The main aim of this paper is to present evidence that challenges the widely held view that population growth is the most important underlying cause of climate change. We show that the main underlying cause of increased greenhouse gas (GHG) emissions has been growth in wealth-related consumption (gross domestic product (GDP)). We show that global GDP per capita has had a larger effect than on emissions than population growth as the former has increased faster than the latter in percentage terms over the period for which accurate data is available. We argue that the poorest countries, despite their generally higher rate of population growth rate, have, to date, made a far smaller contribution to greenhouse gas emissions compared with those of the highly and very highly developed countries and those with recently advanced economic development (Brazil, Russia, India and China known collectively as the BRIC countries). However, the collective annual emissions of the BRIC and other developing countries have already overtaken the emissions of the developed countries (that is the highly and very highly developed ones). Moreover, the cumulative emissions of BRIC and other so-called “developing” countries are also likely to exceed those of the developed countries in the foreseeable future if current trends continue. Thus, as cumulative emissions provide a better measure of culpability for climate change than annual emissions, the greatest responsibility for this highly dangerous phenomenon is likely to shift from the aggregated “developed” countries to the aggregated “developing” ones.

We start by considering how the population might grow in the future and the factors that will influence this. We then define wealth and GDP. Thereafter we present the evidence that population growth per se is not the primary underlying cause of increased greenhouse gas emissions and climate change. We do this first by reviewing the work of Bradshaw et al. (2010) who in a country-by-country study provided evidence that impact on the global environment did not correlate with national population growth rate, population size, or population density but correlated strongly with gross national income (GNI). We move on to review the evidence that national energy consumption and greenhouse gas emissions are
both closely related to total national expenditure as measured by gross domestic product (GDP). We then briefly review the work of Druckman and Jackson (2008) that used household surveys to show that income levels are the major determinant of carbon footprints in the UK. We move on to consider recently published data which shows that global energy-related CO₂ emissions correlate more closely over time with global GNP per capita than with global population. We then discuss these findings in relation to the Kaya identity

\[iv\]

which describes the relationship between global energy-related emissions, GDP per capita, population growth, energy efficiency and carbon intensity. Finally, we consider the implications of our analysis for both climate change and population policies.

**How is the global population predicted to grow?** According to the International Programs Center of the US Census Bureau\(v\), the world population on the 7\(^{th}\) of October 2012 was estimated to be 7 billion. The UN predicts that, despite a steady decline in the population growth rate, there will be a continued increase in population size which will reach between 7.5 and 10.5 billion by the year 2050\(vi\). However the UN predictions are only projected increases and are far from set in stone. The actual size of the population in 2050 will be influenced by a combination of socioeconomic factors, the behaviour of individuals and, probably to a much lesser extent, by national population policies. More importantly the UN predictions do not consider the possible effects of widespread food and water shortages, pandemics, serious global energy supply/demand imbalance post-peak conventional oil, war, environmental degradation and catastrophic economic collapse which could lead to a considerable undershoot on the projected figures. In this connection we note that feedback effects from profligate use of fossil fuels may contribute directly or indirectly to a drastic reduction in the human population\(vii\ viii ix\).

Setting aside uncertainty about the size of the global population by 2050, the argument is frequently voiced that any increase in global population is bad for climate change simply because more people would mean more manmade emissions. However as we shall see from the evidence presented below, this is too simplistic and even if it were true it would not imply that “Overpopulation is the single factor driving climate change [and other environmental and resource problems]” as asserted in a recent AVAAZ petition\(ix\).

**How is wealth and GDP defined and how are they related?** Has global growth in wealth-related consumption of goods and services been the main driver of greenhouse gas emissions rather than population growth? Has population growth had a lesser though important effect on emissions by increasing the number of consumers? Before we seek to
answer these questions, we first need to consider what wealth is and how it relates to consumption. To do this we need definitions. Wealth is about assets and can be defined as the combined monetary value of assets less liabilities. Assets can be subdivided into personal property, monetary savings and the capital wealth of income producing assets, including real estate, stocks, bonds, and businesses. It can be argued that, generally speaking, wealth is not of itself a problem from a climate perspective until it is spent. As long as wealth sits in a bank’s computers in the form of digital code or, in gold bars in a vault, its carbon footprint is very low. According to this argument wealth becomes a problem when it is spent as private consumption, government expenditure, the purchasing of investments, and to finance exported goods and services. The total of this expenditure in cash terms at national level is referred to as gross domestic product (GDP) which can also be defined more concisely as the total value of goods produced and services provided within a country in one year.

So, in a planet still heavily dependent on fossil fuels for energy, the consumption of goods and services drives fossil-fuel related emissions. But goods and services cannot be consumed unless they are produced or provided. Accordingly, as we shall see later, emissions can be accounted for under consumption or production headings at national or regional level. Both methods of accountancy are useful.

Although it is arguable that emission are more directly related to consumption rather than wealth this does not mean that increased wealth does not contribute to the climate problem. This is because in general, the wealthier an individual, socio-economic grouping or nation, the more goods and services it consumes, the more energy it uses, and the more fossil fuel-related emissions it produces. This, as we shall see later, does not imply that the relationship between GDP and fossil fuel emissions is linear (statistically following a straight line), or is unalterable, or that no other factors help to determine emissions.

