CORRESPONDENCE:

Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis

To the Editor — Global carbon dioxide emissions from fossil-fuel combustion and cement production grew 5.9% in 2010, surpassed 9 Pg of carbon (Pg C) for the first time, and more than offset the 1.4% decrease in 2009. The impact of the 2008–2009 global financial crisis (GFC) on emissions has been short-lived owing to strong emissions growth in emerging economies, a return to emissions growth in developed economies, and an increase in the fossil-fuel intensity of the world economy.

Preliminary estimates of global CO_2 emissions from fossil-fuel combustion and cement production show that emissions grew by 0.51 Pg C (5.9%) in 2010 and reached a record high of 9.1±0.5Pg C (Supplementary Methods). This is the highest total annual growth recorded, and the highest annual growth rate since 2003 (and previously 1979). The 2010 growth overcomes the 1.4% drop in emissions recorded in 2009, which was due to the GFC, putting global CO_2 emissions back on the high-growth trajectory that persisted before the GFC (Fig. 1). Thus, after only one year, the GFC has had little impact on the strong growth trend of global CO_2 emissions that characterized most of the 2000s.

For the past two years (2009 and 2010), emissions growth has been dominated by the emerging economies (Supplementary Table S1). The CO_2 emissions in developed countries (which we take as the Annex B countries from the Kyoto Protocol) decreased 1.3% in 2008 and 7.6% in 2009, but increased 3.4% in 2010, and are now lower than the average emissions during 2000–2007 (Fig. 2). The CO_2 emissions in developing countries (non-Annex B countries) increased 4.4% in 2008, 3.9% in 2009 and 7.6% in 2010; the GFC only causing a 40% decrease in emission growth in 2009 compared with the trend since 2000 (Fig. 2). The 2010 growth was due to high growth rates in a few key emerging economies (Supplementary Table S1) — for example, China 10.4% (0.212 Pg C) and India 9.4% (0.049 Pg C) — although, the contribution from some developed countries was also substantial in absolute terms: for example, United States 4.1% (0.060 Pg C), Russian Federation 5.8% (0.025 Pg C) and the 27 member states of the European Union 2.2% (0.022 Pg C).

