Economic growth, Population growth, and Climate Change

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David P. Knight, Winchester Action on Climate Change and Foundation for the economics of Sustainability. david.knight77@ntlworld.com

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Introduction. The main aim of this paper is to review the evidence that challenges the widely held view[i] that population growth is the most important underlying cause of increasing greenhouse gas (GHG) emissions from fossil fuel use. The paper also aims to review the policy implications of our analysis of the relationships between economic growth, population growth and greenhouse gas emissions. A consideration of the likely important effect of the size and growth of the global population on other environmental problems, including for example soil erosion and desertification, is outside the scope of this review. We review the evidence that the main underlying cause of the increase in fossil fuel related emissions has been the growth in global consumption as measured for example by global gross domestic product (GDP) defined more fully later and also known as gross world product (GWP). This metric can be considered to be the product of the global average per capita GDP and the global population. We show that faster growth in percentage terms of the former compared with the latter has had a larger effect on the growth in fossil fuel related emissions over the period for which accurate data is available (1971-2005). However we note that although over this period taken as a whole the global per capita GDP increased faster than the global population, much of this relative increase occurred after 2000 and it is far from clear how long into the future the growth in the former will outstrip the latter. We argue that collectively, the poorest individuals in the poorest countries, despite their generally higher rate of population growth, to date have made a far smaller contribution to fossil fuel based emissions than the richest individuals in the highly and very highly developed [ii] countries and those with recently advanced economies (Brazil, Russia, India and China known collectively as the BRIC countries). This is simply because the poorest's consumption is far lower than the richest's. However, the collective annual emissions of the BRIC and the poorest countries lumped with them in the category "developing countries" have recently 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[iii] , it could be argued that the greater responsibility for climate change may eventually shift from the aggregated "developed" countries to the aggregated "developing" ones. However it is necessary at the outset of this review to caution that the use of data aggregated or averaged at any level, including national or global, or grouped as developing or developed countries does not give the complete picture. This is because it fails to account for the distribution of consumption within groupings. The suggestion of the world famous climate scientist , Kevin Anderson cuts across this problem by concluding that application of the Pareto principle (also known as the 80/20 rule) [iv] makes it likely that the richest 20% of the world's inhabitants account for approximately 80% of emissions while the top 1% account for approximately 20%[v] .

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 as it ignores consumption and how this is distributed. Thus we argue that the AVAAZ petition [vi] which stated that, "Overpopulation is the single factor driving climate change [and other environmental and resource problems]" is incorrect. We argue instead that it would be accurate to claim that the most important factor underlying these problems is consumption. We would agree with AVAAZ if they had stated that the combination of growth in individual consumption and in the number of consumers are the major determinants of fossil fuel related emissions and other resource problems. We consider that even the present rate of global consumption cannot be sustained without increasing the risk of irreparable damage to the planet's climate and life support systems.

We start by considering how the world 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 closely with national population growth rate, population size, or population density but instead 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 consumption 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 CO_2 emissions correlate more closely over time with global GDP per capita than with global population. We then discuss these findings in relation to the Kaya identity[vii] 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[viii], the world population on the 7th 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 to between 7.5 and 10.5 billion by the year 2050 [ix]. However the UN predictions are only projected increases and are far from certain. 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 one or more of 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[x] [xi] [xii].

How are 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? 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 could 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. However even money sitting in a bank account has a carbon footprint as it can be loaned to both companies and individuals who in turn spend it on goods and service while wealth in the form of stocks and bonds also comes with a carbon footprint.

The total (grossed) expenditure, on private consumption, government expenditure, the purchasing of investments, and finance for exported goods and services less the expenditure on imported goods and services, a is referred to as gross domestic product (GDP) which can also be defined more concisely as the total value added 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 and wealth plays a part in consumption. 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 separate consumption and production headings at national or regional level. Both methods of accountancy are useful.

Although, as we have argued above, 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 are consumed, the more energy is used, and the more fossil fuel- related emissions are produced. 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 over time, or that no other factors help to determine emissions.

We discuss the effect on energy use and fossil fuel emissions of the way in which GDP is distributed from country to country and at national level within social groupings in a country later in this paper.

What is the relationship between rates of population growth and fossil fuel related emission growth within groups of countries and from country to country? Figure 1 taken from Satterthwaite (2009) [xiii] enables the growth in both population and annual production emissions [xiv] of fossil fuel related greenhouse gas emissions (expressed as CO_2 equivalent emissions) to be compared over the period 1980-2005 for countries grouped according to their income per capita. The grouped data indicates the lack of a close correlation between rate of population growth and rate of emissions growth over this period (Figure 1). Similarly Figure 2 from the same source indicates the absence of a close correlation 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 a close correlation between emissions growth and population growth shown in Figures 1 and 2 provides evidence that rapid population growth has not been the principal cause of growth in national production emissions between 1980 and 2005.

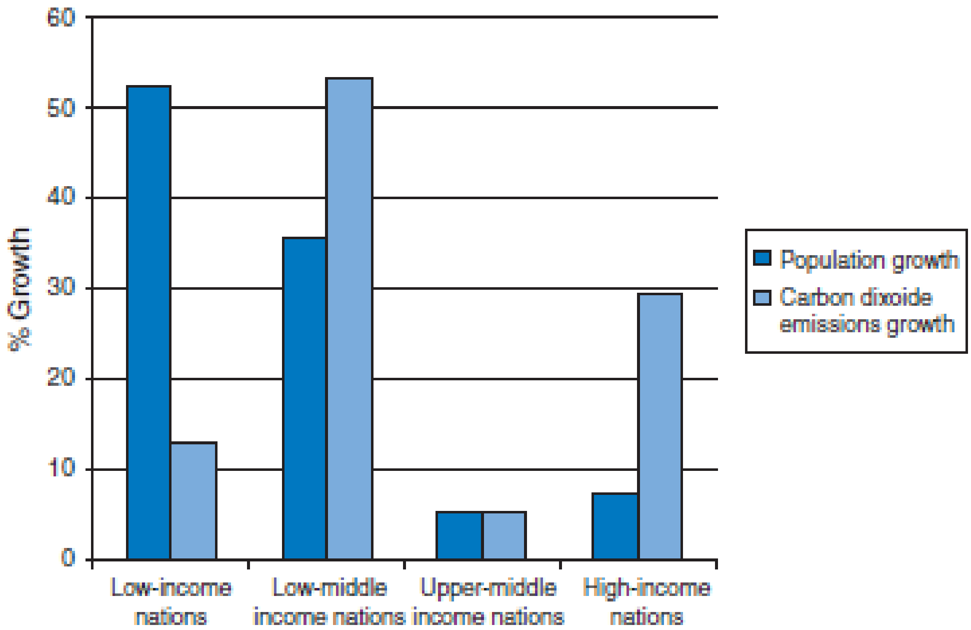


Figure 1. *Growth in population and CO_2-equivalent emissions (production figures) over the period 1980–2005 by groups of nations classified according to their average per capita income levels. This illustrates the lack of close correlation between population growth and emissions growth. Source: Satterthwaite (2009) loc.cit.*

