19.08	4.26	3.41	148	111	86.06	67.83
Other Annex 1	28.04	16.79	3.57	2.86	311	273	99.54	78.46
China	30.39	22.77		3.36	1148	784		63.16
India	30.39	14.12		3.36	838	1,292		45.11
Other Non-Annex 1	25.82	7.13		4.19	1991	5,070		43.41

TABLE 5 | Key Parameters in for CEEP's LCES for Major Economies under Alternative Scenario

	CO ₂ Intensity in 2100 (g/MJ)		Energy Intensity in 2100 (MJ/\$)		Population (Million)		Per Capita GDP in 2100 (Thousand \$2005)	
	BAU	LCES	BAU	LCES	1990	2100	BAU	LCES
United States	29.30	23.44	2.88	0.93	250	425	113.03	89.08
OECD Europe	29.30	23.44	2.88	1.51	477	498	113.03	89.08
Japan	29.30	23.44	2.88	2.15	124	91	113.03	89.08
Russia	26.78	21.42	4.26	3.03	148	111	86.06	67.83
Other Annex 1	28.04	22.43	3.57	2.14	311	273	99.54	78.46
China		30.39	3.36	2.52	1148	784		63.16
India		30.39	3.36	1.56	838	1292		45.11
Other Non-Annex 1		25.82	4.19	1.16	1991	5070		43.41

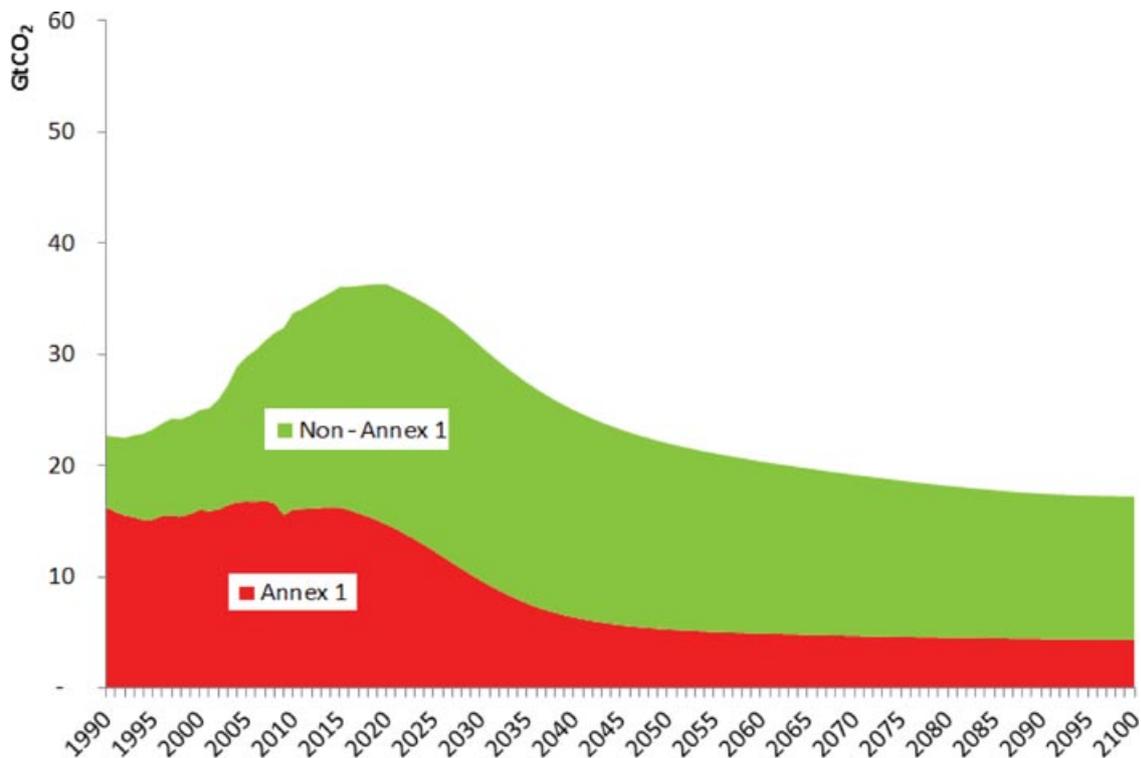


FIGURE 18 | Global CO₂ emissions from fossil fuels under CEEP's LCES.

