Persistent growth of CO_2 emissions and implications for reaching climate targets

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Efforts to limit climate change below a given temperature level require that global emissions of CO_2 cumulated over time remain below a limited quota. This quota varies depending on the temperature level, the desired probability of keeping below this level, and the contributions of other gases. In spite of the limited quota, global emissions of CO_2 from fossil fuel combustion and cement production have continued to grow by 2.5% per year on average over the past decade. Two thirds of the CO_2 emission quota consistent with a 2°C temperature limit has been used, and the total quota will likely be exhausted in a further 30 years at the 2014 emissions rates. We show that CO_2 emissions track the high end of the latest generation of emissions scenarios, due to lower than anticipated carbon intensity improvements of emerging economies and higher global GDP growth. In the absence of more stringent mitigation, these trends are set to continue and further decline the remaining quota until the onset of a potential new climate agreement in 2020. Breaking current emission trends in the short term is key to retain credible climate targets within a rapidly diminishing emission quota.

Recent studies have identified a near-linear relationship between global mean temperature change and total CO_2 emissions cumulated over time[1-9]. This relationship leads to an intuitive and appealing application in climate policy. A global "quota" on cumulative CO_2 emissions from all sources (fossil fuel combustion, industrial processes and land-use change) can be directly linked to a nominated temperature threshold with a specified probability of success. It can be used regardless of where or, to a large degree, when the emissions occur[10].

Despite the many reservoirs and timescales that affect the response of the climate and carbon cycle[11], the proportionality between temperature and cumulative CO_2 emissions is remarkably robust across models. The relationship has been called the Transient Climate Response to cumulative carbon Emissions (TCRE) and was highlighted in the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC)[12]. The near-linear relationship has strong theoretical support: radiative forcing per emitted tonne of CO_2 decreases with higher CO_2 concentrations, an effect which is compensated by the weakening of the ocean and biosphere carbon sinks leading to a larger fraction of emitted CO_2 remaining in the atmosphere[13-15]. The uncertainty in the TCRE, accounted for here in the given probability[12,16], thus comes from the climate response to CO_2 and the carbon cycle feedbacks[14,17-19]. The near-linear relationship holds for cumulative CO_2 emissions less than about 7500 $GtCO_2$ and until temperatures peak[16].

Although CO_2 is the dominant anthropogenic forcing of the climate system[20], non-CO_2 greenhouse gases and aerosols also contribute to climate change. However, unlike for CO_2, the forcing from short-lived agents is not related to the cumulative emissions but directly determined by annual emissions[21-23]. Therefore it is necessary to account for the additional warming from non-CO_2 agents separately when estimating CO_2 emission quotas compatible with a given temperature limit. The forcing from non-CO_2 agents has a considerable range across emissions scenarios in the recent IPCC Working Group III (WGIII) database[24], reflecting expected development pathways, coherently for CO_2 and other forcing agents given the underlying climate and other policies[25]. Generally, forcing from non-CO_2 agents contributes 10-30% of the total forcing[9] (Figure S1).

For a 66% probability of keeping below a temperature threshold of 2°C, CO_2 emissions would need to be kept below 3670 $GtCO_2$ if accounting for forcing from CO_2 only (4440 $GtCO_2$ for a 50% probability)[12,26]. When accounting for both CO_2 and non-CO_2 forcing as represented in the multiple scenarios available in the IPCC WGIII database, the quota associated with a 66% probability of keeping warming below 2°C reduces to 3200 [2900-3600] $GtCO_2$ (3500 [3100-3900] $GtCO_2$ for a

50% probability) (Table 1, Table S1, Supplementary Information). Every additional 900 $GtCO_2$ emitted will increase warming by about 0.5°C globally (50% probability).

In recent years, interest has grown in using cumulative emissions more directly in climate policy[9,27-30]. In the following we update regional and global emission estimates up to 2014 and provide projections up to 2019. The emission estimates and trends are used to update the emission quota remaining from 2020, the potential year for the onset of a new global climate agreement. We explore various uncertainties with cumulative emissions and the consequences for the remaining quota. We compare the emission trends and remaining emission quota with the emissions scenarios used in the recently published IPCC AR5 WGIII report that are consistent with keeping the global temperature increase below 2ºC above preindustrial levels. This analysis thus brings together currently disjoint perspectives: 1) the dependence between cumulative emission and global temperature changes, 2) the decomposition of recent trends in emission, and 3) mitigation pathways from Integrated Assessment Modelling, and analyses their consistency with the 2ºC climate target.

CO_2 emission update

The CO_2 emission quota compatible with a given temperature limit encompasses both past and future emissions. Since CO_2 is emitted each year, the remaining quota decreases with time. Here, we first update the remaining emissions quota, by providing updated estimates of cumulative emissions through to 2013 before projecting emissions up to 2019. CO_2 emissions from fossil fuel combustion and cement production (E_{FF}) were estimated at 36.1 (34.3–37.9) $GtCO_2$ in 2013, 2.3% above emissions in 2012 (Figure 1a, Methods). Cumulative emissions from fossil fuel combustion and cement production from 1870 to 2013 were 1430±70$GtCO_2$. Historical emission estimates are based on energy consumption statistics[31], and include uncertainties in the energy statistics and conversion rates[31,32]. Recent attempts have been made to verify emissions from atmospheric measurements and modelling[33], but their interpretation is hindered by the influence of the carbon sinks[34,35].