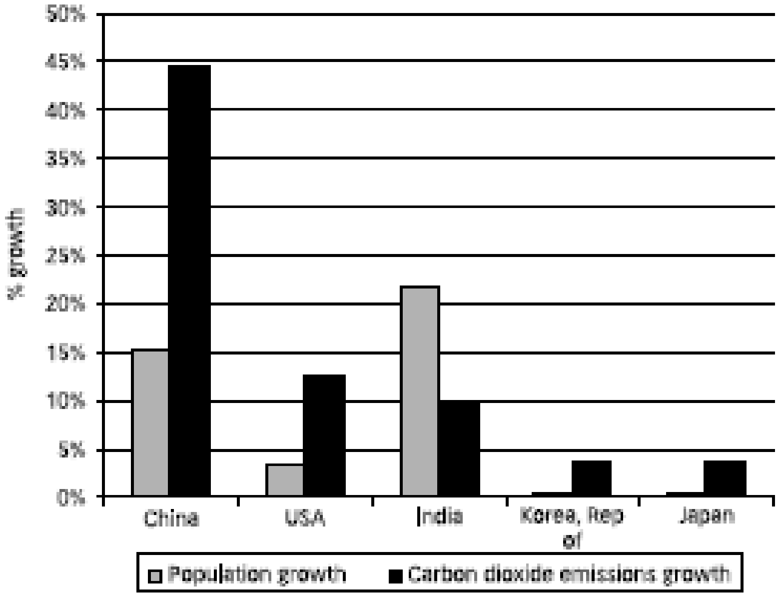
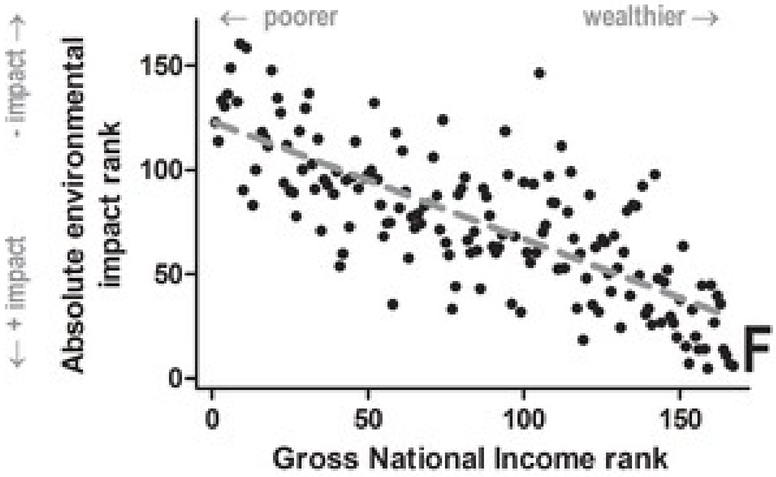


Figure 2. *Percentage growth in population and CO_2-equivalent emissions 1980–2005 by the nations with the largest growth in annual emissions. Source: As Figure 1.*

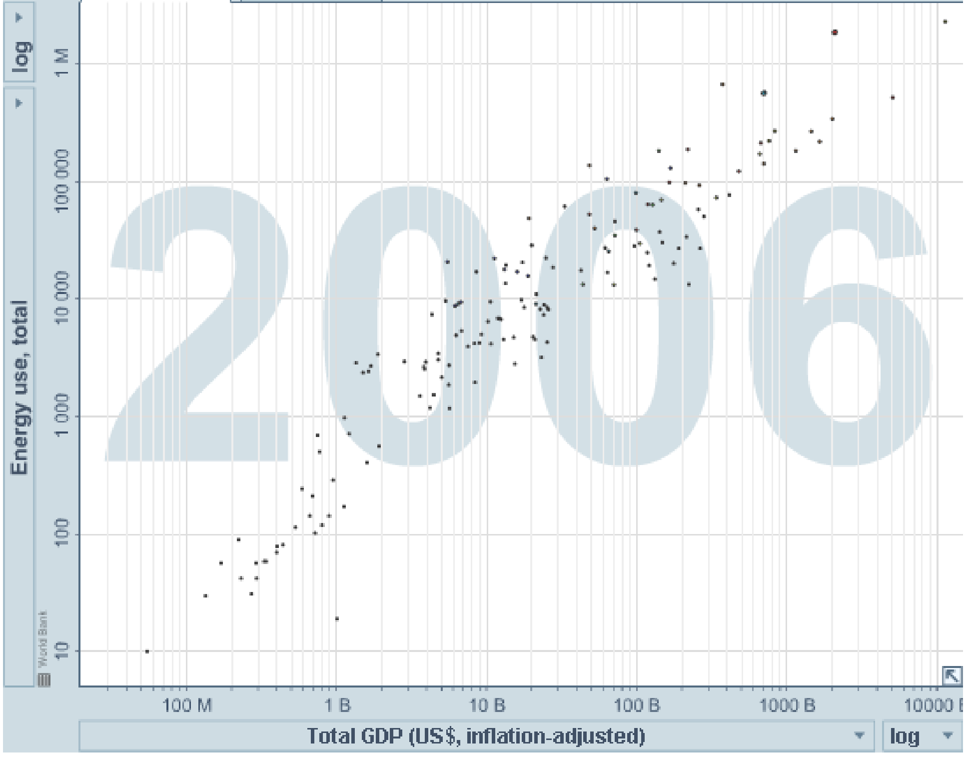
However a criticism of Satterthwaite's analysis is that it is incomplete as it is based solely on production emissions (emissions produced within a country) rather than consumption emissions which additionally include emissions resulting from the manufacture of imports (less emissions from exports). A more informative picture is likely to have emerged if consumption emissions had been used in place of production ones. A further criticism is that Satterthwaite's figures did not include emissions from land use changes. The latter omission needs to be considered as it is the largest source of greenhouse gas emission in a few, but by no means all, of the developing countries. For example in 2000, production emissions for Belize were said to be 8.4 tonnes CO_2 e per capita without land-use change and 93.9 tonnes per capita when land-use was added, giving a final figure about four times higher than the equivalent US one[xv]. Similar considerations apply to Guyana and Malaysia and likely to other countries that are in the process of rapidly losing their once extensive tropical forests. However it is to be noted that considerable uncertainty is attached to estimates of national annual greenhouse gas emissions from land use change[xvi], particularly with regard to methane emissions. In addition Satterthwaite's omission of land use change emissions is probably not as serious on a world scale as the data from Belize, Guyana and Malaysia figures might at first suggest. This is because averaged figures for the 1990's indicated that about 75% of global anthropogenic carbon emissions were derived from fossil fuel burning and "only" 25% from land use changes[xvii]. Thus it would be worth repeating Satterthwaite's analysis using consumption rather than production emissions, and including emissions from land use change.



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)[xviii]. 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[xix]. They also ranked these countries separately for five additional parameters: Average income as measured by per capita Gross National Income adjusted for parity in purchasing power[xx] (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 rank, 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 (negative) slope of the regression line in this somewhat unconventional plot indicates positive correlation. Source: Bradshaw et al. (2010) see text.*

The authors concluded that national income per person was the most important correlate of environmental impact. They also concluded that population size accounted for all of the additional variation in absolute environmental impact over and above that explained by GNI. The latter finding is in line with the hypothesis that population growth rate, population size and population density have had, compared with income per person, a lesser and secondary though significant effect on global environmental impact. However the establishment of correlation is a necessary though insufficient condition to establish causation particularly as the variables, income per person and the population parameters are interrelated. However the establishment of correlation is a necessary though insufficient condition to establish causation, particularly as the income and population variables are interrelated. Nonetheless the fact that none of the three population variables 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 CO_2 emissions are both strongly related to GDP, supporting the hypothesis[xxi] that manmade climate change is largely driven by income led consumption. A scatter plot shows that for low to moderate income countries with GDPs less than about US$10 billion there was a close relationship between their national GDP and total energy use (Figure 4). The relationship may be 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. The relationship is clearly not a straight line one in this log/log plot.