GDP per capita at national or global level is often used as a measure of the average standard of living. Gross Domestic Income (GDI) per capita is in theory identical in amount to GDP per capita as within a country, total GDI should equal total GDP. However a difference in the way in which accountancy is done for GDI and GDP result in slight discrepancies between the two measures. Thus, it is reasonably accurate to state that GDP relates to income or expenditure. It is important to remember that GDP per capita has the major limitation that it gives no indication of how GDP is distributed within a country. If it is distributed very unevenly those in the bottom tenth will consume much less and produce less emissions than those in the top tenth. We discuss the effect of GDP distribution on energy use and fossil fuel emissions later in this communication.
What is the relationship between population growth and GHG emission rates? Figure 1 taken from Satterthwaite (2009) enables the growth in both population and annual production emissions of GHG (expressed as CO₂ equivalent emissions) to be compared over the period 1980-2005 for countries grouped according to their income per capita. The grouped data clearly shows no relationship between rate of population growth and rate of emissions growth over this period. Similarly Figure 2 from the same source shows that there was no relationship between the rate of population growth and emissions growth for the five countries with the highest emissions growth rates. Three of these fast growing emitters are very highly developed (USA, Japan and South Korea) and two moderately developed (China and India). Taken together, the lack of relationship between emissions growth and population growth shown in Figures 1 and 2 provides strong evidence that rapid population growth has not been the principal cause of growth in national production emissions since 1980.

![Figure 1](image-url)

**Figure 1.** Growth in population and CO₂-equivalent emissions (production figures) over the period 1980–2005 by groups of nations classified according to their average per capita income levels. This illustrates the lack of relationship between population growth and emissions growth. Source: Satterthwaite (2009) loc.cit.
So if the population growth rate isn't the primary underlying cause of the current high rate of GHG emissions and impact on the global environment, what is? Evidence that Income per person and not population size, population density, or population growth rate is the primary determinant of environmental impact at national level comes from the work of Bradshaw et al. (2010). These authors developed a novel measure of environmental impact at country level. The measure takes into consideration natural forest loss, natural habitat destruction, effect on fish stocks, fertilizer use, water pollution, carbon emissions, and species loss. They used these scores to rank 228 countries in order of their contribution to degradation of the global environment. They also ranked these countries separately for five additional parameters: wealth as measured by Gross National Income (GNI) adjusted for parity in purchasing power (GNI-PPP); population growth rate; population size; population density; and an indicator of quality of governance in the country. They found that total environmental impact rank was correlated only with GNI-PPP, and not with any of the other four socio-economic indicators, giving a highly significant (P<0.0001) positive rank correlation (Figure 3) which shows that, statistically, countries' impacts on the global environment increased significantly with income per person.
Figure 3. Plot for 228 countries shows highly significant correlation between gross national income rank and absolute environmental impact rank. The downward slope of the regression line in this somewhat unconventional plot indicates positive correlation. Source: Bradshaw et al. (2010) loc.cit.

The authors concluded that national income per person was the most important correlate of environmental impact. They also concluded that population size accounted for the additional variation in absolute impact environmental impact over and above that explained by GNI. The latter finding is in line with the hypothesis that population size has a lesser secondary though significant effect on global environmental impact. However the establishment of correlation is a necessary though insufficient requirement to establish causation particularly as the two variables, income per person and population size, are interrelated. However the fact that none of the three population-based parameters correlated strongly with environmental impact suggests that they are neither the single or principal underlying cause of environmental impact.

Next we present evidence that shows that total national energy use and annual CO₂ are both strongly related to GDP, supporting the hypothesis that manmade climate change is largely driven by wealth-led consumption. A scatter plot shows that for low to moderate income countries with GDPS less than about US$10 billion there is a close relationship between their national GDP and total energy use (Figure 4). The relationship is non-linear. It is somewhat less close at higher income levels in part because cheap oil prices in the rich oil-exporting
countries give rise to exceptionally high energy use compared to other similarly high income net oil importers.

Figure 4. The relationship between total national GDP and total primary energy use for low to moderate income countries. Each dot represents data for a different country. 2006 has been selected because it is the most recent year for which a reasonably complete data set is currently available and a log/log scale to accommodate the large disparities in GDP and energy use. The reader is encouraged to visit gapminder to follow the historical development of changes in energy use and GDP. Source: http://www.gapminder.org/

As would be expected from Figure 4, the relationship between wealth and energy use can also be seen in a scatter diagram from a different source which shows how energy use per capita and GDP per capita changed with time (Figure 5). The decline in the rate of increase in energy consumption also seen in carbon emissions, starting at income levels above about $2,000, probably represents a shift from an industrial towards a service economy. The individual trajectories in this plot show that the close relationship between GDP per capita and energy consumption per capita has generally been maintained over long periods. The trajectories also give an indication that in general there is a “toe-in”, an initial region in the plot in which energy consumption increases slowly at first at very low levels of GDP per capita.
before accelerating. This toe-in probably arises for two reasons: First, an increase in income of the poorest people is initially spent on satisfying unmet primary needs including the intake of locally produced staple foods and other essential items with low energy and carbon footprints. As wealth increases households start to be able to afford lower priority items including white goods, consumer electronics, meat, motorised transport and other services to satisfy secondary needs, all with higher footprints. Second, with increased income there is often a switch to fossil fuels and electricity from biomass fuels, for example wood and dried animal dung not usually included in primary energy surveys. The implications of the toe in is that any national or international redistribution of wealth from those with high or middle incomes to the poorest would in general be likely to produce a net overall drop in energy use and perhaps in greenhouse gas emissions. In general at about GDP-PPP (2005) per capita of about $20,000 the log/log plot of energy use with increasing GDP tends gradually to flatten out somewhat (Figure 5).