On short time scales, the changes in CO_2 emissions from fossil fuels combustion and cement production are generally driven by increases in economic activity as measured by the Gross Domestic Product (GDP) and the decrease (improvements) in the carbon intensity of the world economy (I_{FF})[36,37]. A decomposition of emissions into a simplified Kaya identity, $E_{\mathrm{FF}} = \mathrm{GDP} \cdot I_{\mathrm{FF}}$, offers an effective way to understand short-term emissions trends[38-42]. This simple relationship will be used through this article to understand drivers of recent past emission changes and provide short-term emission projections.

In the last decade (2004-2013) global CO_2 emissions have continued strong growth of 2.5%/yr. This growth rate was below the 3.3%/yr growth rate averaged over the 2000-2009 decade because of the lower 2.4%/yr growth rate since 2010 (Figure 1a). Using the simplified Kaya identity, the decrease in the growth rate of global CO_2 emissions in recent years has been due, in roughly equal parts, to a slight decrease in GDP growth rate and a slightly stronger decrease in I_{FF} (Figure S2). The high decadal growth rate in global emissions is due to strong growth in economic activity and emissions in emerging economies, partly due to the intensification of world trade[43,44], and slightly decreasing emissions in some large developed countries[44]. These patterns have led to a significant regional redistribution in emissions in all key dimensions: absolute, per-capita, and cumulative (Table 2, Figure 2a). The top four emitters play a critical role in emissions growth, China accounted for 57% of the growth in global emissions from 2012-2013, USA for 20%, India for 17%, while EU28 had a negative contribution of -11%.

The developed countries (taken as Annex B in the Kyoto Protocol) had a 0.4% increase in emissions in 2013, reversing the trend of decreased emissions since 2007. The USA's 2.9% growth in emissions in 2013 reversed the nation's trend of decreasing emissions since 2007 as a result of a return to stronger economic growth rate (2.2%), and an unusual increase in I_{FF} (0.7%) (Figure 2c and Figure S2c), largely because coal has regained some market share from natural gas in the electric power sector[45]. The EU28's 1.8% decrease in emissions in 2013 continued the persistent downward trend despite increased coal consumption in some EU countries (e.g., Poland, Germany, and Finland). The decrease in emissions in the EU28 was driven by a relatively low GDP growth rate (0.5%) and decrease in I_{FF} (2.2%) (Figure 2d and Figure S2d), with largest emission decreases occurring in Spain, Italy, and the United Kingdom, and the largest increase in Germany.

Developing countries and emerging economies (taken as non-Annex B) had a 3.4% increase in emissions in 2013, continuing previous trends[42]. China's 4.2% growth in emissions in 2013 continued its decelerating growth (Figure 2b) from 10% per year for 2000-2009 to 6.1% per year for 2010-2013. The reduction of the emissions growth rate in China is due to decreasing GDP growth combined with stronger decrease in I_{FF} (Figure S2b). It is too early to say whether the recent decline in I_{FF} in 2013 can be attributed to dedicated mitigation policies. Despite the stronger decrease in I_{FF}, the high absolute I_{FF} in China, combined with strong GDP growth, is the main reason for the weakening I_{FF} at the global level (Figure S3). India's 5.1% growth in emissions in 2013 compares to growth rates of 5.7% from 2000-2009 and 6.4% from 2010-2013 (Figure 2e). The recent Indian emissions growth was driven by robust economic growth, and by an increase in I_{FF} (Figure S2e). India is the only major economy with a sustained increase in I_{FF} (carbonisation of its economy) from 2010-2013 (Figure 2 and Figure S2).

The robust emerging relationship between GDP and E_{FF} in the past (Figure 1 and Figure 2) is used here to estimate future emissions on short time scales using projected growth rates of GDP by the International Monetary Fund (IMF)[46] combined with an assumption of persistent trends in I_{FF}[40,42]. This method provides first-order estimates of CO_2 emissions in the absence of additional emission mitigation policies. Based on the forecast 3.3% increase of global GDP in 2014 (IMF)[47], and the trend in I_{FF} over 2004-2013 of -0.7%/yr, we estimate 2014 E_{FF} to be 37.0 [34.8–39.3] $GtCO_2$, or 2.5 % [1.3%–3.5%] over 2013 and 65% over 1990 emissions (Figure 1). The uncertainty range takes into account the uncertainty in IMF GDP projections and variability in I_{FF} caused by a range of socio-economic factors[42] (Supplementary Information). Similar estimates are made at the country level (Table 2 and Figure 2). While strong inertial factors maintain global emissions growth within a relatively small range, at the regional level significant and unexpected events can lead to strong deviations, and regional uncertainty is much more difficult to quantify. We therefore do not provide uncertainty estimates at the regional level, but acknowledge that they are potentially large.

Emissions from land-use changes have been stable or decreasing in the past decade[48], and currently contribute about 8% of total CO_2 emissions. We estimate land-use change emissions to 2013 using the most recent Global Carbon Budget[49] based on a combination of a bookkeeping estimate[48] and fire emissions in deforested areas[50] (Methods). We estimate emissions of 3.2±1.6 $GtCO_2\ yr^{-1}$ in 2013 and use the 2004-2013 average of 3.3±1.6 $GtCO_2\ yr^{-1}$ for 2014-2019. Thus, total CO_2 emissions from all sources are estimated to be 39.4 [35.9–42.8] $GtCO_2$ in 2013 and 40.3 [36.4–44.2] $GtCO_2$ in 2014.

Based on combined data and our 2014 estimate, cumulative CO_2 emissions from all sources during 1870-2014 will reach 2000±180 $GtCO_2$. About 25% of this 145 year period was emitted over the last 15 years alone (2000-2014). The cumulative emissions from 1870 were 75% from fossil fuels and cement production and 25% from land-use change.