Figure 4. *The relationship between total national GDP and total primary energy use for low to moderate income countries. Each point 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, a similar relationship between per capita GDP and per capita energy can also be seen in a scatter diagram from a different source which shows how these parameters changed with time over the period for which data is available (Figure 5). The decline in the rate of increase in energy consumption also seen in carbon emissions (Figure 6) starting at income levels above about $2,000 probably represents a shift from an industrial towards a service economy. The individual trajectories in Figure 5 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. This exclusion is justified when analysing greenhouse gas emissions provided that the biomass fuels are derived from sustainable sources. The implications of the toe in is that any national or international redistribution of wealth from those countries with high or middle incomes to the poorest might in general produce a net overall drop in energy use and perhaps in greenhouse gas emissions. This would in part depend on whether their increase in income was large enough to take them into the rapidly accelerating part of the primary energy use curve and whether they moved away from sustainable biomass energy to a greater dependency on fossil fuels.

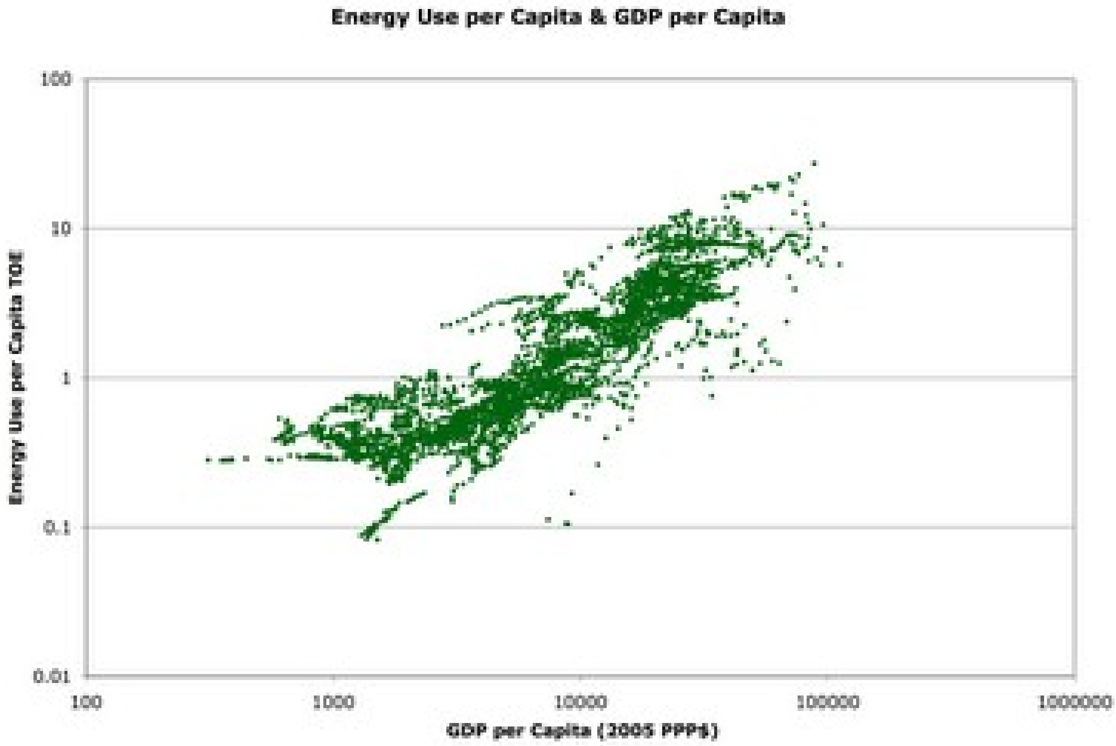


Figure 5. *Relationship between energy use per capita (measured in tonnes of oil equivalent) and GDP per capita (measured in US$ with equivalent purchasing power in 2005). The trajectories show how individual countries' energy use has changed with GDP over the period for which data was available. Source: 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/ .*

A further conclusion can be drawn from Figure 5. 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 the data does not provide evidence for the decrease in either energy use or emissions at high levels of national GDP as would be predicted on the basis of the Environmental Kuznets Curve theory[xxii], at least at GDP per capita levels up to about $70,000. This theory, now largely discredited, has been used to provide an environmental justification for continued economic growth by the rich. The central postulate of the original Kuznets Curve theory is that market forces drive a natural cycle of economic activity which first increases income 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 a accompanied by a switch from physical capital (factory buildings , machinery and other physical tools and infrastructure 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 in Figure 5 for the Environmental Kuznets hypothesis is in line with a recent review [xxiii] of the empirical literature.

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 is an important determinant of 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 country-by-country relationship between fossil fuel-related CO_2 emissions per capita and GDP per capita that can be seen in 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 CO_2 emissions per \$ GDP) from country to country. The latter parameter is defined and discussed in more detail later in the paper.