Figure 5. Relationship between energy use per capita (measured in tonnes of oil equivalent) and GDP per capita (measured in US$ with equivalent purchasing power in 2005). The trajectories show how individual countries’ energy use has changed with GDP over time. Source: [http://stochastictrend.blogspot.com/2009_09_01_archive.html](http://stochastictrend.blogspot.com/2009_09_01_archive.html). Individual trajectories can be followed more clearly by selecting the appropriate plot at [http://www.gapminder.org/](http://www.gapminder.org/).
The relationship between GDP and energy use seen in Figures 4 and 5 stems from a circular relationship between these two parameters. The availability of cheap fossil fuel has been an important driver of GDP generation while national GDP in turn largely determines how much energy each nation uses.

As nearly all national economies are highly dependent on fossil fuels, the close relationship between GDP and energy consumption underlies the relationship between them seen in the scatter diagram of CO₂ emissions per capita and GDP per capita plotted country-by-country (Figure 6). The greater scatter in this plot compared with those for energy use (Figures 4 and 5) probably results largely from variations in carbon intensity of the economy (tonnes of CO₂ emissions per $ GDP) from country to country. The latter parameter is defined and discussed in more detail later in the paper.

**Figure 6.** The relationship between annual GDP per capita (PPP$ inflation adjusted) and annual fossil fuel-derived CO₂ emissions (tonnes per person). Each dot represents data for a different country. [http://www.gapminder.org/](http://www.gapminder.org/)
A further conclusion can be drawn from the plots shown in Figures 4, 5 and 6. Only in a few of the richest countries with GDPs per capita over about $40,000 is there any indication of an actual decline in per capita energy consumption and carbon emissions. Thus these plots provide little evidence for the decrease in either energy use or emissions decrease at high levels of national GDP as would be predicted on the basis of the Environmental Kuznets Curve theory\textsuperscript{xvii}, at least at GDP per capita levels up to about $70,000. The theory, now largely discredited, has been used to provide an environmental justification for continued economic growth by the rich. Its central postulate is that market forces drive a natural cycle of economic activity which first increases inequality, and then decreases it after a critical, high level of average income is attained. A corollary of the theory postulates that progress to the highest levels of economic development is accompanied by a switch from physical capital (factory buildings, machinery and other physical tools for production) to human capital (knowledge, social and personal skills including creativity) for generating GDP, entailing reductions in energy intensity of the economy, and in greenhouse gas emissions and other forms of pollution. The lack of evidence for the Kuznets hypothesis in the plots presented above is in line with a recent review\textsuperscript{xviii} of the empirical literature.

Druckman and Jackson (2008)\textsuperscript{xix} provide further evidence for a link between income on the one hand and energy use and emissions on the other, based on a household survey of energy use in the UK in 2004. This excluded personal transport and energy embedded in goods and services purchased by households. The survey showed that, when all the national data was considered, there were strong positive correlations between disposable income (DI) and total direct household energy use, and between DI and associated carbon dioxide emissions ($r=0.27$; $p<0.01$ for both). Interestingly, the correlation was marginally stronger for electricity ($r=0.25$; $p<0.01$) than for gas ($r=0.23$; $p<0.01$)\textsuperscript{xx}. A subsequent paper by the same two authors\textsuperscript{xxi} examined, for six different socio-economic groupings, the carbon footprints disaggregated into CO\textsubscript{2} emissions from direct energy use, personal flights, purchase of goods and services, and personal vehicle transport. The study further emphasises the importance of income as a determinant of carbon footprints in the UK. In the authors' words, “The findings highlight the sheer scale of the challenge facing UK policy-makers, and suggest that policies should be targeted towards segments of society responsible for the highest carbon footprints.”

Further evidence that growth in GDP per capita has had a greater effect than the population growth on global fossil fuel-related CO\textsubscript{2} emission comes from data covering 1971-2009 recently published by the International Energy Agency (IEA)\textsuperscript{xxii}. This is summarised in Figure 7 which shows changes in global CO\textsubscript{2} emissions, global GDP per capita, energy intensity of GDP...
and carbon intensity of energy, all normalised by setting 1971 values to 100% for ease of comparison. These variables are the components of the so called Kaya identity which seeks to describe the annual rate of global energy-related CO$_2$ emissions in terms of population size, GDP per capita, and carbon intensity of the economy. These terms are defined in the next section. Figure 7 shows that from 1971-2009, emissions increased by 105%, GDP per capita increased by a very similar value (106%) while the population grew by a markedly smaller but still large 79%. These percentages are in line with the hypothesis, supported by evidence cited earlier in this paper, that growth in GDP per capita rather than in population size played a greater part in determining global emissions from 1971-2009 and is certainly not compatible with the suggestion that population was the principal or single determinant of global emissions. This argument is further supported by the fact that the emissions curve rather closely follows the fluctuations in the GDP per capita curve while that of population growth does not. The closer relationship of emissions to GDP per capita is borne out by a comparison of the correlation coefficients ($R^2$) for the raw data used to prepare the summary shown in Figure 7; 0.9834 for emissions against GDP and the smaller value of 0.9501 for emissions against population growth.