Remaining CO_2 quota

Taking into account CO_2 emissions to 2014, the remaining emissions quota (from 2015 onwards) associated with a 66% probability of keeping warming below 2°C is estimated to be 1200 [900-1600] $GtCO_2$. This 2°C quota will be exhausted in about 30 [22-40] years of emissions (which we refer to hereafter as *equivalent emission-years*) at the 2014 emission level (40.3 $GtCO_2$/yr). Due to inter-annual and decadal variability[51-53], the actual year when 2°C will be reached is more uncertain. The remaining quota associated with a 50% probability of committing to 2°C of warming is estimated to be 1500 [1100-1900] $GtCO_2$ (Table 1), with equivalent emission-years of 37 [27-47] years at the 2014 emission level. The remaining quota is significantly higher for 3°C (Table 1), but it is limited for all warming levels, even the highest ones. The equivalent emission-years indicator is a simple and transparent metric to communicate the size of the remaining carbon budget compatible with a warming level given our current emission levels.

Many of the low stabilisation scenarios in the literature, such as the RCP2.6, rely on emissions below zero (so called ‘negative emissions’) in the second half of the century, in effect compensating for emissions today[24,54]. Most models achieve negative emissions through intensive use of bioenergy coupled with carbon capture and storage (BECCS)[55-57], and the availability of BECCS is important in cost-effective 2°C mitigation pathways[55,56]. Negative emissions at the global level will reduce the cumulative emissions over time, leading to a peak and decline in cumulative emissions[58].

The validity of TCRE in negative emissions scenario remains to be fully assessed, analyses with comprehensive Earth System models are required to fully explore the carbon cycle and climate response to negative emission scenarios (though research has started in this area[10,59-61]). There is also a need to fully explore the risks of relying on BECCS (currently unavailable at scale) for 2°C mitigation pathways. Studies show that explicitly limiting or eliminating the availability of CCS and carbon dioxide removal (CDR) technologies in mitigation scenarios does not necessarily rule out the feasibility of 2°C, but does increase the need for deep emission reductions in the short term[55,56,62]. The few studies that explored 2°C pathways without CCS and CDR from emission levels that are in line with the current emission reduction pledges of countries by 2020 found these to be either infeasible[63-68] or extremely costly[64,67-69].

Emission projections and climate targets

Current emission growth rates are twice as large as in the 1990s despite 20 years of international climate negotiations under the United Nations Framework Convention on Climate Change (UNFCCC). For illustration, we expand our GDP-based emissions projections to 2019 using GDP projections from the IMF[46,47] and continued trends in I_{FF}. Assuming a continuation of past climate policy trends through to 2019 (the last available year of IMF's GDP projections), we project an average growth of fossil fuel and cement emissions of 3.1 %/yr to reach 43.2 [39.7–45.6] GtCO$_2$/yr in 2019. The uncertainty range accounts for the uncertainty in GDP and fossil fuel intensity projections (Supplementary Information), but does not account for unforeseen events (e.g., a global financial crisis[40]). Policies or trends that further reduce I_{FF}, or would lower GDP growth rates, would directly reduce these emission estimates. The recent US policy announcements on power plant emissions or China's energy efficiency and renewable targets would at least continue existing I_{FF} trends, but it unclear at present if they would lead to stronger decreases in I_{FF}. Emission projections accounting for current policies such as those from International Energy Agency[70] and baseline projections available in the literature and summarised in IPCC WGIII often show a lower growth rate than our GDP-based projection (Figures 3 and 4), either based on an assumption of slower GDP growth of a stronger decrease in I_{FF}.

We additionally extend these projections to the regional level using the same methods. Figure 2 show the regional trends in GDP, I_{FF} and hence E_{FF}. In general, anticipated GDP growth is offset by decreases in I_{FF} (Figure S2). We find that Chinese emissions would continue to grow at 3.9%/yr over 2014-2019, USA emissions at 0.2%/yr similar to recent estimates by the US Energy Information Administration[71], EU28 emissions reduce by -0.9%/yr, and Indian emissions grow at 5.9%/yr (Table 2, Figure 2 and Figure S2).

Based on these projections, the cumulative fossil fuel and cement emissions over 2015-2019 are estimated to be 200 [190-210] GtCO$_2$. Assuming stable land-use change emissions, we expect additional 16 [8-24] GtCO$_2$ during that period. This brings total cumulative emissions for 2015-2019 to 220 [200-240] GtCO$_2$, and the remaining emission quota from 2020, associated with a 66% probability of limiting warming below 2°C, down to 1000 [700-1400] GtCO$_2$, or 22 [15–30] equivalent emission-years from 2020. The remaining quotas from 2020 onwards and equivalent emission-years for 3°C and 4°C levels are given in Table 1.

Our GDP-based emission estimates are higher than all cost-effective 2°C scenarios in the literature (Figure 3) for 2010–2019. In fact, current IPCC WGIII scenarios that attempt to keep warming to below 2°C, show lower emissions for 2014 than our projection (Figure 3b), mostly because these scenarios were published before 2014 and assumed a 'cost-optimal' mitigation pathway starting 2010. In 2019, the discrepancy between our GDP-based estimates and the cost-effective mitigation pathways is even more exacerbated, with the GDP-based emissions projections being about 40% higher than the levels suggested by cost-effective 2°C scenarios (Figure 3c). This indicates that without a rapid and clear break in historical trends of I_{FF} or GDP the opportunity to follow cost-effective 2°C mitigation pathways in the near-term, as reported in IPCC WGIII, has passed, and the challenges to mitigation would need to be framed around the more costly scenarios that assume a delay in comprehensive mitigation[64,67-69].