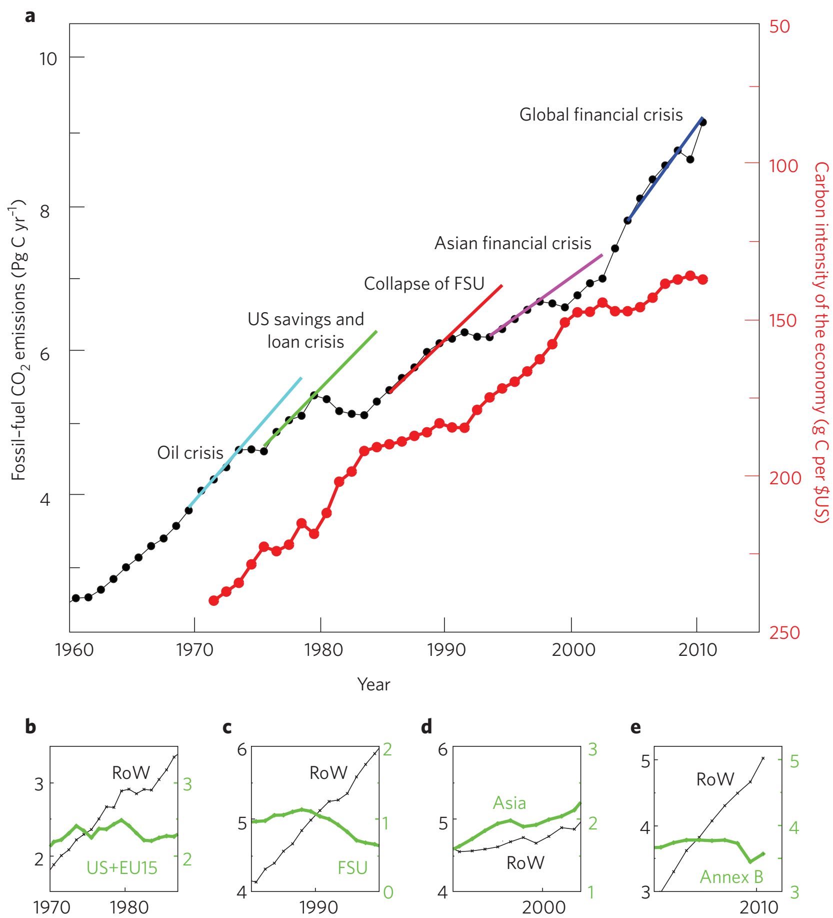

Figure 1 | Global CO_2 emissions and carbon intensity. **a**, Emissions of CO_2 from fossil-fuel combustion and cement production for the world (Pg C yr^{-1}; black curve) and the carbon intensity of world GDP (g C per $US (2000); red curve, inverted axis). The most important recent financial crises are highlighted with a linear trend fitted to the five years before the beginning of each crisis. **b–e** CO_2 emissions (Pg C) for the regions most affected by each financial crisis (right axis) and the rest of the world (RoW; left axis). **b**, The oil crisis (1973) and the US savings and loans crisis (1979), where EU15 is the 15 member states of the European Union as of 1995. **c**, The collapse of the Former Soviet Union (FSU; 1989). **d**, The Asian financial crisis (1997). **e**, The recent global financial crisis (2008–2009).

For recent decades, the growth in global CO_2 emissions can be explained mainly by the growth in economic activity corrected for decreases in the fossil-fuel carbon intensity (FFCI) of the global economy (fossil-fuel and industrial CO_2 emitted per US dollar of economic output, that is CO_2 per unit of gross domestic product (GDP))[1]. Using constant-price GDP measured in purchasing power parities[2] (real GDP), the FFCI decreased by 1.4% yr^{-1} on average between 1980 and 2000. Since 2000 however, the FFCI has decreased by only 0.9% yr^{-1} (Fig. 1), a sign that the positive trend of

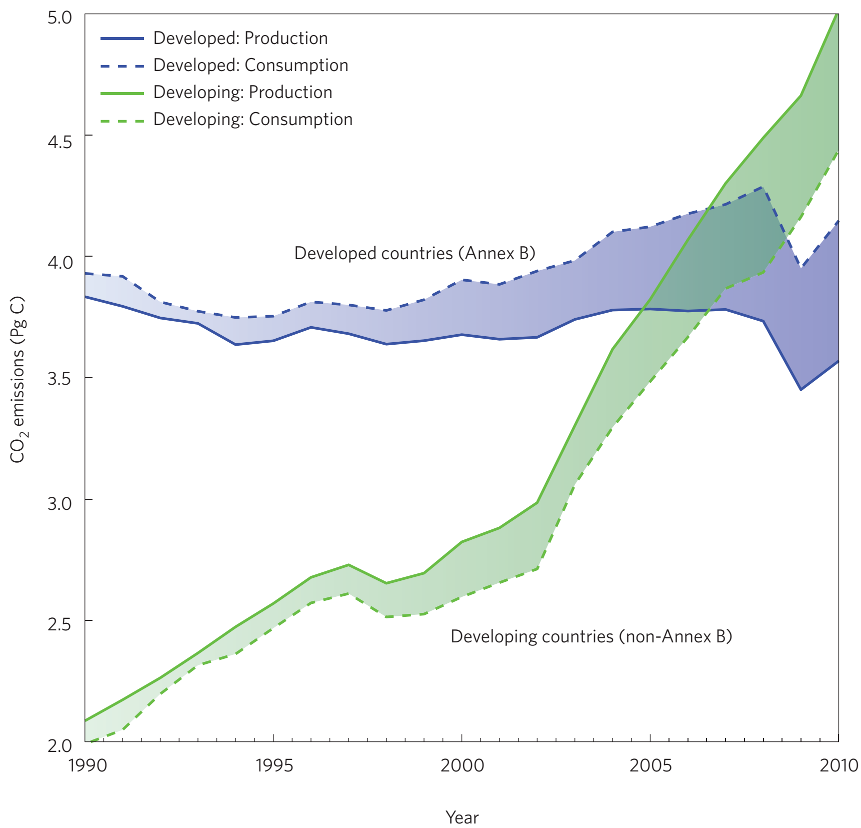

Figure 2 | Historic CO_2 emissions from 1990 to 2010 of developed (Annex B) and developing (non-Annex B) countries with emissions allocated to production/territorial (as in the Kyoto Protocol) and the consumption of goods and services (production plus imports minus exports). The shaded areas are the trade balance (difference) between Annex B/non-Annex B production and consumption[6,14]. Bunker fuels are not included in this figure.