More evidence that GDP has been the main determinant of fossil fuel related emissions comes from a study by Raupach et al (2007) who used data for 1980 to 2004 from the EIA, CDIAC, UN and IMF instead of the IEA. These authors showed that global, national and regional emissions for this period can be explained mainly by changes in economic activity corrected for changes in carbon intensity of the economy.

In summary, the evidence presented so far is in line with the hypothesis that, in general, income or expenditure determines energy use which in turn drives GHG emissions as most countries energy is supplied largely by burning fossil fuels, currently without carbon capture and storage. Put in the simplest terms, climate change has in the past been more the consequence of the global GDP explosion than the population explosion. Climate change certainly cannot be blamed on the rapid population growth of the poorest in developing countries whose consumption of goods and services is minimal.
GDP growth, population growth and the Kaya identity. As GDP per capita appears to have been the largest primary determinant of annual GHG emissions, can we dismiss the impact of population growth on climate change? Certainly not – global population growth has had a significant and very important effect on emissions. We now discuss this in relation to the Kaya identity developed by Japanese energy economist Yoichi Kaya. This describes total global carbon emissions arising from fossil fuel use as the product of four terms, the global population, GDP per capita, energy intensity of GDP generation and carbon intensity of energy generation as follows:

Total carbon emissions from fossil fuel use = population * (global GDP / population) * (total primary fossil fuel energy supply/ global GDP) * (carbon emissions/ total primary energy supply)

- where the third and fourth terms of the identity are respectively the primary energy required on average to create a dollar of the world’s GDP and the quantity of carbon emitted on average in producing a unit of primary energy supply. These two terms depend largely on

Figure 7. Changes in global energy-related CO₂ emissions and factors influencing this (1971-2009) (see text). Source: IEA loc.cit.
technological choices. The product of the third and fourth term simplifies to what is called the carbon intensity of the global economy (carbon emissions/unit global GDP). The product of the first two terms, average GDP per capita and global population is global GDP. Thus the evidence presented above that global fossil fuel-related emissions over the period 1971-2009 correlated very closely with global GDP per capita and less closely with population size is in agreement with the hypothesis that growth in the former has played the largest part in the growth of energy related emissions while population growth has had its smaller effect on emissions by increasing total global GDP.

While the Kaya identity as initially conceived refers to global emissions it can also be applied at other scales, for example at national level, using either emissions derived from production or consumption within territorial boundaries, provided that the data is chosen consistently and appropriately. Both measures are relevant for informing national reduction policies. The Kaya identity therefore also provides a useful checklist of the four approaches that can, at least in theory, be used to reduce emissions: reduction in GDP per capita; reduction in population; increase in the efficiency with which energy is used to produce GDP (energy intensity); and reduction in carbon emissions produced by the energy mix (carbon intensity).xxviii

There is a limit to the extent to which energy efficiency of GDP generation (energy intensity) can be improved. This is because most forms of income generation involve devices which convert one form of energy into another. Although it is possible to switch from less efficient devices to more efficient ones, the efficiency of even the most efficient device is still limited by the second law of thermodynamics, a corollary of which states that no energy converting device can be 100% efficient. Practical considerations also limit the reduction in carbon intensity as this can only be achieved by a switch to energy sources that produce less CO$_2$. The latter include renewable sources, fossil fuel burnt with efficient carbon capture and probably nuclear power. We have written “probably nuclear power” because the extreme complexity of the civil nuclear fuel cycle and its entanglement with the military nuclear fuel cycle makes life cycle analysis of CO$_2$ emissions unreliable. Be that as it may, there are doubts about whether alternative energy sources can be deployed at a rate and extent sufficient to prevent rapid and dangerous warming. For example, industrialised agriculture is currently highly dependent on oil for traction and natural gas for nitrogenous fertilisers making its complete decarbonisation difficult. In addition the law of diminishing returns may apply to attempts to achieve improvements in both carbon intensity and energy intensity.

The effect of these limitations can be seen by referring back to Figure 7 which shows that although the 40% reduction in energy intensity and 6% reduction in carbon intensity of energy
between 1971 and 2009 reduced emissions by approximately 40% compared with what they would have been without these improvements, they were nowhere near enough to prevent the massive rise in emissions resulting from the 106% increase in GDP per capita and 79% increase in population. Forward extrapolation of the energy intensity and carbon intensity curves suggests that enormously increased effort is required in these if the global economy is to be decarbonised in time to prevent catastrophic global warming unless there is a parallel reduction in global GDP. As we have seen the latter can only be reduced by manipulating two factors, GDP per capita and global population. However few politicians are likely to be elected for advocating planned economic contraction or a steady state economy. This is despite the increasing evidence that both the global economy and the global environment are hitting the biophysical limits to growth. As GDP is a poor indicator of wellbeing, there is increasing awareness that its reduction would not necessarily be coupled with a reduction in the quality of life, particularly if GDP per capita was distributed more equitably.