The IPCC WGIII mitigation scenarios consistent with the 2°C limit show a reduction or even reversal in the CO_2 emissions growth due to radical decreases of I_{FF} (Figure 4c). While GDP growth rates are similar to our estimate (Figure 4b), they show a carbon intensity decreasing by 2 to 5% per year, as opposed to 0.8% per year in our estimate based on recent trends[64,66-68] (Figure 4c). The rapidly changing structure of the world economy with a growing contribution from emerging economies and developing countries with a high carbon-intensity drives increases in I_{FF} at the global level (Figure S3) and further exacerbates the mitigation challenge. For emerging economies and developing countries, the carbon intensity decreases in the recent past, which we use for our near-term projections, has been significantly below the near-term trends anticipated by most emission scenarios, even baseline scenarios in absence of climate policy (see Figure S4-S8 for a comparison of regions trends in GDP and I_{FF} with IPCC WGIII emission scenarios).

Climate Policy Implications

Climate policy discussions have progressed since 2010 and many countries have pledged to limit or reduce their greenhouse gas emissions by 2020[72-74]. While projected GDP-based projections of emissions are considerably higher than those of the cost-optimal 2°C scenarios, recent studies have shown that even from such high emission levels in 2020, options exist to limit warming to below

2°C[64,66-69]. However, following such trajectories entails important consequences and risks. Five main challenges and trade-offs must be overcome[64,66-68,75-77]: (a) higher emissions in the near term require stronger emission reductions thereafter – a trade-off which has become trivially understandable since the introduction of the TCRE concept and the quantification of 2°C-consistent carbon emission quota; (b) an increased lock-in into carbon-intensive and energy-intensive infrastructure[66,67,78,79] – the recent trends discussed above provide real-world support for this concern; (c) reduced societal choices for future generations – modest near-term emission reductions increase the dependence on specific mitigation technologies and therewith foreclose choices and options of future generations[55,64,66-69,79] (dependence on negative emissions technologies is one example); (d) higher overall costs and economic challenges; and (e) higher climate risks through e.g. higher near-term rates of change, higher cumulative climate impact damages, or an increased probability of abrupt or irreversible changes[64,68,77,80].

Stabilization of global temperature rise at any level requires global carbon emissions to become eventually virtually zero[81]. The existence of a limited global emission quota raises many issues of how to share remaining emissions, including how to take into account historical responsibilities and development needs. These issues are discussed in a companion paper[82]. Irrespective of the difficulty of how to share the remaining quota, our review of recent emission trends and the mitigation scenario literature shows that, if keeping warming to below 2°C relative to pre-industrial levels is to be maintained as an overarching objective, a break in current emission trends is urgently needed in the short term.

Methods

Data: Global and regional CO_2 emissions from fossil fuel combustion and cement emissions are based on emissions estimates from the Carbon Dioxide Information Analysis Center[83] (CDIAC), extended to 2013 using anomalies in energy statistics from BP[84] following the methodology and country definitions used in the Global Carbon Budget[42]. CO_2 emissions from land-use change are estimated using a bookkeeping method[48] from 1850-2010 and then supplemented and extended from 1997- 2013 using satellite-based fire emissions in deforestation areas[50], following the methodology in the most recent Global Carbon Budget[49]. GDP data is from the International Energy Agency[85] up until 2011 and extended to 2013 using the growth rates from two editions of the IMF's World Economic Outlook[46,47]. The IPCC WGIII scenarios are obtained from the scenario database[24,86].

Uncertainty: We place an uncertainty of ±5% (1σ) on the fossil-fuel and cement emissions[31,42] consistent with recent detailed analysis of uncertainty[32] and apply the same uncertainty for the cumulative emissions (Supplementary Information). The uncertainty in emission projections includes the uncertainty in future GDP estimates and different time periods for estimating I_{FF}, and consecutive emission estimates are assumed to be uncorrelated (Supplementary Information). The allowable cumulative emissions quota is derived with a certain modelled likelihood (% of model runs) that a specified warming level is exceeded (e.g. 2°C above the average over 1850-1900) including non-CO_2 forcing (Supplementary Information). Quotas are shown with a 5%–95% range, rounded to the nearest 100. The range in equivalent emission-years is obtained taking the range in remaining budget, neglecting the relatively small uncertainty due to global annual emissions uncertainty.

Growth rates: Growth rates between two years (e.g., 2012-2013) are based on the percentage increase over the first year. To prevent invalid interpretations of annual change we make leap year adjustments to annual growth rates, such that growth rates go up approximately 0.3% if the first year is a leap year and down 0.3% if the second year is a leap year. Growth rates over more than two consecutive years are computed by taking the first derivative of the linear regression of the logarithm of all variables available in this time period (Supplementary Information).

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Authors Contributions

PF, GPP, JGC, JR and CLQ designed the study. PF coordinated the conception and writing of the paper. RMA and GPP provided data and analysis on historical and near-term projections of emissions, GDP and carbon intensity. MS provided all data on cumulative emission budgets compatible with warming levels from the IPCC WGII scenarios database. JR and GL coordinated the assessment of trade-offs in delayed action scenarios. RMA produced Figures 1 and 2. JR produced Figures 3 and 4. All authors contributed to the writing of the paper.

Competing Financial Interests

The authors declare no competing financial interest.

Figure Legends

Figure 1. Global CO_2 emissions and decomposition into GDP and carbon intensity. Global CO_2 emissions from fossil fuel combustion and cement production (**a**) and global GDP and carbon intensity of GDP (I_{FF}) (**b**) over the historical 1990–2013 period (black, blue, and green dots) and estimates to 2019 (red dots). Historical emissions are from CDIAC and BP, while GDP are from IEA and IMF (Methods). Uncertainty in CO_2 emissions is ±5% (1σ) over the historical period with an additional uncertainty for the projection based on a sensitivity analysis of GDP and I_{FF}.