improvements in carbon intensity reversed. Although real GDP grew strongly in 2010 at 5.0% (ref. 3), CO_2 emissions grew even faster at 5.9%, leading to an increase in the FFCI of 0.9% in 2010 (Fig. 1). The deteriorating trend in the FFCI since 2000 is continuing with the return to growth in GDP in 2010 (Fig. 1), but it is too early to tell if the large 'green' stimulus packages[4] will have a longer-term effect on emissions growth. The growth in global CO_2 emissions was 3.1% yr^{-1} on average since 2000, higher than 1990–2000 (1.0% yr^{-1}) and 1980–1990 (2.0% yr^{-1}). Based on the average reduction in the FFCI from 2000–2010 (−0.9±1.5%) and a GDP growth rate of 4.0% (ref. 5), we estimate CO_2 emissions to grow 3.1±1.5% in 2011 to reach ~9.4 Pg C.

Over time we find that variations in CO_2 emissions are larger than variations in GDP. Since 1970, global GDP has had one year of negative growth[3] (2009), whereas CO_2 emissions have had ten disparate years of negative growth. As a consequence, interannual variations in FFCI are correlated with variations in CO_2 emissions. This suggests that in times of crisis, countries maintain economic output by supporting less energy-intensive activities. Major economic crises (financial, energy shortages or political) since the 1960s have led to important changes in the trajectory of global fossil-fuel and industrial CO_2 emissions (Fig. 1). The oil crises in 1973 and 1979 caused persistent price shocks and structural changes in energy production and consumption, leading to a reduction in the global reliance on oil, an increase in reliance on natural gas and a decrease in emissions. A series of events starting in 1990, and later in 1997, had a similar effect on global CO_2 emissions, but in these cases there was a drop in emissions owing to political developments and economic downturns, and not structural changes in energy consumption. Although these earlier economic crises were persistent and caused extended reductions in CO_2 emissions, the 2008–2009 GFC led to a sharp but short-lived decrease in GDP, and global CO_2 emissions quickly rebounded in 2010. These burst-like dynamics are related to: (1) rapid easing of energy prices removing pressure for structural changes in energy consumption; (2) large government investment in many countries to promote a rapid return to economic recovery; and (3) the effect of a decade of high economic growth (around 7% yr^{-1}) in the developing world, providing a strong foundation for the recovery after the GFC, which propagated into a rapid global post-GFC return to high emissions.

During the GFC there was a large drop in international trade as countries supported domestic activities. Even though this reduction was significant in many trade-dependent emerging economies, the reductions were compensated by increased activities in other parts of the economy. The reduction in international trade suggests that countries became temporarily less dependent on imports, hence slowing down the trend of developed countries stabilizing production/territorial-based emissions while increasing consumption-based emissions[6,7] (at the country level, consumption-based emissions include emissions associated with imports, and exclude emissions associated with exports). Including data up to 2010 (Fig. 2 and Supplementary Methods), we found that developed countries had a large drop in consumption-based emissions (7.9% decrease in 2009, 4.9% increase in 2010 and 1.8% yr^{-1} decrease over 2009–2010) with drops in international trade supporting the decline in production-based emissions. In developing countries the reverse occurred, with consumption-based emissions increasing 5.8% in 2009, 6.7% in 2010 and 6.1% yr^{-1} over 2009–2010. As a consequence, 2009 marked the first time that developing countries had higher consumption-based emissions than developed countries (and China passed the United States in consumption-based emissions) — a trend that is likely to continue in the future based on current developments (Fig. 2).