The effects of economic recession on emissions. Recent work by Peters et al (2012) highlights the effect of negative economic growth on both fossil fuel related emissions and carbon intensity of the economy. Figure 8 taken from their paper shows that annual global emissions actually fell in the last four recessions between 1960 and 2010 while the rate of growth in emissions also stalled in the first recession in this period but was not significantly negative(See Figure 8). It also shows that, while the overall trend over the period was towards a reduction in carbon intensity the rate of improvement has declined. There is also some suggestion that the rate improvement in carbon intensity generally increased during the four years preceding the onset of each recession and fell again at some time during the recovery period. This can also be seen in the energy intensity data from the IEA (See figure 7). In this connection it should be noted that 10 out of 11 of the most recent recessions have been immediately preceded by a rise in oil prices generally correlated with rises in other fossil fuel prices. Thus in the run up to a recession, high energy prices and the need to maintain growth may motivate a switch to less energy intensive methods of production resulting in the observed increase in the rate of improvement in the carbon efficiency of GDP generation. It is possible that increased funds for investment assisted this switch. The switch to less carbon intensive production to maintain economic growth may also explain why, in percentage terms, global GDP per capita has varied less than emissions over the last four decades (see Figure 7). Thus both overall trends and short term fluctuation in GDP are important in determining emissions.
Figure 8. Annual global CO2 emissions and carbon intensity. Emissions of CO2 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 GDP PPP 2000; red curve). Note that the axis for the latter is inverted for ease of comparison with the emissions curve. The most important recent financial crises are highlighted with a linear trend fitted to the five years before the beginning of each crisis. Source: Peters et al. (2012) loc. cit.

Present and future changes in national responsibility for climate change. As we have seen above, the increase in emissions in the 20th century was in the main, attributable to economic growth in the Annex B (“Developed”) countries while the world’s poorest people had little impact on emissions. This is not to imply that accelerating economic growth in so-called “developing” (non-Annex countries) with emergent or rapidly developing economies has had or will have little impact on climate change. Indeed the aggregate production plus consumption emissions of the non-Annex countries overtook those of the Annex B ones in 2007 (see Figure 9). This was largely due to the outsourcing of production to the BRIC
countries and the latter’s rapid economic growth.

Figure 9. Annual fossil fuel related CO2 emissions from 1990 to 2010 of developed (Annex B) and developing (non-Annex B) countries with emissions allocated to production within the territory (as 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. Bunker fuels are not included in this figure. Source: Peters et al. (2012) loc.cit.
The aggregated total annual emissions of the non-Annex countries continued to rise after 2007, while those of Annex B countries fell until the start of 2009. This mainly due to a slowing of the western economies as a result of the global financial crisis in 2008 while the economies of the BRIC countries continued to grow rapidly. This in turn probably resulted from the latter economies countries smaller dependence on both expensive fossil fuel imports and debt to fuel their economies. 2009 was the first year that their non-annex countries consumption emissions exceeded those of Annex B ones as a consequence of growth in domestic consumption while in the same year China’s annual emissions exceeded those of the United States.\textsuperscript{xxxii}

The fact that non-Annex countries aggregated annual emissions have overtaken those of the Annex B means that in the future, their aggregated cumulative ones \textsuperscript{iii} may also eventually overtake those of the developed ones if current trends continue. There are two reasons for thinking that this may happen. First, although the rate of economic growth in the BRIC countries had started to slow in 2012, their economies are still collectively expanding faster than those of the developed and highly developed countries. Second the economies of a further group of Annex B countries including Bangladesh, Indonesia, South Korea, Mexico, Nigeria, Pakistan, and the Philippines with large, growing and youthful populations may also grow significantly in the near future\textsuperscript{xxxiii}. However, although several of the moderately developed, and even a few of the least developed, countries have shown increases in GDP in the last five years, it is far from certain that this economic improvement will continue into the future. The peaking of conventional oil, water, phosphate fertilizers, food, water and other resources threaten economic growth in the underdeveloped countries at least as much, and probably more, than in the developed ones. In addition, climate change is likely to have effect on GDP in the least developed countries as it has been shown that years in which the regional temperature was 1°C hotter than average are associated with an average reduction their GDPs of 1.3% while the effect of such heat shocks can last as long as ten years.\textsuperscript{xxxiv}

Many other factors may continue to have negative impacts on the economic development of the least developed countries. These include the imposition of inappropriate free-market/ free-trade policies by the World Bank and the IMF \textsuperscript{xxxv}, other aspects of neo-colonialist exploitation \textsuperscript{xxxvi}, corruption, dictators, and armed conflict.