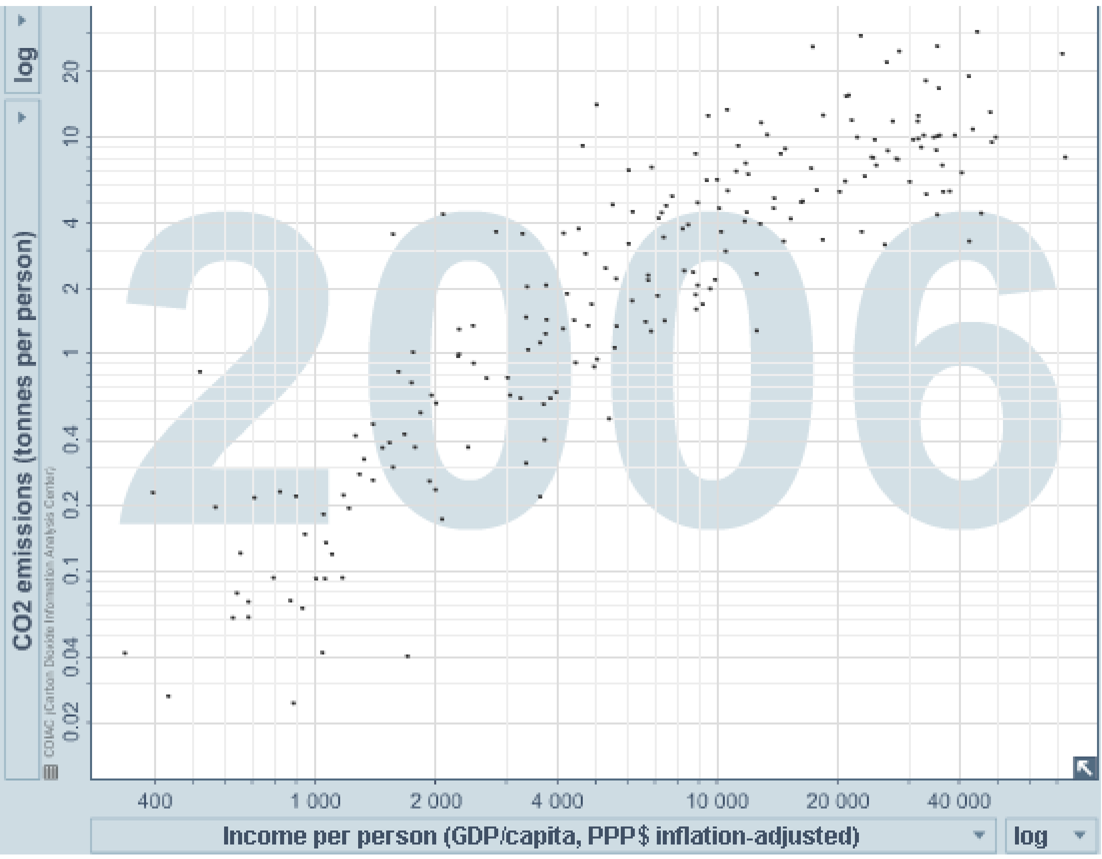


Figure 6. *The relationship between annual GDP per capita (PPP$ inflation adjusted) and annual fossil fuel-derived CO_2 emissions (tonnes per person). Each point represents data for a different country.* http://www.gapminder.org/

Again Figure 6 is based only on production emissions and does not include emissions from land use change. It would be interesting to repeat this analysis correcting these omissions.

Druckman and Jackson (2008) [xxiv] 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 ($r=0.23$; $p<0.01$) [xxv]. A subsequent paper by the same two authors [xxvi] examined, for six different socio-economic groupings, the carbon footprints disaggregated into CO_2 emissions[xxvii] 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_2 emission comes from data covering 1971-2009 recently published by the International Energy Agency (IEA)[xxviii]. This is summarised in Figure 7 which shows changes in global CO_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 [vii] 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.

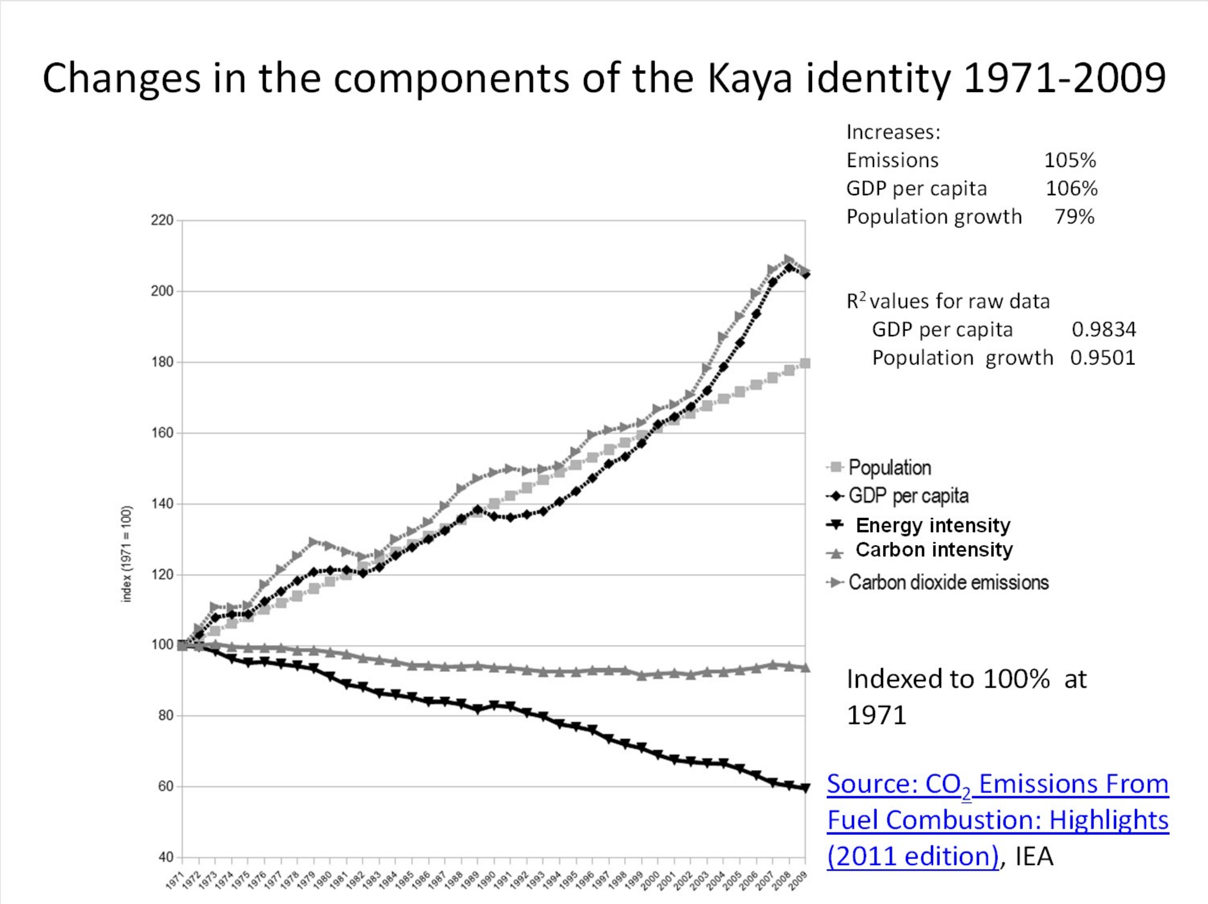


Figure 7. Percentage changes in global energy-related CO_2 emissions and in the different components of the Kaya Identity (see text). *Source: IEA loc.cit.*

Figure 7 shows that from 1971-2009, emissions increased by 105%, inflation adjusted 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 above, that growth in GDP per capita rather than in population size played a greater part in determining global emissions over the period 1971-2009 and is certainly not compatible with the suggestion that population was the principal or single determinant of global fossil fuel related emissions over this period. 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 per capita and the smaller value of 0.9501 for emissions against population growth. However it is to be noted that the percentage increase in global GDP per capita only exceeded that of the percentage increase in global population over the periods 1971-1982 and 2002-2009. A lack of reliable historic data makes it difficult to assess how these parameters changed between the onset of the industrial revolution and 1971. There is also considerable uncertainty about how these two parameters will change in the future.

More evidence that GDP has been the main determinant of fossil fuel related emissions over the period 1980 to 2004 comes from a study by Raupach et al (2007)[xxix] who used data from the EIA, CDIAC, UN and IMF[xxx] 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 considered so far is in line with the hypothesis that, in general in recent times, in economic groupings within the UK (Druckman and Jackson 2008, see above) and at the national and global levels, income and expenditure is the main determinant of both energy use and of fossil fuel related GHG emissions. Put in the simplest terms, the growth in fossil fuel related emissions has in the recent past been more the consequence of the global increase in income and consumption than the increase in population though population has contributed to global consumption. Fossil fuel related emissions certainly cannot be blamed on the rapid population growth of the poorest individuals in developing countries as their consumption of goods and services is minimal. However, as noted above, population growth rather than growth in per capita income may in certain developing countries have been the largest determinant of both greenhouse gas emissions from land use change and of other environmental problems including soil erosion and desertification.