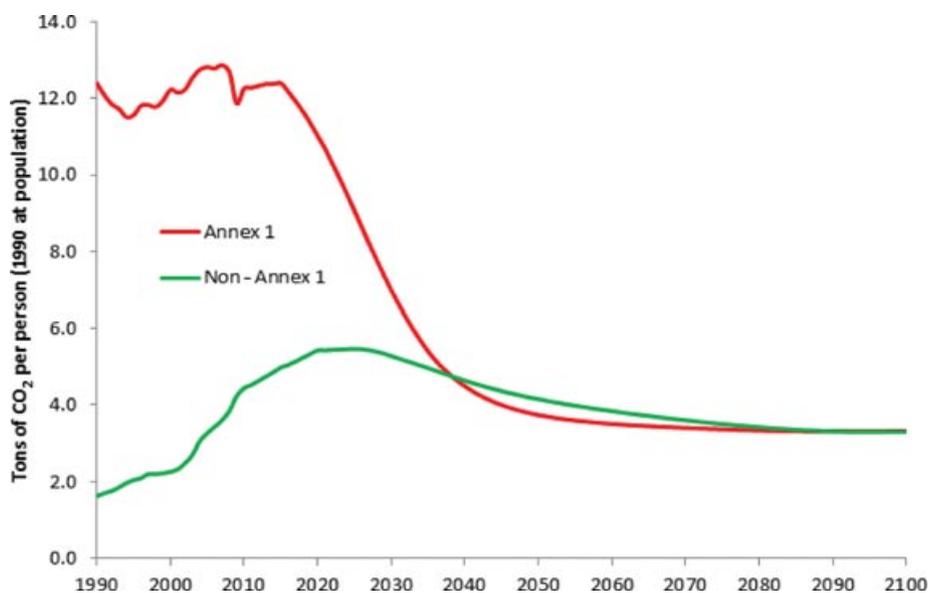


FIGURE 19 | Per capita CO₂ emissions for Annex 1 and Non-Annex 1 countries under CEEP’s LCES.

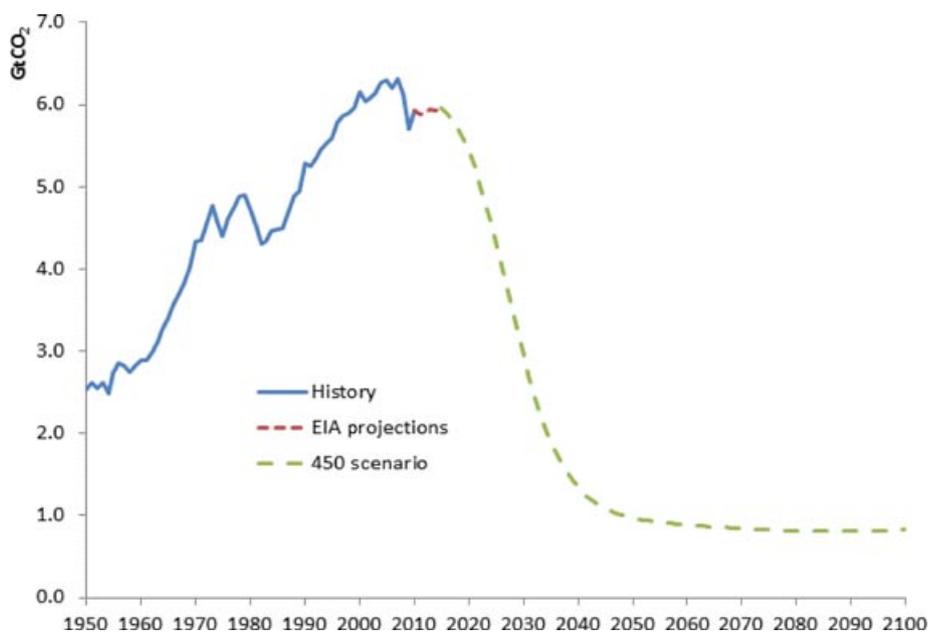


FIGURE 20 | U.S. CO₂ emissions under CEEP’s LCES.