Figure 2. **Regional CO_2 emissions and decomposition into GDP and carbon intensity.** The CO_2 emissions in the top 4 emitters (China, US, EU28, India) (**a**) and the GDP and I_{FF} in each region (**b-e**) over the historical (1990-2013) and future (2014-2019) period. See Figure 1 caption for details and Figure S2 for an annual decomposition of the trends.

Figure 3. Consequences of current emissions and projected near-term trends. Comparison of annual carbon emissions from fossil fuel combustion and cement production (**a**) together with time slices for 2014 (**b**) and 2019 (**c**). The scenarios are from the IPCC AR5 WGIII emission database (red, blue), and updated estimates and projections from this study (black and red dots). Horizontal lines show median estimates. Panel (**c**) additionally includes 2019 emission levels estimated to result from a full implementation of Cancún pledges (yellow). The values in panel (**c**) indicate the number of scenarios available in the WGIII scenario database for each category.

Figure 4. Comparison of trends in the IPCC AR5 WGIII scenario database and projected near-term trends. Histogram of growth rates 2010-2019 in global CO_2 emissions (**a**), world GDP (**b**), and carbon intensity of GDP (**c**). Colours differentiate the baseline scenarios (red) and

mitigation scenarios without delay (blue) and with delay (brown), and our GDP-based projections (red vertical lines) with their uncertainty (grey).

Table 1. Cumulative carbon budget ($GtCO_2$), remaining emission quota from 2015 and 2020 ($GtCO_2$) and equivalent emission years associated with a 66% or 50% probability of global-mean warming below 2°C, 3°C, and 4°C (relative to 1850-1900). The equivalent emission-years correspond to the emission quota divided by the last available year of emissions, given for 2°C and 3°C only. Cumulative emissions and quotas are shown with a 5%–95% range, rounded to the nearest 100.

		2°C		3°C		4°C	
		66%	50%	66%	50%	66%	50%
Cumulative budget (since 1870)		3200 [2900-3600]	3500 [3100-3900]	4900 [4500-5700]	5300 [5000-6200]	6400 [6100-7700]	7100 [7000-8500]
From 2015	Remaining quota	1200 [900-1600]	1500 [1100-1900]	2900 [2500-3700]	3300 [3000-4200]	4400 [4100-5700]	5100 [5000-6500]
	Emission-years	30 [22-40]	37 [27-47]	72 [62-92]	82 [74-104]	-	-
From 2020	Remaining quota	1000 [700-1400]	1300 [800-1700]	2700 [2300-3500]	3100 [2800-4000]	4200 [3900-5500]	4900 [4700-6300]
	Emission-years	22 [15-30]	28 [19-38]	58 [49-75]	67 [60-86]	-	-

Table 2. Estimated CO_2 emissions from fossil fuel combustion and cement production for years 2013, 2014, and 2019, together with growth rates.

	2013				2014		2019		
	Total ($GtCO_2$/yr)	Per capita (tCO_2/p)	Cumulative 1870-2013 ($GtCO_2$)	Growth 2012-13 (%)	Total ($GtCO_2$/yr)	Growth 2013-14 (%)	Total ($GtCO_2$/yr)	Cumulative 1870-2019 ($GtCO_2$)	Growth 2014-19 (%)
World	36.1 [34.3-37.9]	5.0	1430 [1360-1500]	2.3	37.0 [34.8-39.3]	2.5 [1.3-3.5]	43.2 [39.7-45.6]	1670 [1590-1750]	3.1
China	10.0	7.2	161	4.2	10.4	4.5	12.7	230	3.9
US	5.2	16.4	370	2.9	5.2	-0.9	5.2	401	0.2
EU28	3.5	6.8	328	-1.8	3.4	-1.1	3.3	348	-0.9
India	2.4	1.9	44	5.1	2.5	4.9	3.4	62	5.9

We make leap year adjustments to these growth rates and this causes growth rates to go up approximately 0.3% if the first year is a leap year and down 0.3% if the second year is a leap year.