GDP growth, population growth and the Kaya identity. As GDP per capita appears to have been the largest primary determinant of annual GHG emissions in recent years, can we dismiss the impact of population growth on climate change? Certainly not – global population growth has had a highly significant and very important effect on emissions. We now discuss this in relation to the Kaya identity [xxxi] developed by Japanese energy economist Yoichi Kaya. This describes total global carbon emissions arising from fossil fuel use[xxxii] 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 fossil fuel energy supply)*

- where the third and fourth terms of the identity are respectively the primary energy required on average to create an inflation adjusted dollar of the world's GDP and the quantity of carbon emitted on average in burning a unit of primary fossil fuel energy supply. The size of these two terms depends largely on technological choices. The product of the third and fourth term simplifies to what is called the carbon intensity of the global economy (carbon emissions per dollar of 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 (106% between 1971 and 2009) has played the largest part in the growth of energy related emissions while the slower growth in population (79% over the same period) has had a smaller effect, by increasing total global GDP, on fossil fuel related emissions.

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 fossil fuel related 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)[xxxiii].

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 to greater or smaller extent, 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 energy converting device must always have an efficiency of less than 100%. There is also the problem that increased efficiency of an energy conversion device leads to a reduction in costs and a consequent increase in energy use which can partially (Rebound effect) or totally (Backfire) offset any saving in emissions (Khazzoom–Brookes postulate and Jevon's paradox)[xxxiv]

Practical considerations about changing the energy infrastructure 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 any combination of alternative energy sources can be deployed at a rate and extent sufficient to avoid dangerous warming[xxxv]. For example, industrialised agriculture is currently highly dependent on oil for traction and natural gas for nitrogenous fertilisers making its complete decarbonisation difficult. A further complication is that a very large quantity of fossil fuels must be used to bring about the transition to very low carbon energy and greatly increased energy efficiency. In addition the law of diminishing returns may apply to attempts to achieve improvements in both carbon intensity and energy intensity.

The overall effect of these limitations can be seen by combining the percentages[xxxvi] in the Kaya decomposition data shown in Figure 7. The 40% reduction in energy intensity and 6% reduction in carbon intensity of energy between 1971 and 2009 reduced emissions by a combined 44% compared with what they would have been without these improvements. However this is nowhere near enough to fully offset the massive rise in fossil fuel related emissions resulting from the 106% increase in GDP per capita and 79% increase in population which combined give an increase of 269% . Forward extrapolation of the curves suggests that reducing the energy intensity and carbon intensity cannot decarbonise the global economy in time to prevent catastrophic global warming unless there is a parallel drastic 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 currently likely to be elected for advocating planned economic contraction or even a steady state economy and a rigorous population reduction policy. This is despite the increasing evidence that both the global economy and the global environment are hitting the biophysical limits to growth[xxxvii]. As GDP is a poor indicator of wellbeing, there is increasing awareness that its reduction would not necessarily be coupled with a proportional reduction in the quality of life, particularly if GDP per capita was distributed more equitably.

A further cause for concern is that data from the EIA (US Energy Information Administration) showed an unexpected increase in both the global energy intensity and carbon intensity from 2002- 2004[xxxviii] [xxxix]. This resulted mainly from increases in both these parameters in the BRIC countries probably as a result of increased use of inefficient industrial processes and the burning of more coal to raise industrial output. These increases continued at least into 2008 [xl] but the carbon intensity of the global economy appears to have fallen by 0.7% in 2010-2011 despite a 6.7% annual increase in carbon intensity in Australia and significant increases in China, Japan and Spain in that year[xli].

The effects of economic recession on emissions. Recent work by Peters et al **(**2012) [xlii] supports our central thesis by highlighting 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 from fossil fuels actually fell in the last four serious global economic crises between 1960 and 2010 while the rate of growth in emissions also stalled in the first crisis in this period but was not significantly negative (See Figure 8). It also shows that, although the overall trend over the period was towards a reduction in carbon intensity, the rate of improvement declined particularly after 2000. There is also some suggestion in Figure 8 that the rate of decline 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. There is also some indication of this 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 economic crises have been immediately preceded by a rise in oil prices [xliii] 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 have motivated 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 during periods of economic growth 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 [xliv] (see Figure 7). Thus the work of Peters et al (2012) indicates that both overall trends and short term fluctuation in GDP are important in influencing fossil fuel related emissions.

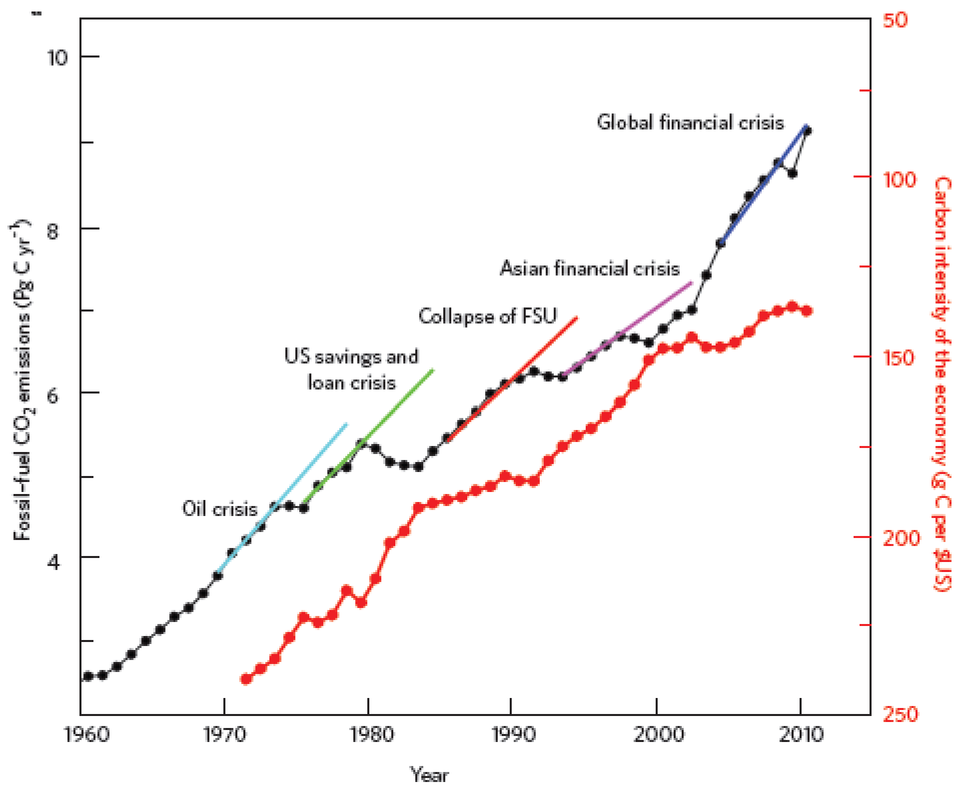


Figure 8*. Annual global CO2 emissions and carbon intensity. Emissions of CO2 from fossil-fuel combustion and cement production for the world (Pg C yr−1; black curve) and the carbon intensity of world GDP (g C per $US GDP PPP 2000); red curve). Note that the axis for the latter is inverted for ease of comparison with the emissions curve. The most important economic 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 fossil fuel related emissions. As we have argued 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 B) countries with emergent or rapidly developing economies has had or will have little impact on emissions. Indeed production emissions of the non-Annex B countries overtook those of the Annex B ones in 2004 (see

Figure 9). This was largely due to the outsourcing of production from the developed to the BRIC countries.