carbon intensity of its energy supply by nearly 70% to comply with the aim of the LCES. By comparison, the remainder of the Annex 1 group needs to lower the carbon intensity of their energy supplies by 26–48%. Two factors affect this result: (1) U.S. population is projected to nearly double by 2100 from 1990 levels and (2) the country’s historically higher carbon intensity means that it must deploy low/no-carbon energy options faster and more extensively than would otherwise be the case. These results highlight the impor-

tance of population and historical trends in fuel mix in efforts of the Annex 1 group to meet long-term sustainability goals.

For Non-Annex 1 countries, it was assumed that the shape of the energy intensity curve under the LCES would follow the same pattern for this group as in the CEEP’s BAU Scenario. When the CO₂ intensity factor is then allowed to vary, our model suggests that the ‘Other Non-Annex 1’ countries (principally those of Africa, the Middle East, and Latin America)

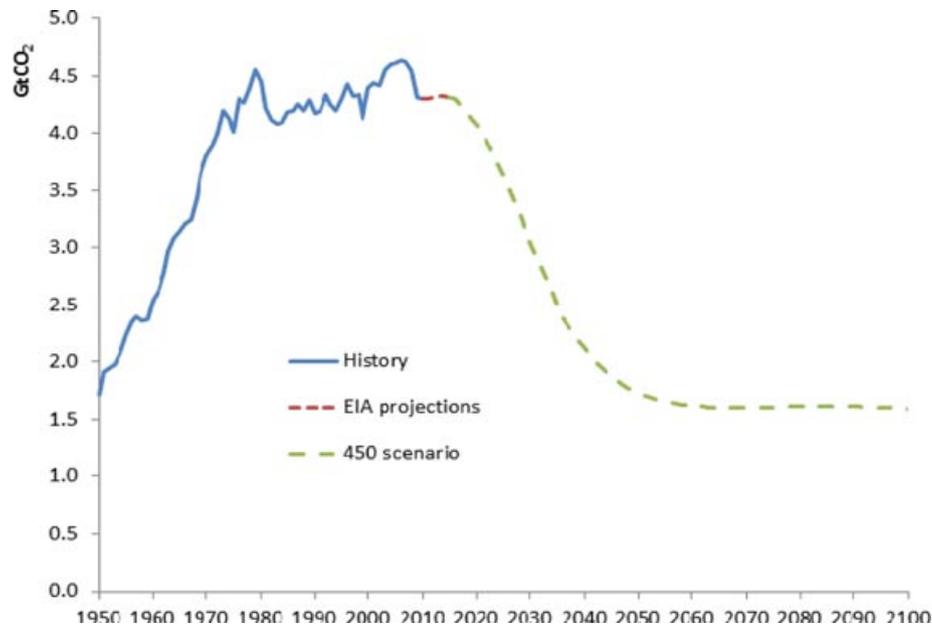


FIGURE 21 | OECD Europe's CO₂ emissions under CEEP's LCES.