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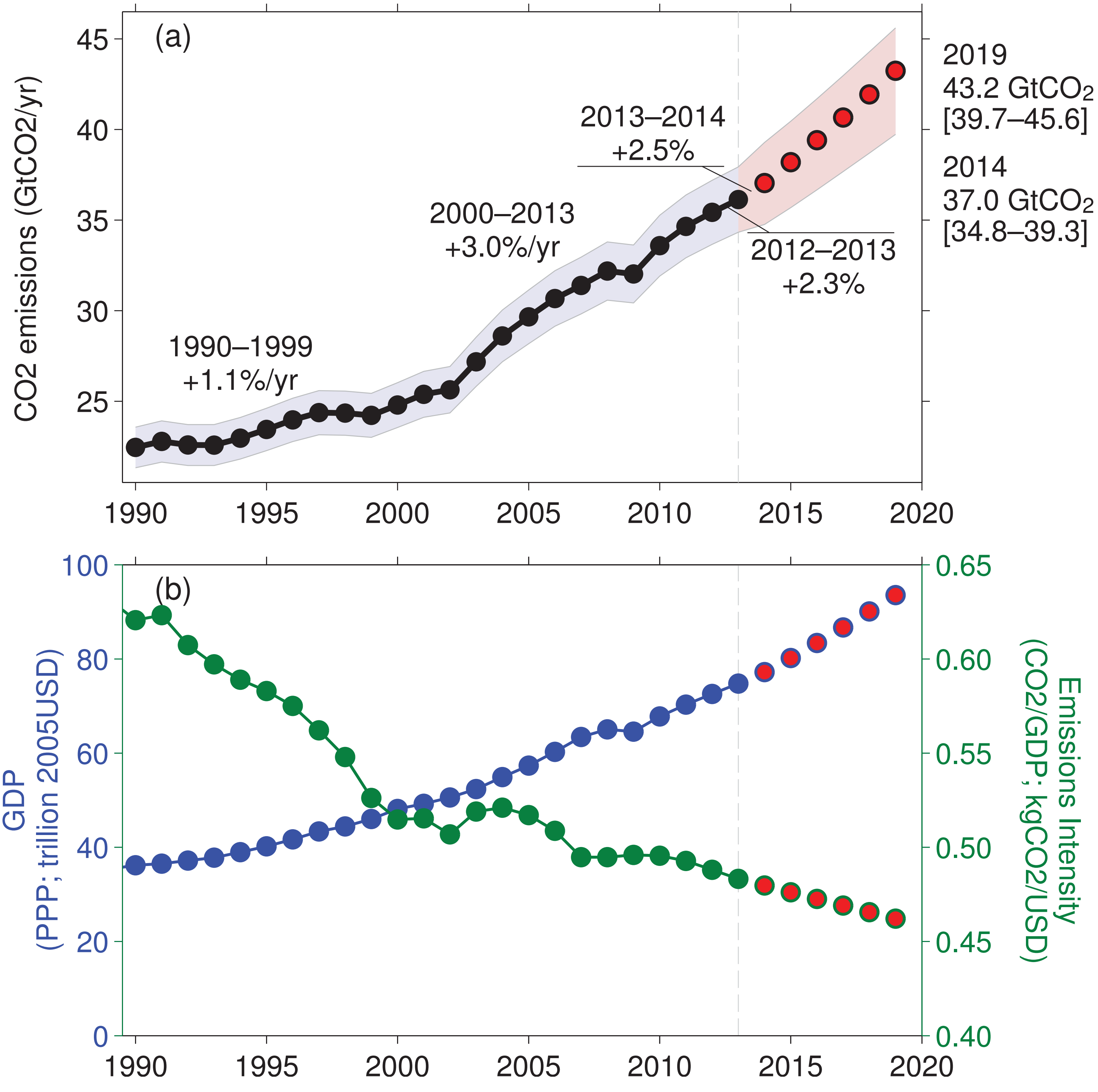