What are the implications of the above analysis for changes in national and international policy on climate change and economic development? We have reviewed the evidence that economic development in BRIC countries and other emergent or rapidly growing economies is having an increasing effect on global emissions,
partly as a result of their increasing exports to the developed countries. This raises the question of what is the fairest way to apportion responsibility for action on climate mitigation and adaptation to each country. Should it be simply on the basis of current cumulative or annual emissions estimated on the basis of the Kyoto protocol and therefore only counting production emissions? Against this proposal is the strong argument that fairness dictates that a BRIC country’s increase in emissions resulting from our outsourcing of both manufacturing and the supply of raw materials should be allocated to the importer rather than the manufacturer. For example, if this was done China’s emissions for 2006 would fall from 5,500 to 3,840 mtCO$_2$ and the rate of the growth rate of emissions between 2001 and 2006 would be reduced from an average of 12.5 per cent p.a. to 8.7 per cent p.a. $^{xxxvi}$ A compromise would be to share consumption emissions between importer and exporter, not necessarily on a 50/50 basis. Whatever the outcome of this debate it is manifestly clear that the changing economic circumstances mean that country’s existing listing $^{xxxviii}$ as Annex B or non-Annex cannot be used as a basis for equitable action on climate change.

A further consideration is that fairness and pragmatic considerations require that the least developed countries that currently have relatively little impact on emissions should be encouraged or allowed to develop. Consideration of trends in global emissions and carbon sensitivity shown Figures 7 and 8 might be taken to suggest that this would lead to an increase in carbon emissions. It is certainly clear that in the past that economic growth non-Annex B countries has been coupled with an increase in emissions as can be seen in the trajectories viewed on www.gapminder.org (see caption for Figure 6). However, as we have noted above there is some evidence that, in the poorest countries and individuals, energy use increases slowly at first with increase in GDP in the “toe in” region before accelerating at moderate incomes. This means that on a global scale any transfer of wealth to the poorest individuals and countries from the richer or richest would be likely to lead to a net global reduction in total energy use and fossil fuel related greenhouse gas emissions. This could be described as a negative Kuznets effect. One practical way of achieving this redistribution of income to the poorest, least emitting individuals would be to introduce national Cap and Share $^{xxxix}$ or Cap and Dividend $^{x}$ carbon trading schemes. An international or EU scheme would also result in some redistribution of income between countries. The upstream cap in these schemes would provide the primary and potentially very effective way of cutting emissions while the discussion above is relevant to how to determine the the size of each country’s cap.

The leaders of the low income, high fertility countries are very aware that their countries already, and will increasingly in the future, bear the brunt of climate change caused largely by
the developed and BRIC countries. Events at the UN Climate Change Conferences in Copenhagen and Cancun make it manifestly clear that international agreement on mitigation of climate change will not be achieved unless the rich and emergent nations accede to demands of the poor countries for financial assistance to help them adapt to climate change, limit emissions increases, and reverse the destruction of their forest carbon sinks. Some of the funds required for this could be obtained from the global operation of Cap and Share or similar schemes.

**The impact of population policy.** We have seen above that reductions in the rate of population growth could eventually play a part in reducing the increase in global emissions growth by helping to reduce the rate of increase in aggregate GDP. This means that the greatest impact of population reduction on decline of fossil fuel-related emissions would take place if it occurred in the highest income countries and in the richest families in these. As we have argued above, an equivalent reduction in the population growth rate in the poorest families and poorest countries is likely to have a much lower impact on emissions, at least at current income levels.

Data for March 2011 from the Population Reference Bureau shows twenty countries currently with negative or zero population growth (Ukraine, Russia, Belarus, Bulgaria, Latvia, Lithuania, Hungary, Romania, Estonia, Moldova, Croatia, Germany, Czech Republic, Japan, Poland, Slovakia, Austria, Italy, Slovenia and Greece). All except Japan are located in Europe. Although many of them are the poorer central and southern European countries, all are classified on a world scale as highly or very highly developed. All this is hardly surprising as the demographic transition required for reduced population growth rates is dependent on mainly expensive socioeconomic improvements predominantly the prerogative of the richer countries. These include better public health and health care leading to reduced child mortality, widespread adult female literacy, and good employment prospects for women and child care while they are at work, good child welfare, and the provision of care and financial security for the elderly.

Zero or negative population growth in a given country does not, however, necessarily imply a global reduction in greenhouse emissions; it depends on how much of the decrease in population growth rate has been produced by emigration, how much the émigrés earn in the country to which they migrate, and the carbon intensity of the economies of the two countries in question. In this connection, recent population growth in the UK’s is linked to both immigration from central and Eastern Europe and higher birth rates in recent immigrants. Thus the effect of the negative population growth rate in Poland and other central European
countries on emissions reduction may be partially or wholly offset by an increase in emissions as émigrés from these countries. This is because, at least in the past, these émigrés have generally increased their GDI-PPP and hence personal carbon footprints by working in the UK. However, although the Population Reference Bureau's predictions of future population growth rates do not account for changes in immigration and emigration, even when these are taken into consideration, out of these 20 countries listed above, only Austria's population is predicted to grow. This may be encouraging from the perspective of emissions reduction, but there is clearly scope for other developed countries with high current emission rates including USA, Canada, UK, France and the Scandinavian countries to join this list of countries with negative population growth rates. However negative population growth resulting solely from an increase in emigration is likely to increase rather than decrease global emissions as we have already noted. Moreover, the ageing population that accompanies the demographic transition is not without its problems and some of these are already apparent in China.

The BRIC countries currently account for some 40% of the world population and have the following population growth rates: Brazil 1.26, Russia -0.51, India 1.46, China 0.47 per cent per annum, according to UN figures for 2005-2010. There is therefore considerable scope for Brazil, and India to reduce emissions growth by reducing the population growth rate. This holds true even if the argument above is accepted that they should not be held responsible for their emissions resulting from exports.