Our estimated emissions from fossil-fuel combustion and cement production of 9.1±0.5 Pg C, combined with the emissions from land-use change of 0.9±0.7 Pg C (ref. 8), led to a total emission of 10.0±0.9 Pg C in 2010. Uncertainty is growing owing to an increasing share of fossil-fuel and cement emissions from developing countries[9]. Half of the total emissions (5.0±0.2 Pg C) remained in the atmosphere, leading to one of the largest atmospheric growth rates in the past decade (2.36±0.09 ppm of CO_2) and an atmospheric concentration at the end of 2010 of 389.63±0.13 ppm of CO_2 (ref. 10). Of the remainder of the total emissions (5.0±0.9 Pg C), we estimated that the ocean sink was 2.4±0.5 Pg C (Supplementary Methods), and the residual attributed to the land sink was 2.6±1.0 Pg C. The land sink was more than 1 Pg C below the strength of the sink over the previous two years[8,11], but this high variability of the land sink is well known and due to natural variability[11].

The GFC was an opportunity to move the global economy away from a high emissions trajectory. Our results provide no indication of this happening, and further, indicate that the GFC has been quite different from previous global crises. The quick rebound from the GFC has emphasised pre-existing challenges for global CO_2 emission reductions[12]. The deteriorating trend in FFCI has continued, emerging economies have maintained strong emissions growth, and the net import of embodied CO_2 emissions into developed countries through international trade has continued. The GFC has helped developed countries to meet their production/territorial-based emission commitments, as promised in the Kyoto Protocol and Copenhagen Accord[13], yet the GFC had minimal impact on emissions growth in emerging economies. Reversing the growth in global fossil-fuel and industrial CO_2 emissions will require countering the trends in all of the underlying contributors simultaneously. Although the GFC was an opportunity to reverse some of the trends leading to increased CO_2 emissions[4], the return to high emissions growth in 2010 may make the GFC a lost opportunity. However, it is too early to conclude whether the GFC has fully passed, and it may take some time for the 'green' stimulus packages introduced during the GFC to have an impact on emissions. ❐

References

1. Raupach, M. R. *et al. Proc. Natl Acad. Sci. USA* **104,** 10288–10293 (2007).
2. Vuuren, D. & Alfsen, K. *Climatic Change* **75,** 47–57 (2006).
3. International Monetary Fund *World Economic Outlook — Update June* (IMF, 2011).
4. Bowen, A. & Stern, N. *Oxford Rev. Econ. Policy* **26,** 137–163 (2010).
5. International Monetary Fund *World Economic Outlook — September 2011: Slowing Growth, Rising Risks* (IMF, 2011).
6. Peters, G. P., Minx, J. C., Weber, C. L. & Edenhofer, O. *Proc. Natl Acad. Sci. USA* **108,** 8903–8908 (2011).
7. Davis, S. J. & Caldeira, K. *Proc. Natl Acad. Sci. USA* **107,** 5687–5692 (2010).
8. Friedlingstein, P. *et al. Nature Geosci.* **3,** 811–812 (2010).
9. Marland, G. *J. Ind. Ecol.* **12,** 136–139 (2008).
10. Conway, T. & Tans, P. Trends in atmospheric carbon dioxide. http://www.esrl.noaa.gov/gmd/ccgg/trends (2011).
11. Le Quéré, C. *et al. Nature Geosci.* **2,** 831–836 (2009).
12. Blanford, G. J., Richels, R. G. & Rutherford, T. F. *Energ. Econ.* **31,** S82–S93 (2009).
13. Rogelj, J. *et al. Nature* **464,** 1126–1128 (2010).
14. Caldeira, K. & Davis, S. J. *Proc. Natl Acad. Sci. USA* **108,** 8533–8534 (2011).

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Author contributions

All authors contributed to the planning of the paper. G.P.P. led the work. G.M. and T.B. contributed the updated CO_2 emission data. C.L.Q. carried out the analysis of previous financial crises (Fig. 1). G.P.P. contributed the updated consumption-based emissions (Fig. 2). C.L.Q. and J.G.C. updated the carbon budget. M.R.R. analysed the growth rates. All authors contributed to other data analysis and to the writing of the paper.

Additional information

The authors declare no competing financial interests. Supplementary information accompanies this paper on www.nature.com/natureclimatechange. Reprints and permissions information is available online at http://www.nature.com/reprints. All data presented in this paper, including the full global CO_2 budget for 2010, can be accessed at http://www.globalcarbonproject.org/carbonbudget/.

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