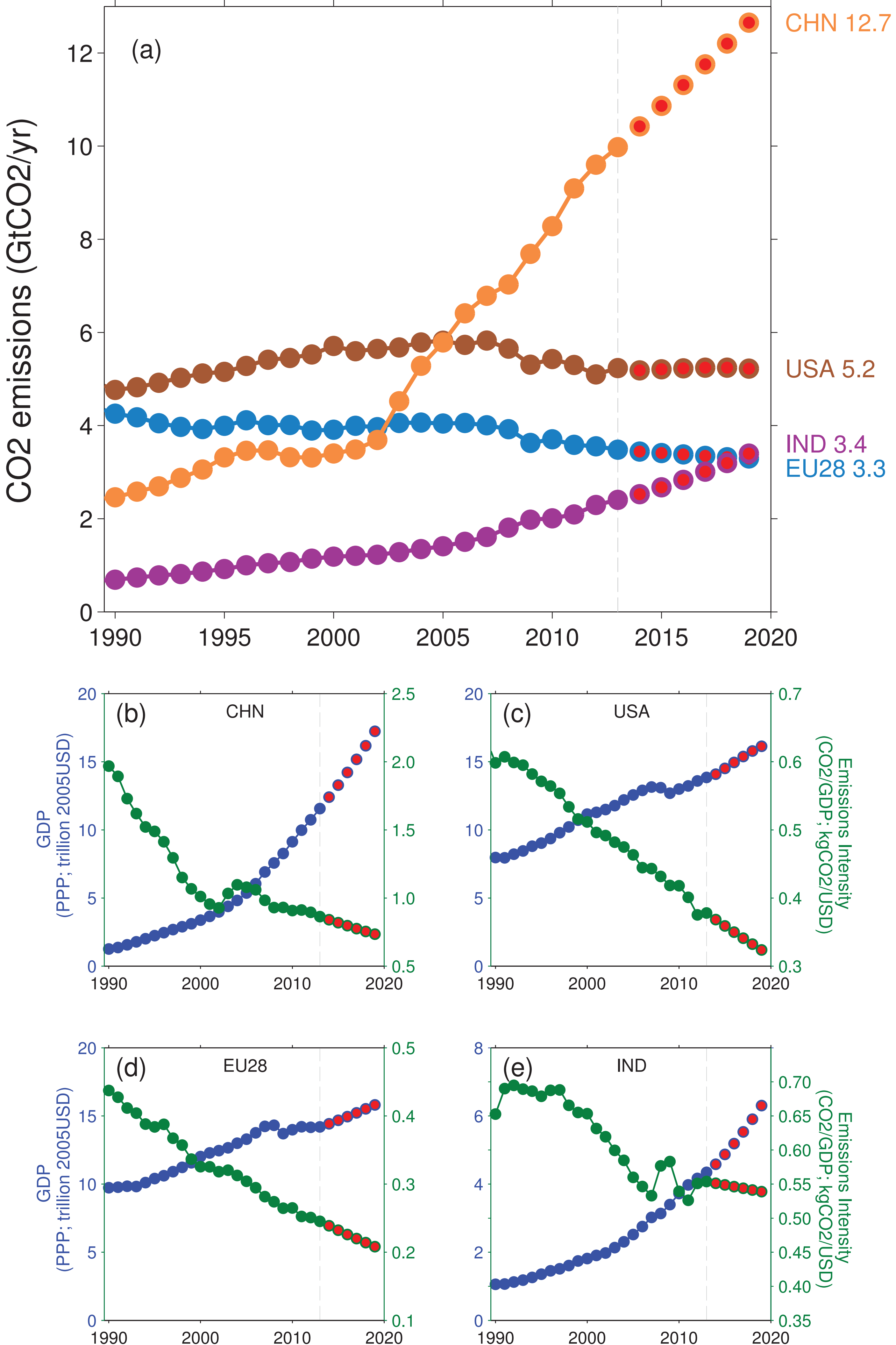
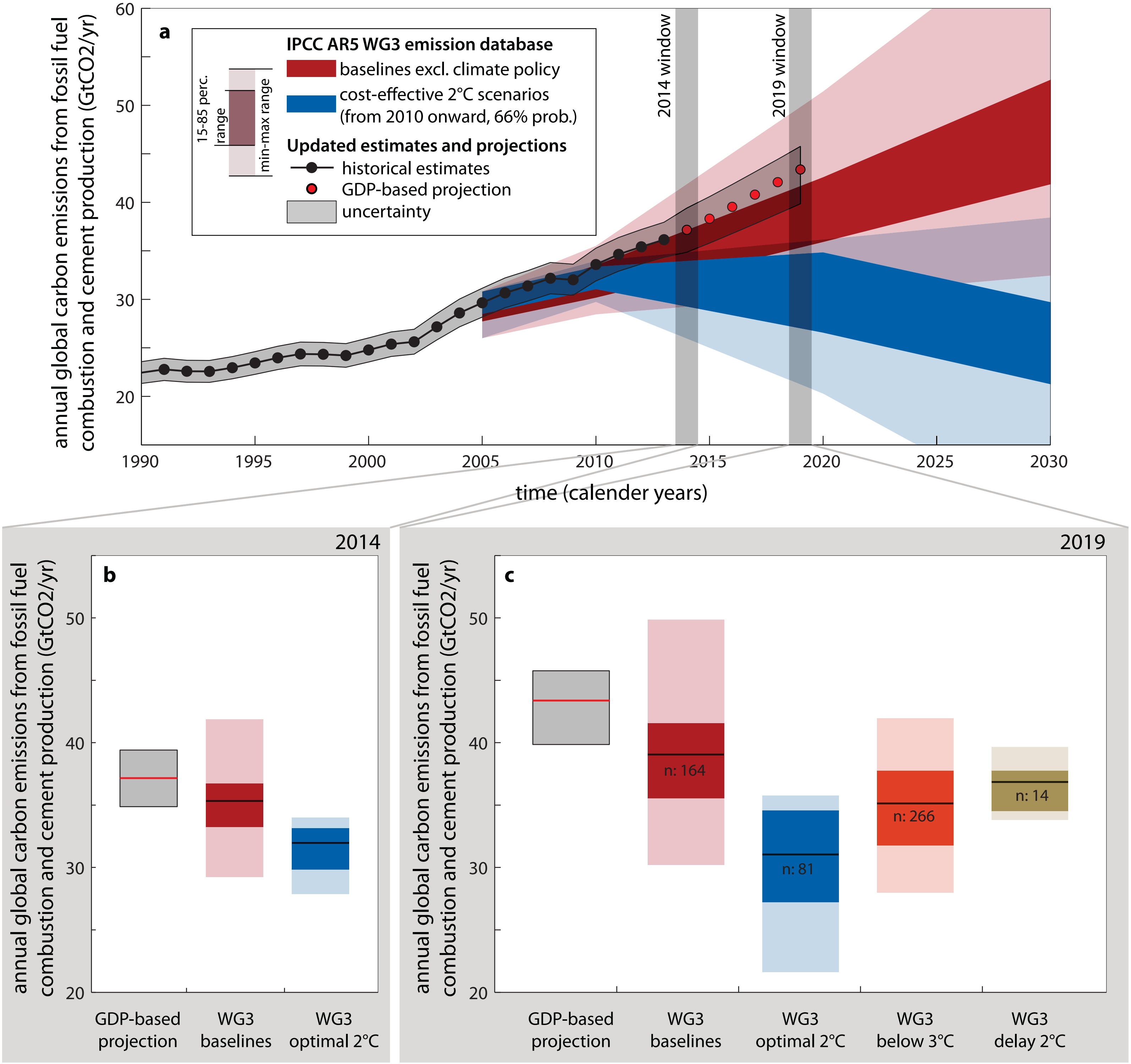
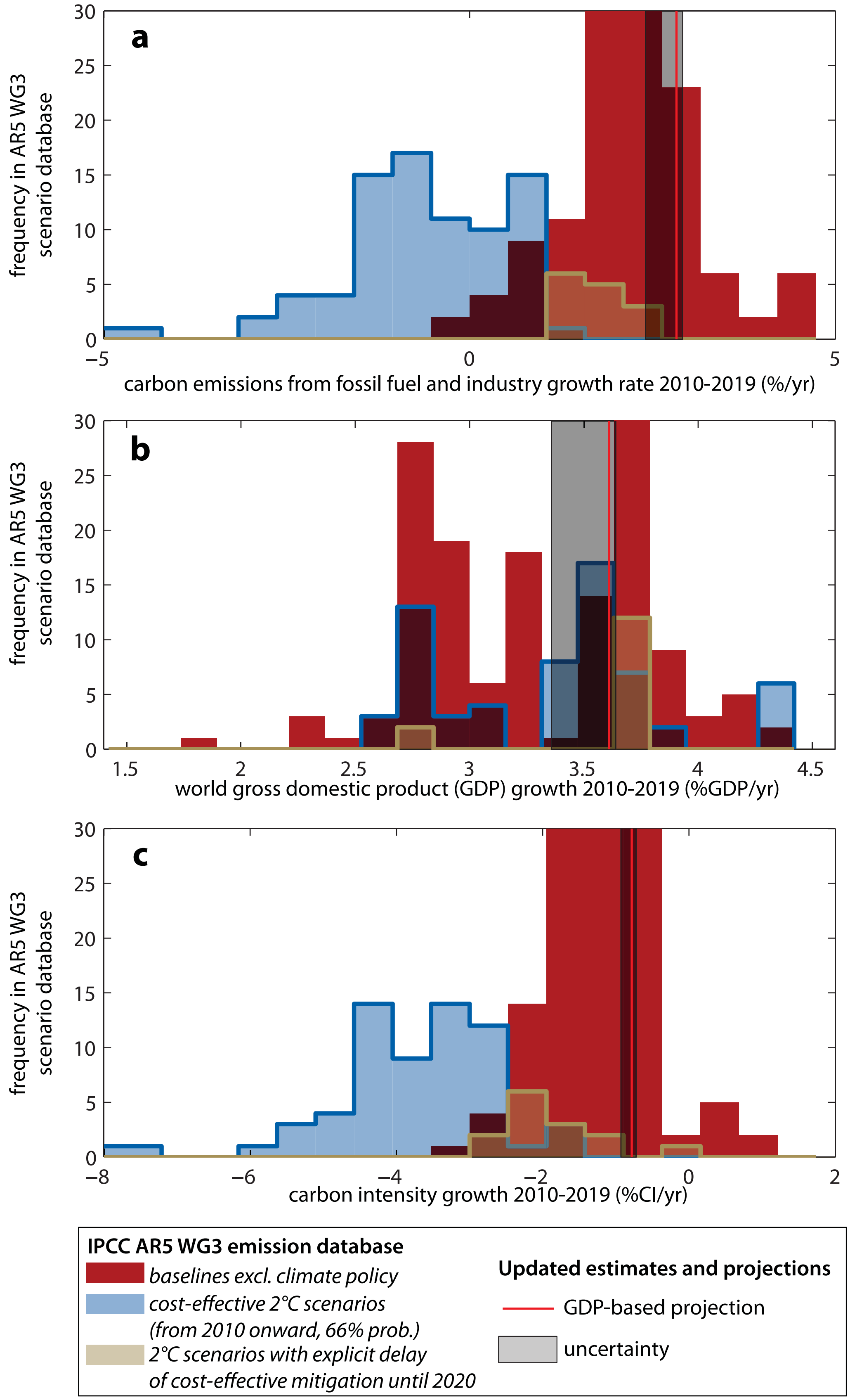