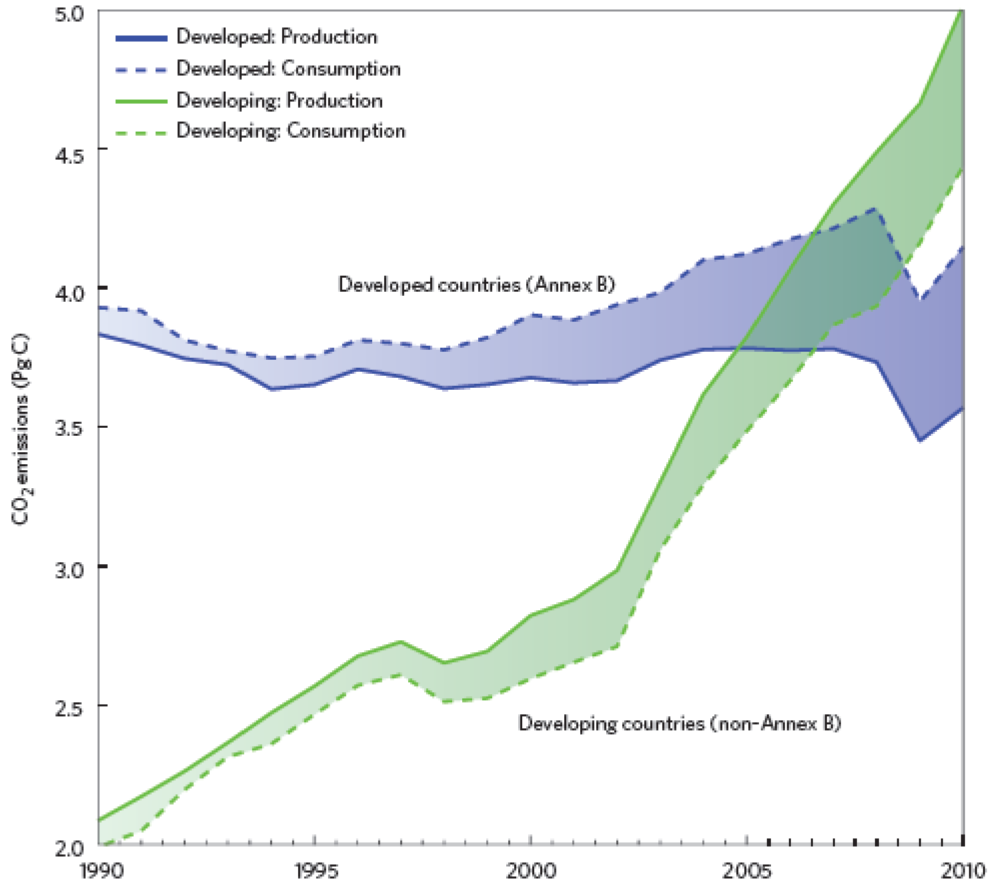


Figure 9. *Annual fossil fuel related CO2 emissions from 1990 to 2010 of developed (Annex B) and developing (non-Annex B) countries with emissions allocated as production emissions (those produced within the territory (as in the Kyoto Protocol) and to consumption emissions (production plus imports minus 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.*

Annual consumption emissions of non-Annex B countries continued to rise after 2007, while those of Annex B countries fell until the start of 2009. This was 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. The continuance of rapid growth in the BRIC economies is likely to result, in part, from their lesser dependence on both expensive fossil fuel imports and debt to fuel their economies. This rise in non-Annex B consumption emissions and fall in those of Annex B meant that 2008 was the first year that the former group of countries' consumption emissions exceeded those of Annex B ones while in the same year China's annual emissions exceeded those of the United States.[xlv]

The fact that non-Annex B countries annual consumption emissions have overtaken those of the Annex B means that in the future, their cumulative consumption emissions [iii] could also eventually overtake those of the developed ones if current trends continue. There are two reasons for thinking that this might happen. First, although the rate of economic growth in the BRIC countries had started to slow in 2012, their economies were still collectively expanding faster than those of the developed and highly developed countries. Second the economies of a further group of non-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[xlvi]. 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 their economic growth will continue into the future. The peaking of conventional oil, phosphate fertilizers, food, water and other resources threatens economic growth in the underdeveloped countries at least as much, and probably more, than in the developed ones. In addition, climate change is likely in general to have a greater effect on GDP in the least developed countries than the developed ones as it has been shown that years in which the regional temperature the former was 1°C hotter than average were associated with an average reduction in their GDPs of 1.3% while the effect of such heat shocks can last as long as ten years. [xlvii] 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 [xlviii], other aspects of neo-colonialist exploitation [xlix], corruption, dictators, and armed conflict.

What are the implications of the above analysis for changes in national and international policies 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 fossil fuel related 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 the developed countries' outsourcing of both manufacturing and the supply of raw materials should be allocated to the consumer rather than the manufacturer. For example, if this was done, it is estimated that 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.[l] A compromise would be to share traded 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 a country's existing listing [li] as Annex B or non-Annex B cannot in every case be used as a basis for equitable action to reduce fossil fuel emissions.

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 allowed or encouraged to develop. Consideration of trends in global emissions and carbon sensitivity shown in 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 in non-Annex B countries has been coupled with an increase in emissions as can be seen in their emission 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, energy use increases slowly at first with increase in GDP in the "toe in" region before accelerating at moderate incomes. This toe in may apply to the distribution of income and energy use within, as well as between countries. This means that on a global or national scale a moderate transfer of wealth to the poorest individuals and countries from the richer might under certain conditions we have considered above lead to a net global reduction in total energy use and fossil fuel related greenhouse gas emissions. One practical way of achieving this redistribution of income to the poorest, least emitting countries and individuals would be to introduce Cap & Share[lii] [liii] or the closely related Cap & Dividend[liv] scheme. An international or regional scheme of this kind would also result in some redistribution of wealth between countries as well as within countries. The main advantage of these schemes is that they use an upstream cap which would provide a very effective and probably the only way of cutting fossil fuel related emissions directly and in line with the rate required to avoid dangerous global warming as indicated by the latest climate science.

The leaders of the low income, high fertility countries are very aware that in general their countries already, and will increasingly in the future, bear the brunt the effects of increased atmospheric CO_2 concentration which is thought account for some 48% of the warming that has occurred since 1750 [lv]. The majority of this CO_2 is derived from the burning of fossil fuels (as evidenced by work on the annual growth rings in corals, sponges, trees, stalagmites and stalactites[lvi]). CO_2 produced in this way has been deposited in the atmosphere largely by the developed and BRIC countries. Events at the UN Climate Change Conferences in Copenhagen and Cancun made 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 poorer countries for financial assistance to help them adapt to climate change, limit fossil fuel emissions increases, and reverse the destruction of their forest carbon sinks. Some of the funds required for this could be obtained from the global or regional operation of Cap & Share or similar schemes[lvii]. The destruction of land based carbon sinks is clearly of considerable importance as this may have accounted for 10% of the total warming effect in the 1990's[lviii] . As we have noted above the latter problem is not limited to the developed and BRIC countries. A Carbon Maintenance Fund financed by a Cap & Share scheme [lix] and/or a Land Value Tax could provide funds to help tackle destructive land use change, latter could having direct effect on this by limiting urban sprawl, deforestation and the replacement of subsistence and small scale agriculture with large scale industrial farming[lx].