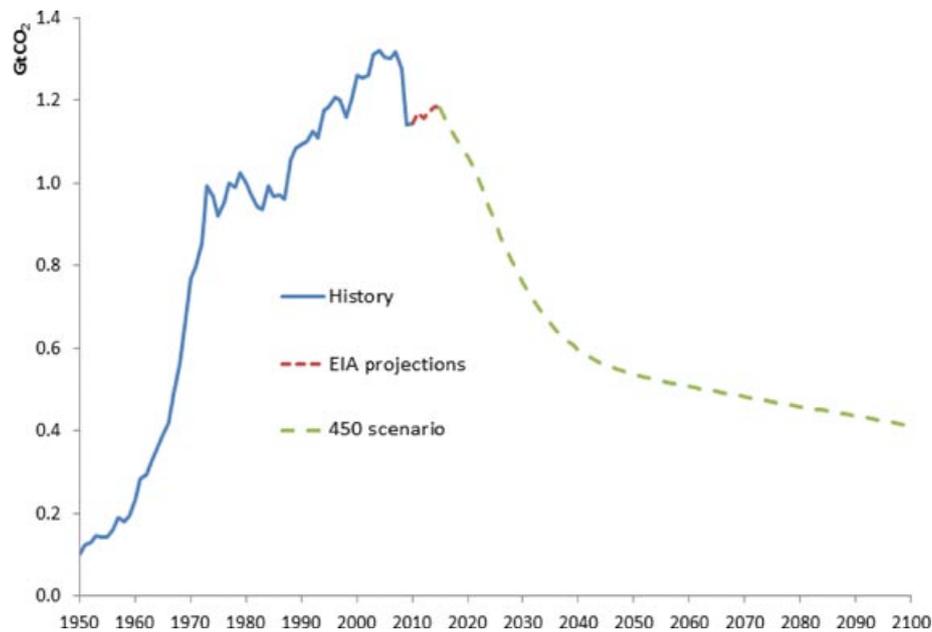


FIGURE 22 | Japan's CO₂ emissions under CEEP's LCES.

would face real challenges to decarbonize their energy supplies to meet an end-of-the-century overall target of 3.3 tons per person-year. India's challenge would be very high too but not as difficult. In the case of both members of the Non-Annex 1, the United Nations Population Office's forecast of sustained population growth is the principal cause of this result.

Next, a model run was prepared in which CO₂ intensity was expected to be 20% lower than the forecasted BAU values for the Annex 1 group for 2100, whereas CO₂ intensity for Non-Annex 1 countries was assumed to be the same as their forecasted BAU levels in 2100. This case isolates the change in energy intensity needed to meet the long-term target concentration of 450 ppm CO₂ (see Table 5). This scenario

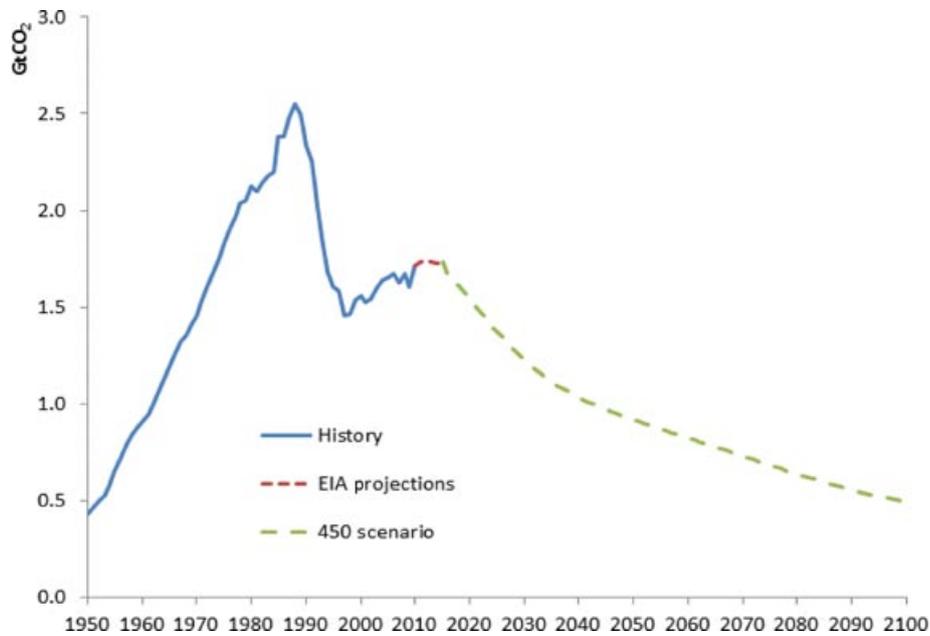


FIGURE 23 | Russia's CO₂ emissions under CEEP's LCES.