(a)
CO2 emissions (GtCO2/yr)
45
40
35
30
25
1990–1999
+1.1%/yr
2000–2013
+3.0%/yr
2013–2014
+2.5%
2012–2013
+2.3%
2019
43.2 GtCO$_2$
[39.7–45.6]
2014
37.0 GtCO$_2$
[34.8–39.3]
1990
1995
2000
2005
2010
2015
2020
(b)
GDP
(PPP; trillion 2005USD)
100
80
60
40
20
0
Emissions Intensity
(CO2/GDP; kgCO2/USD)
0.65
0.60
0.55
0.50
0.45
0.40
1990
1995
2000
2005
2010
2015
2020


(a)
CO2 emissions (GtCO2/yr)
0
2
4
6
8
10
12
1990
1995
2000
2005
2010
2015
2020
CHN 12.7
USA 5.2
IND 3.4
EU28 3.3
(b)
CHN
(c)
USA
(d)
EU28
(e)
IND
GDP (PPP; trillion 2005USD)
Emissions Intensity (CO2/GDP; kgCO2/USD)
0
5
10
15
20
0.5
1.0
1.5
2.0
2.5
0.3
0.4
0.5
0.6
0.7
0.1
0.2
0.3
0.4
0.5
2
4
6
8
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
1990
2000
2010
2020


a
IPCC AR5 WG3 emission database
baselines excl. climate policy
cost-effective 2°C scenarios (from 2010 onward, 66% prob.)
Updated estimates and projections
historical estimates
GDP-based projection
uncertainty
15-85 perc. range
min-max range
2014 window
2019 window
annual global carbon emissions from fossil fuel combustion and cement production (GtCO2/yr)
60
50
40
30
20
1990
1995
2000
2005
2010
2015
2020
2025
2030
time (calender years)
2014
b
50
40
30
20
GDP-based projection
WG3 baselines
WG3 optimal 2°C
2019
c
n: 164
n: 81
n: 266
n: 14
GDP-based projection
WG3 baselines
WG3 optimal 2°C
WG3 below 3°C
WG3 delay 2°C


a
frequency in AR5 WG3 scenario database
0
5
10
15
20
25
30
−5
0
5
carbon emissions from fossil fuel and industry growth rate 2010-2019 (%/yr)
b
frequency in AR5 WG3 scenario database
0
5
10
15
20
25
30
1.5
2
2.5
3
3.5
4
4.5
world gross domestic product (GDP) growth 2010-2019 (%GDP/yr)
c
frequency in AR5 WG3 scenario database
0
5
10
15
20
25
30
−8
−6
−4
−2
0
2
carbon intensity growth 2010-2019 (%CI/yr)
IPCC AR5 WG3 emission database
baselines excl. climate policy
cost-effective 2℃ scenarios (from 2010 onward, 66% prob.)
2℃ scenarios with explicit delay of cost-effective mitigation until 2020
Updated estimates and projections
GDP-based projection
uncertainty