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 global 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 fossil fuel related emissions, at least at current income levels. However a reduction in the population growth rate would be likely to have a highly significant effect in a small number of developing countries including Belize, Guyana and Malaysia where emissions from land use change (caused by loss of virgin forest cover stimulated by both population growth and per capita economic growth) is thought to account for considerably more greenhouse gas emissions than their use of fossil fuels.

Data for March 2011 from the Population Reference Bureau[lxi, lxii] 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 and Russia are located entirely in Europe. Although many of them are the somewhat poorer central and southern European countries[lxiii], 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 access to contraception, widespread adult female literacy, good employment prospects for women, a reduction in the value of child labour, and an increase in parental investment in the education of children, and the provision of care and financial security for the elderly [lxiv] .

It is to be noted that 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 the 20 countries with negative or zero population growth listed above, only Austria's population is predicted to grow between 2006 and 2050 [lxv]. 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, zero or negative population growth in a given country does not necessarily imply a global reduction in greenhouse emissions. Whether the latter occurs depends on several factors including how much of the decrease in population growth rate has been produced by emigration, how much the émigrés purchase and the carbon intensity of their purchases in the country to which they migrate, and how much of their earnings in the host country are remitted to their homeland, and the carbon intensities of the economies of the host and homeland countries. In this connection, recent population growth in the UK is linked to both immigration from central and Eastern Europe and higher birth rates in recent immigrants[lxvi] Thus the effect of the negative population growth rate in Poland and other central European countries on emissions reduction in their homelands may be partially or wholly offset by increased emissions in the UK leading to an overall increase in global emissions. This is because, at least in the past, these émigrés have generally increased their incomes by working in the UK and hence are likely to have increased their personal carbon footprints.

A further consideration with regard to zero or negative growth is that the ageing population which accompanies the demographic transition is not without its problems some of which are already apparent in China.

The BRIC countries currently account for some 40% of the world population[lxvii] and have the following population percentage 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.[lxviii] There is therefore considerable scope for Brazil, and India to reduce emissions growth by reducing their population growth rates. This holds true even if the argument above is accepted that they should not be held responsible for their emissions relating to net exports.

However, the introduction of 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 natural removal of carbon dioxide from the atmosphere means that global emissions need to start to fall in the next few years and decline to practically zero by 2050 if dangerous climate change is to be avoided[lxix]. 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, the availability of effective and affordable artificial methods of contraception for both men and women though generally thought to be highly desirable will not on its own bring about a rapid demographic transition. The additional socio-economic conditions required to achieve this are in the main expensive and require a relatively high levels of economic development as noted above.

Fourth, our argument above from the Kaya identity shows that unless the percentage reduction in the rate of population that results from population control measures is larger than the percentage increase in per capita GDP there will be no net reduction in fossil fuel related emissions without a parallel, huge and unprecedented reduction in the carbon intensity of the economy as we have already noted.

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, global pandemics, and the impact of climate change may result in a global scale, unplanned , irreversible and catastrophic reduction in both GDP and the human population [vi-viii]. The combination of the interdependence of economies resulting from globalisation, economic instability from fractional reserve banking together and the dependence of western economies on debt, and potentially escalating conflicts in the Middle East and North Africa increases the likelihood of a global economic crash. While an unplanned and irreversible crash would be likely to reduce man-made greenhouse gas emissions it would have unspeakably dreadful consequences for many human societies.

Planned economic contraction would be infinitely preferable to unplanned, and perhaps irreversible, economic collapse provided that it had limited negative impacts on wellbeing. Planned contraction would need to be coupled with a more equitable distribution of wealth and resources to avoid intolerable hardship in people already struggling to survive. It is also arguably necessary to limit unrest and prevent societal disintegration. 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 [lxx], was largely responsible for a 9.8% reduction in its carbon dioxide emissions in the same year [lxxi].

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 [lxxii]. Nor does it imply that population growth is not an important factor in the causation of almost all environmental and resource problems.

Summary and policy implications

1.
The increase in global fossil fuel related greenhouse gas emissions since 1971 has not been solely or even primarily caused by population growth, least of all by rapid population growth in the countries with low incomes and high birth rates. We argue that the main driver of increasing fossil fuel related greenhouse gas emissions has been economic growth per capita. The latter has been driven by low

fuel prices, cheap credit, consumerist policies, sophisticated advertising, and the pursuit of extrinsic goals[lxxiii] **including financial success, status, image and conformity. Population growth does however have a large effect by increasing both global consumption and emissions from land use change, and contributing to many other resource and environmental problems. It is extremely difficult to predict, even for the next 10 year, whether the rate of global economic growth per capita will be higher than that of global population growth and therefore whether its future contribution to fossil fuel related emissions will continue to be smaller than that of per capita economic growth.**

2.

In general, population policies in the least developed countries with high birth rates are unlikely to have a large impact on global emissions within the time scale required to avoid dangerous global warming as indicated by the latest climate science.

3.

Reduction in consumption by wealthier individuals could have a quicker and larger impact than population policy in the short term. There is a strong argument that fiscal policies should be used to achieve the former. In the longer term it will probably be necessary to limit births to two per woman or less if all societies are to live within the limits imposed by the earth's life support system and their fair share of the planet's sustainable resources.

4.

Far-reaching changes in economic, technological, social and political systems are needed to reduce the risk of highly dangerous climate change and irreversible damage to biodiversity and the planetary life support systems. A combination of a radical increase in energy efficiency and carbon intensity, together with a drastic reduction in consumption is urgently needed. However, a concerted focus on a rapid adjustment of the components of the Kaya identity is a necessary but in itself insufficient condition for the effective tackling of climate change. A top down, progressively constricting, upstream cap on fossil fuel introduction into the global economy seems the only practical means of guaranteeing reduction in the unabated burning of fossil fuels at a rate dictated by the latest climate science. The enormous size of the remaining fossil fuel resources[lxxiv] **and reserves**[lxxv]

particularly of coal and of planned projects to extract them[lxxvi] **make such a cap absolutely necessary. In addition to these measures, the active withdrawal of large quantities of carbon dioxide from the atmosphere probably required by 2050 to give a reasonable chance of avoiding disastrous warming** [lxxvii] **and it is arguable that it would be safest to achieve this by afforestation on a gargantuan scale.**

5.

A strong case can be made that the above changes require the establishment of an independent global climate commons trust to regulate the use of the finite resource of atmosphere along with that of land and water[lxxviii] [lxxix]**.**

6.

Evidence reviewed here does not support the Environmental 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 might on its own have a small advantageous effect on both total global energy use and fossil fuel related emissions. 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. A more equitable distribution of wealth and resources is arguably necessary to to improve cohesion within and between nations.

7.