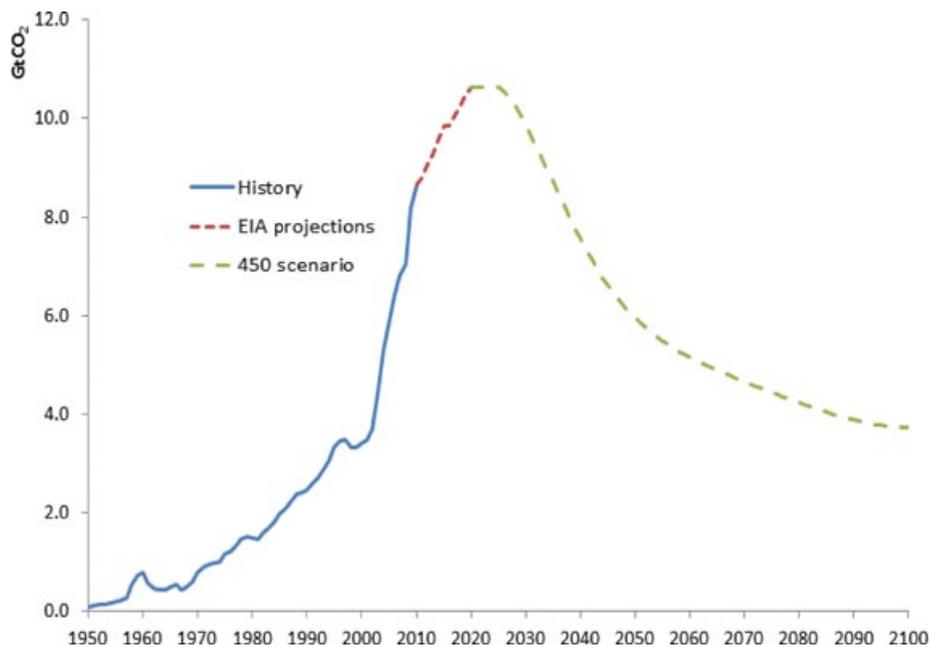


FIGURE 24 | China's CO₂ emissions under CEEP's LCES.

shows that significant improvements will be needed in energy intensity.

Here again, it is the United States, Africa, the Middle East, and Latin America who must make dramatic changes and, as with Table 4, population growth is a problem to each of these members. For the United States, there is the additional problem that it begins with a higher per capita GDP and a somewhat

higher energy intensity rate compared to the energy intensity of OECD Europe and Japan (see Table 3).

Of course, a combination of energy intensity and carbon intensity can be applied to meet the long-term 450 ppm target for CO₂. But Tables 4 and 5 are offered to 'book-end' the range of option values to highlight countries and regions that are likely to face the greatest difficulties if all are to reach a sustainable

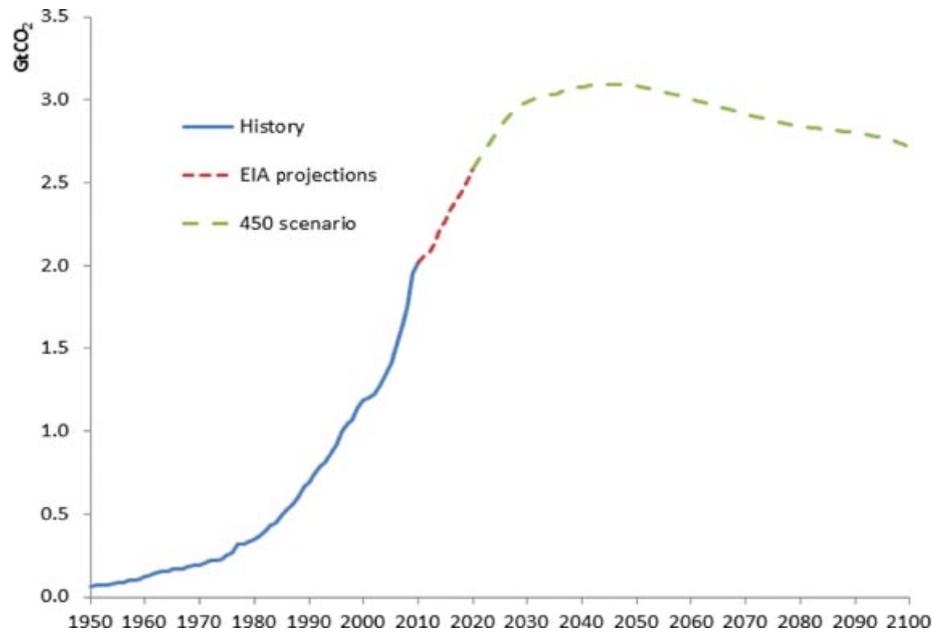


FIGURE 25 | India's CO₂ emissions under CEEP's LCES.