However, population control measures cannot be the first line of action to reduce global GHG emissions for the following reasons:

First, while China's “One Child” policy with near-compulsory abortions and selective female infanticide was effective in producing a rapid reduction in population growth rate, it is inconceivable that such policies could be introduced in the developed countries or in Brazil and India, or even in today’s China.

Second, the slowness of the removal of carbon dioxide from the atmosphere has the consequence that global emissions need to start to fall in the next few years and decline to practically zero by 2050. Even more seriously, a growing body of evidence suggests that carbon negativity is probably required by 2050 to give a reasonable chance of avoiding disastrous warming. However the slow response time of acceptable population policies means that they are likely to have only a small impact within this time frame.

Third, there is no easy and cheap method for reducing birth rates. The universal availability of effective and affordable artificial methods of contraception for both men and women though
highly desirable is only a small factor in accelerating the demographic transition. Effective policies depend on far reaching and expensive socio-economic changes as outlined above.

Fourth, our argument above from the Kaya identity suggests that unless the percentage level of population reduction resulting from population policies was larger than the percentage reduction in per capita GDP, the effect of the former on emissions would not offset the effect of economic growth. Although it is at present unthinkable that any country would voluntarily reduce their GDP, the predicted future scarcity of water, food, oil and other resources and the impact of climate change may result in a global scale, unplanned, irreversible and catastrophic reduction in both GDP and the human population. The combination of the interdependence of economies resulting from: globalisation; economic instability from fractional reserve banking and the dependence of western economies on debt; and potentially escalating conflict in the Middle East and North Africa increases the plausibility of this scenario. While an unplanned and irreversible crash would be likely to reduce man-made greenhouse gas emissions it would have unspeakably dreadful consequences for human societies.

Planned economic contraction would be infinitely preferable to unplanned, and perhaps irreversible, economic collapse if it had limited negative impacts on wellbeing. A modest planned reduction in national GDP could produce a large reduction in emissions. In this connection it is interesting to note that in 2009 during the recession following the Credit Crunch, an unplanned reduction of 2.8% inflation adjusted GDP in the UK, was largely responsible for a 9.8% reduction in its carbon dioxide emissions in the same year.

Our argument here that population growth has not been the principal cause of climate change does not imply that rapid population growth is not a contributory factor limiting the ability of poor countries with high birth rates to adapt to climate change. Nor does it imply that population growth is not an important factor in the causation of many other environmental and resource problems.

**Summary and policy implications**

1. **Climate change has not been solely or even primarily caused by population growth, least of all by rapid population growth in the low income, high birth rate countries. We argue that the prime driver of increasing greenhouse gas emissions has been economic growth per capita fuelled by cheap fossil fuel prices, borrowing and consumerist**
policies. Population growth does however play an important, though to-date significantly smaller part in causing climate change by contributing to the increase in global consumption. It is extremely difficult to predict whether the rate of global economic growth per capita will be higher than that of global population growth in the next 20 years.

2. Population policies in the least developed countries with high birth rates will not produce large reductions in global emissions within the time scale dictated by the latest climate science.

3. Vigorous population policies in the highly and very highly developed, BRIC and other countries with emerging economies could eventually play a part in reducing emissions but cannot be the first line of action as their effects are too slow to produce the required emission cuts. Reduction in consumption by wealthier individuals would have a quicker and larger impact. There is a strong argument that fiscal policies should be used to do this.

4. Far-reaching changes in economic, technological, social and political systems are needed if disastrous global warming is to be prevented. These changes entail concerted action on: both economic and population descent; a large improvement in both energy efficiency and carbon intensity; and the maintenance of existing carbon sinks and the development of new ones on a very large scale. In addition, the enormous size of the remaining fossil fuel resources particularly of coal and of planned projects to extract them means that the unabated burning of fossil fuels needs to be capped at a rate in line with the latest science. This could be achieved using modified carbon
market mechanisms such as Cap and Share\textsuperscript{iv}, or Cap and Dividend\textsuperscript{iv}. Massive geo-engineering projects may also be required but their effect on local climate is unpredictable and might be damaging to some countries, particularly the least developed ones. Attempts to reduce energy efficiency and carbon intensity are unlikely on their own to address the scale and urgency of the problem. The rate and extent of reductions in emissions is unlikely to be sufficient unless economic growth is halted and reversed.

5. While it is currently unthinkable that countries would introduce policies designed to reduce GDP per capita and population growth, such policies could have a dramatic impact on fossil fuel consumption and energy related greenhouse gas emissions. If global GDP per capita and population are not reduced, serious oil supply/demand imbalance and other resource limitations including food and water, exacerbated by climate change might trigger global economic collapse with advantageous effects on climate change. However the effects of such unplanned and possibly rapid economic collapse would be unspeakably dreadful and would impact much more seriously on the poor than the rich. There is considerable uncertainty as to whether such a collapse could take place within the time frame required to prevent catastrophic temperature rises.