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

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Footnotes and references

i For example: Anon (2009) Does Population Growth Impact Climate Change? Scientific American, 14 July 29, 2009 ; see also Anon (2009) Gaia Scientist to be OPT Patron, Optimum Population Trust, 26th August 2009 . http://www.optimumpopulation.org/releases/opt.release26Aug09.htm

ii 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 consumption figures which additional include emissions embedded in imports less those embedded in exports. The primary sources of the data should be consulted for further information on how the 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.)

iii Cumulative emissions since the start of industrialisation in a given country are a better indicator of culpability for climate change because CO_2 is, in effect, very slowly removed from the atmosphere. This means that much of the CO_2 deposited there by Britain since the start the industrial revolution initiated the rapid burning of coal is still contributing to climate change.

iv http://en.wikipedia.org/wiki/Pareto_principle

v Anderson, K. (2012). “Climate change- going beyond dangerous– Brutal numbers and tenuous hope” *Development Dialogue* September 2012 , What Next Volume III, Climate, Development and Equity. PP16-40.

vi AVAAZ pettion posted September 2013
http://www.avaaz.org/en/petition/That_the_UK_government_should_takes_steps_to_limit_human_population/?cGSwtbb

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

viii 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

ix World Population Prospects:The 2008 Revision, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. June 2009.
http://www.un.org/esa/population/publications/popnews/Newsltr_87.pdf

x Richard Heinberg. (2005) “The Party's Over: Oil, War and the Fate of Industrial Societies”. New Society Publishers, Gabriola Island, Canada.

xi Ruppert , M. C. and Campbell , C. (2009) "Confronting Collapse: The Crisis of Energy and Money in a Post Peak Oil world". Chelsea Green Publishing Company, Vermont, USA

xii Richard C. Duncan . (2009). "The Olduvai Theory:Toward Re-Equalizing the World Standard of Living" The Social Contract. Summer 2009 thesocialcontract.com/pdf/nineteen-four/tsc_19_4_duncan.pdf

xiii Satterthwaite, D., 2009, "The implications of population growth and urbanization for climate change". Environ. Urban ; 21: 545–67.

xiv 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) and land use change on the relationship with national income.

xv http://en.wikipedia.org/wiki/List_of_countries_by_greenhouse_gas_emissions_per_capita

xvi Marelli L., Ramos, F.,Hiederer, R., Koeble, R. (2010). Estimate of GHG emissions from global land use change scenarios. JRC. European Commission. Directive 2009/28/EC (2010/335/EU), OJ L151 17.06.2010 pp. 19-41. Background.http:// ec.europa.eu/.../land_use_change/presentation_iluc_jrc_nov_2011.pdf

xvii Woods Hole Research Centre, Carbon and Changes in Land Use Project http://www.whrc.org/global/carbon/landuse.html

xviii Bradshaw, C. J. A., Giam, X., Sodhi, N. S. (2010). "Evaluating the Relative Environmental Impact of Countries". PLoS ONE 5(5): e10440. doi:10.1371/journal.pone.0010440 downloaded free from http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0010440

xix 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.

xx GNI per capita is calculated by adding all sources of income and dividing by the total population within a country. GNI-PPP per capita is a more accurate measure of the average level of affluence 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.

xxi Stephenson, J., Newman, K., Mayhew, S. (2010) “Population dynamics and climate change: what are the links?”, Journal of Public Health   Vol. 32, No. 2, pp. 150–156

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

xxiii Rosa, E.A., and Dietz, T., “Human drivers of national greenhouse-gas emissions”. Nature Climate Change 10th June 2012. DOI 10.1038/NCLIMATE1506

xxiv Druckman, A. and T. Jackson (2008). "Household energy consumption in the UK: a highly geographically and socio-economically disaggregated model." Energy Policy 36(8): 3167– 3182.

xxv 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.

xxvi Druckman, A., Jackson, T. (2009) The carbon footprint of UK households 1990-2004: A socio-economically disaggregated, quasi-multi-regional input-output model , *Ecological Economics* 68 (7) , pp. 2066-2077

xxvii Excluding non-CO2 greenhouse gas emissions and land use change.

xxviii http://en.wikipedia.org/wiki/File:Changes_in_components_of_the_Kaya_identity_between_1971-2009._Includes_global_energy_related_carbon_dioxide_emissions,_world_population,_world_GDP_per_capita,_energy_intensity_of_world_GDP_and_carbon_intensity_of_world_energy_use.png

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

xxix Raupach, M.R., Marland, G., Ciais, P., Le Que´ , C., Canadell , J.G., Klepper, G., and Field, C.B. (2007) PNAS June 12, 2007, vol. 104 , 10288–10293.

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

xxxi http://en.wikipedia.org/wiki/Kaya_identity xxxii 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 related to fossil fuel use.

xxxiii 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.

xxxiv http://en.wikipedia.org/wiki/Jevons_paradox

xxxv See for example the following: http://www.sciencemag.org/content/339/6117/280.full

http://www.kecn.org.uk/wp-content/uploads/2013/07/Hansen-NEW.pdf

http://rsta.royalsocietypublishing.org/content/369/1934/20.full

http://www.pnas.org/content/106/11/4133.short

xxxvi The equation used for combining percentages in this case is ((1+a/100)(1+b/100)-1) x 100 where a and b are the percentages to be combined.

xxxvii www.sustainer.org/pubs/limitstogrowth.pdf

xxxviii Le Quéré, C., Raupach, M.R., Canadell, J.G.Gregg Marland et al. (2009) Trends in the sources and sinks of carbon dioxide Nature Geoscience 2, 831 – 836.

xxxix Raupach , M.R., Marland, G.,Ciiais , P., Le Quéré, C., Canadell, J.G. , Klepper, G. and Field , C.B. (2007) Global and regional drivers of accelerating CO2 emissions Proc. Nat. Acad. Sci. Wash 104, no. 24, 10288–10293.

xl http://www.pwc.com/gx/en/sustainability/publications/low-carbon-economy-index/index.jhtml

xli http://www.pwc.co.uk/sustainability-climate-change/publications/low-carbon-economy-index-overview.jhtml

xlii Peters, G.P. Le Quéré C., Boden, T. ,. Canadell, J.G. and Raupach, M.R. Nature Climate Change vol 2 JANUARY 2012 , 2-4.

xliii Hamilton, J. D., Historical Oil Shocks (February 2011). NBER Working Paper No. w16790. http://dss.ucsd.edu/~jhamilto/oil_history.pdf

xliv Peters et al. (2012). Loc. cit.

xlv Peters et al. (2012) loc.cit.

xlvi Larry Elliot, "New-wave economies going for growth" The Guardian, Tuesday 18 December 2012. http://www.guardian.co.uk/world/2012/dec/18/booming-economies-beyond-brics

xlvii Dell, M., Jones, B.F. and Olken, B.A. (2012). "Temperature shocks and economic growth: evidence from the last half century". American Economic Journal: Macroeconomics 4: 66–95. http://dx.doi.org/10.1257/mac.4.3.66

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

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lvi Swart, P. K. (2013) Coral Reefs: Canaries of the Sea, Rainforests of the Oceans. Nature Education Knowledge 4(3):5

lvii Douthwaite, R. and Knight, D.P. (2012) “Some reasons for optimism” in “ Sharing for survival” Ed. Brian Davey, FEASTA, Dublin.

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lix Byrne, C., 2010, Turning the Land from an Emissions Source to a Carbon Sink, in Douthwaite, R. (ed.), 2010, Fleeing Vesuvius, FEASTA

lx www-sre.wu.ac.at/ersa/ersaconfs/ersa11/e110830aFinal01472.pdf

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

lxii http://www.prb.org/

lxiii 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.

lxiv http://en.wikipedia.org/wiki/Demographic_transition

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

lxvi At least some of these immigrants and their children may eventually return to their homelands.

lxvii http://www.investordaily.com/cps/rde/xchg/id/style/801.htm?rdeCOQ=SID-3F579BCE-819F182C

lxviii http://en.wikipedia.org/wiki/List_of_countries_by_population_growth_rate

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lxxiii assets.wwf.org.uk/downloads/**weathercocks**_summary2.pdf

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