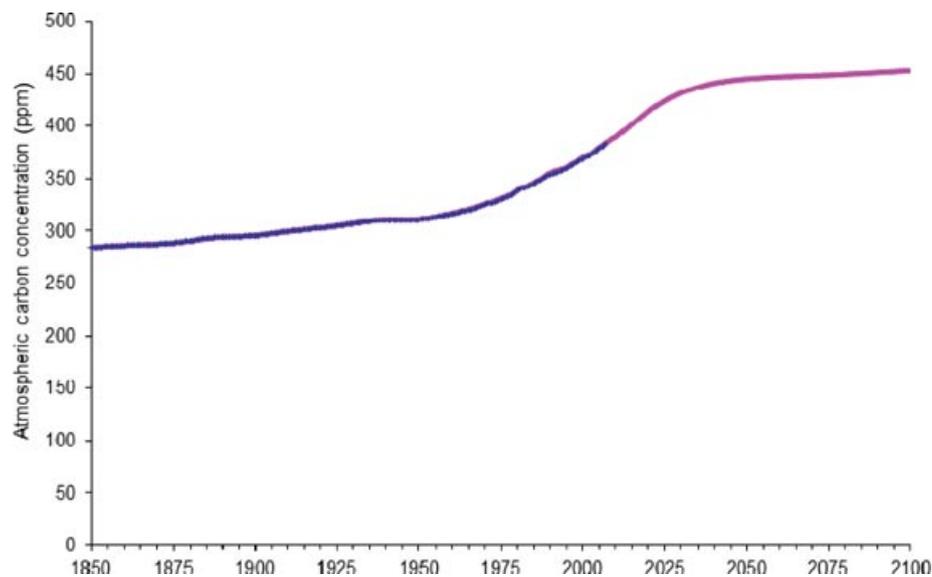


FIGURE 26 | Atmospheric carbon concentration under CEEP's LCES.

and equitable end-of-century target. The combined impact of supply actions (represented by CO₂ intensity) and demand interventions (represented by energy intensity) is what determines a future trajectory of carbon emissions, and variations could be simulated to represent many combinations. But these combinations would affect the emissions pathways for individual countries, not the global result (see Eq. 8).

For CEEP's LCES, global and per capita emissions of the Annex 1 and Non-Annex 1 countries as

groups (expressed in 1990 population values) are presented in Figures 18 and 19, respectively.

Both figures note the significant changes in Annex 1 behavior, which must begin immediately if the world community is to have any hope of reducing climate risk to a level associated with 450 ppm of CO₂ by the end of this century.ⁱ Without such changes, the costs of inaction will be disproportionately felt by those least responsible for the build-up of GHGs in the atmosphere.