6. Both climate change and the potentially worsening oil demand/supply problems require a rapid but planned transition to a carbon-neutral or even a carbon-negative global society. Such a society could have considerable social and health benefits. A planned transition is likely to have far better outcomes than a chaotic one.
7. Evidence reviewed here does not support the Kuznets theory which justifies economic growth on the grounds that it would eventually lead to emissions reduction. It does suggest that a more equitable redistribution of income from the richer and richest individuals and countries to the poorest could on its own have an advantageous effect on both total global energy use and emissions. It is also arguable that redistribution would also be likely to increase wellbeing and social cohesion and reduce conflict at both national and international levels. Such redistribution is also likely to be necessary if the developing countries are to agree to effective collective international action to prevent catastrophic climate change.

8. The current listing of countries in United Nations Framework Convention on Climate Change Annex 1 is no longer appropriate and needs to be extended to include countries whose economies have greatly expanded.

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Footnotes and references

In this paper we use a range of different measures for environmental impact including Total Environmental Impact, CO2 emissions and CO2 equivalent emissions. This is because no single source of data we have found shows the effect of all different socioeconomic factors of interest on CO2-equivalent emissions, the preferred measure for climate impact. The figures and tables reproduced here with the exception of Figure 8 are based on production emissions (Kyoto protocol) and do not include consumption figures (embedded emissions). The primary sources of the data should be consulted for further information on how values used have been calculated. The terms “very highly developed”, “highly developed”, “moderately developed” and “least developed” are used for countries respectively with human development indices ≥ 0.788, <0.788 and = 0.677, >0.677 and = 0.484, and <0.484 as assessed in November 2010 ("Human development Report". United Nations Development Programme. p. 139.)

Cumulative emissions since the start of industrialisation in a given country are a better indicator of culpability for climate change because CO2 is, in effect, very slowly removed from the atmosphere. This means that much of the CO2 deposited there by Britain since the start the industrial revolution initiated the rapid burning of coal is still contributing to climate change.

http://en.wikipedia.org/wiki/Kaya_identity

For a constantly updated estimate of the total world population see the US Department of Commerce population clock. http://www.census.gov/main/www/popclock.html


http://www.avaaz.org/en/petition/That_the_UK_government_should_takes_steps_to_limit_human_population/?cGSwtbb


The study only considers production emissions (emissions produced within the country). It would be interesting to examine the effect of consumption emissions (embedded emissions related to imported goods and services) on the relationship with national income.


Weighting between these factors will of course be controversial and will give different results compared with a measure based solely on greenhouse gas emissions. However the measure represents a useful attempt to assess the absolute environmental impact of different countries on the global environment.
GNI is calculated by taking a measure of adding all sources of income dividing it by the total population within a country. GNI-PPP is a more accurate comparison of standards of living across countries than GNP as it allows for differences in the purchasing power of different countries currencies with respect to a standard basket of goods and services. A GNI-PPP dollar (also referred to as an international dollar) has the same purchasing power as the U.S. dollar has in the United States in a given year.


http://en.wikipedia.org/wiki/Kuznets_curve


The weaker correlation for gas probably results from the fact that this is mainly used for domestic heating, and consequently its consumption is strongly influenced by factors other than disposable income including type of dwelling and its energy performance. The survey indicated that other factors, such as the type of dwelling, type of tenure, household composition and rural/urban location also had an important influence on energy use and emissions, and this was especially so for the size of the household.


Excluding non-CO₂ greenhouse gas emissions


The raw data summarised in Figure 7 can be downloaded as an Excel spreadsheet from a link given in this URL.


US Energy Information Administration (EIA), Carbon Dioxide Information Analysis Centre (CDIAC), UN Statistics Division (UN) and the World Economic Outlook of the International Monetary Fund (IMF).

http://en.wikipedia.org/wiki/Kaya_identity

This does not include greenhouse gas emissions arising from land use, land use change and forestry though these are probably for the main part indirectly driven by fossil fuel use.

Of course, in addition to reducing energy-related GHG emissions there are three other theoretical ways of tackling global warming: 1. Extracting CO2 from the atmosphere by enhancing natural sinks for example by massive afforestation; 2. Creating artificial CO2 sinks for example by applying carbon capture and storage to centralised electricity generation from sustainable biomass burning, ideally with combined heat and power generation; 3. Reflecting more incoming solar energy back out to space, for example by seeding cloud formation on a large scale. However there are serious concerns and uncertainties about the latter two approaches.


Peters et al. (2012) loc.cit.


http://en.wikipedia.org/wiki/Neocolonialism


http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php

DPK 29.01.2013


http://en.wikipedia.org/wiki/Cap_and_dividend


http://geography.about.com/od/populationgeography/a/zero.htm

http://www.prb.org/

Interestingly, recent population growth in the UK’s is linked to both immigration from central and Eastern Europe and higher birth rates in recent immigrants. Thus the effect of the negative population growth rate in Poland and other central European countries on their national emissions reduction may be offset by an increase in emissions as émigrés from these countries have in the past increased their GDI-PPP and hence personal carbon footprints by working in the UK. The situation is complicated by the fact that some of the earnings of émigrés are repatriated to their countries of origin. However overall, emigration from a poorer to a richer country is likely to increase global emissions.

The somewhat higher population growth rates in the northern and western European countries compared with the central and southern ones may result from their greater per capita incomes making larger families more affordable.


http://www.capandshare.org/

http://en.wikipedia.org/wiki/Cap_and_dividend