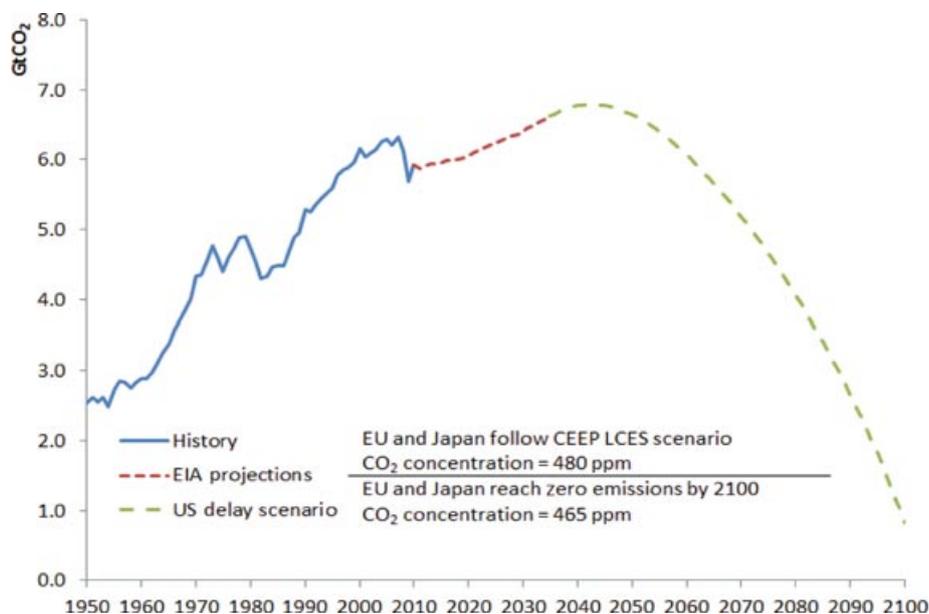


FIGURE 27 | U.S. delayed action scenario.

Emissions trajectories for selected individual countries and regions are presented in Figures 20–25. These graphs underscore that all countries, even those in the Non-Annex 1 group, face major challenges in any common effort to avert the worst consequences forecasted for a world with BAU concentrations. It is a sobering message on the importance of immediate action.

CEEP's LCES stabilizes the CO₂ concentration at 450 ppm (see Figure 26). However, stabilization of CO₂ concentration at 450 ppm requires concerted effort of all members of the international community. As demonstrated in a previous paper,⁵⁰ delay by the United States to reduce emissions until 2050 prevents global realization of 450 ppm of CO₂ by 2100, even when all other Annex 1 countries meet the 3.3 tons per capita emissions target by 2050.⁷ In fact, zero emissions by European Union and Japan by 2100 cannot overcome the effort of the delay by the United States to act. This 'U.S. Delay Scenario' is rerun using the updated model reported here. Figure 27 depicts the dilemma: the failure of the United States to act early leaves the world no ability to realize a stabilization result at 450 ppm of CO₂ by 2100 despite a cliff-like fall in global emissions.

CONCLUSION

It is our hope that the picture of social change etched in the paper will help researchers and policy analysts seeking to better define what is needed by country/region. By grouping options for social change into

menus that dramatically reduce the carbon intensity of human activity and the rate of energy use to develop, we believe practical agendas of action can begin to be formed. Elsewhere^{50,53,54} we have discussed needed political and economic changes to realize a long-term sustainable and equitable rate of per capita emissions (defined in Ref 52).

We are heedful of the record of international gridlock and the particularly disappointing inaction of the United States as we now consider what is to be done with the pictures of social change we have presented here. Recognizing that many have tried their hand at drafting blueprints for climate action and, importantly none has worked, we have decided against what would be an arrogant answer from us—another blueprint. Instead, we offer principles for building a new strategy that bear in mind the less than encouraging evidence on the possibilities of significant social change. In concluding with principles, we admit that our approach is still a long way from answering the challenge. We simply do not have anything better to offer to the research community at this time.

The principles are from a paper prepared by CEEP for the COP-17 meeting in Durban, South Africa.⁵⁵ The paper argues for a reconsideration of what constitutes 'success' and offers a specific redefinition of success for the international community to pursue. CEEP's paper argues that international strategies to date have prioritized commodity-based paradigm, which has failed because (1) it concentrates attention on negotiating emission reductions as though we could trade off marginal risks of

climate change and marginal economic cost; (2) such a paradigm treats the interests of peoples and nations in an equitable and just solution as secondary; and (3) market-based approaches significantly reduce developing country autonomy to select a development pathway in line with their sustainable development objectives, priorities, and needs.

In place of a commodity-based paradigm, CEEP's paper advocates a new approach, which prioritizes social and ecological relations and emphasizes an equitable distribution of capabilities to fulfill human needs and wants. The approach emphasizes sustainable development defined through bottom-up discourses and encourages investigation of a commons-based paradigm, which elevates the principles of autonomy, sustainability, equity, and ecological justice in the (inter)national efforts to address climate change. The strategy outlined in the paper recognizes several recent developments in international negotiations on climate change that would allow for the formulation of bottom-up discourses guided by the principles of autonomy, sustainability, equity, and ecological justice.

Incorporating these principles into the core of decision-making would emphasize the shared responsibility for livelihoods and environments and prioritize social and ecological relations over carbon commerce per se. Considerations of sustainability inform the decision portfolio by highlighting the prerequisite of an emissions trajectory that limits climatic change to a temperature increase of 2°C. In turn, recognition of the need to uphold the principles of equity and justice would call attention to the highly uneven patterns of energy use and GHG emissions now observed among the world's nations and the inequitable distribution of the effects of climate change.

The adoption of these principles would provide insight into the particular social and ecological benefits and disbenefits of the various menus of social change available. Further, the outgrowth of governance opportunities through the specific inclusion of autonomy in the form of a participatory bottom-up discourse allows for a proper and inclusive selection of the menus of social change in line with the country- or region-specific characteristics and social relations. In conclusion, we see the positioning of these principles at the basis of decision-making as a core first step in effectively addressing climate change through social change.

We would like to note that the alternative principles and paradigm we propose are not meant to presume that market-based mechanisms are inappropriate or off limits. Rather, we are suggesting priority be given to bottom-up discourses to identify the ap-

propriate menus for social change—these discourses can decide the suitability of markets or other tools. In effect, we are encouraging the view that we should not choose tools first and purposes, principles, and paradigms later, but the other way around. We are also convinced from the pictures of needed social change provided in the analysis given above that the mentality and associated politics and economics of commodity-based strategies are dampening the level of action and the range of consensus required to avert further, still more dangerous climate change. Humanity has no authority to trade an increment of climate risk for an increment of lowered economic cost. The atmosphere and our ties to it cannot be expressed in this marginal reasoning. It is wrong to assume it can be. It wastes time when we dwell only or mainly on this idea.^k

NOTES

^a'Complexity' refers to the detail of description and number of processes included in the model and not the mathematical representation of a model.¹⁰

^bThe model was developed by faculty and researchers the Climate and Environmental Physics Institute at the University of Bern in Switzerland. Its principle architect is Fortunat Joes (see Ref 16).

^cThe Kaya identity was developed by Yoichi Kaya.^{56,57} The identity was actively used by IPCC in SRES projections. The Kaya identity is similar to the $I = PAT$ equation developed in the 1970s during the course of a debate between Barry Commoner, Paul R. Ehrlich, and John Holdren (see, e.g., Ref 58).

^dFollowing IPCC's SRES practice, we use market exchange rates for our emissions projections.

^eThese groups are referred by IPCC as OECD90, ASIA, REF, and ALM respectively.

^fThe term 'land-use change' refers to the aggregated emissions from biomass burning and decay from logging and deforestation, decay of peat, and peat fires.³⁸

^gNegative emissions could require not only carbon capture and geological storage,^{59,60} but at least some believe a process of atmospheric carbon extraction is needed.⁶¹

^hThe intent of this assumption is to place the burden on finding higher efficiency options among the countries with currently the most extensive public R&D infrastructures and which are best able (because of their comparative wealth) to afford this global cost. In this respect, the equity aim of the (sustainability + equity) criterion of our approach (see Refs 50–52,54) is advanced.

ⁱFigure 19 corresponds to 3.3 tons of CO₂ per person at 1990 population levels or 2.0 tons of CO₂ per person at projected 2100 population levels.

^jThe target is at 1990 population levels. If we account for population growth, it falls to 2.0 tons of CO₂ per person.

^kAgain, we wish to be clear: we are not saying that market mechanisms must be abandoned. Instead, we are suggesting the need to first define the principles, which spur social change, and then second, evaluate all tools, including markets, for their

suitability in meeting our selected principles. In following this strategy, we are hopeful that participation will increase and the willingness to pioneer in menus of social change will expand. A data point in favor of this hope is available from U.S. experience where national policy failure left the country's local jurisdictions (states and cities) to find their own solutions. Researchers worried this would mean U.S. efforts could not scale to meaningful change. In fact, pioneering action from the bottom up led to policies that promise to out perform the Kyoto flexibility mechanisms by 2020 (see Ref 62).

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