WP-US-0907

Greenhouse Gases and Human Well-Being: China in a Global Perspective

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March 31, 2009

Stockholm Environment Institute

Working Paper WP-US-0907

Abstract

Most pollution is an unequivocal social bad – a negative externality – but the relationship between greenhouse gas emissions and human well-being is unusually complex. In the long-run, there is a strong scientific consensus that greenhouse gas emissions will result in higher temperatures and sea levels, and a disruption of historical weather patterns. In the short-run, greenhouse gas emissions, and the activities that produce these emissions, result in a mixed set of consequences. Industrialized countries have higher emissions, but also more revenue from the sale of industrial products. China and a few other rapidly industrializing countries stand in the middle. On one side are poorer, less industrialized countries with little responsibility for the emissions that cause climate change and few resources with which to combat its effects. On the other side are richer, more industrialized countries with enormous culpability – both past and present – for the problem of climate change and ample funds for adaptation measures to protect human well-being. This paper takes China as a case study to examine the relationship between greenhouse gas emissions and human well-being.

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1. Climate Change and Development

Most pollution is an unequivocal social bad – a negative externality – but the relationship between greenhouse gas emissions and human well-being is unusually complex. In the long-run, there is a strong scientific consensus that greenhouse gas emissions will result in higher temperatures and sea levels, and a disruption of historical weather patterns, from heat waves and droughts to more intense storms. The effect of climate change on human well-being will vary greatly from country to country, but if the increase in global average annual temperature exceeds a 2ºC threshold, total world food supplies will begin to shrink even as the risk of triggering feedback processes that would accelerate warming grows steeply (IPCC 2007; Stern 2006).

In the short-run, greenhouse gas emissions, and the activities that produce these emissions, result in a mixed set of consequences. Industrialized countries have higher emissions, but also more revenue from the sale of industrial products. Countries with more automotive transportation, larger homes, warmer homes in winter, cooler homes in summer, more lights and more consumer electronics have higher residential and transportation-related emissions, but also have lifestyles that are – perhaps – more comfortable, more convenient, and more in tune with all of the benefits of the information age.

At the same time, every country suffers the ancillary costs of burning fossil fuels: emissions of SO_X, NO_X and particulate matter, together with a host of attendant health, environmental, and aesthetic impacts. And for a small but ever increasing number of countries, the worst impacts of climate change have already begun. Some countries are especially vulnerable to climatic changes because of their geography, among these: low-lying, small islands; coastal areas in the paths of hurricanes and typhoons; and arid regions where water availability is dropping still lower. Other countries are economically vulnerable; they cannot afford to insulate their populace from the effects of climate change with costly dykes, air conditioning, desalinization plants, or rigorous building codes.

China and a few other rapidly industrializing countries stand in the middle. On one side are poorer, less industrialized countries with little responsibility for the emissions that cause climate change and few resources with which to combat its effects. On the other side are richer, more industrialized countries with enormous culpability – both past and present – for the problem of climate change and ample funds for adaptation measures to protect human well-being. The case of China, viewed from a global perspective, can illuminate a difficult but not intractable issue of international equity: How can the international community balance each individual's right to an adequate standard of living with the imperative of greenhouse gas emissions reductions?

2. Emissions versus Well-Being: The International Context

As global emissions of greenhouse gases increase, the impacts of climate change worsen, but these same emissions are essential to maintain high-consumption lifestyles in rich countries and make development possible for poorer and middle-income countries. A statistical examination of this relationship requires good measures of both emissions and human well-being. In this article, the primary measure of greenhouse gas emissions will be emissions per capita of carbon dioxide for 2004 (hereafter, simply referred to as emissions per capita).[1] It is worth noting that while each country's total emissions are often emphasized in the Western press and are even at times the subject of international negotiation, any serious analysis of the equity implications of climate change requires a per capita measure of emissions[2]: Luxembourg ranks 90th in terms of total emissions, but has the third highest per capita emissions in the world; conversely, China rivals even the United States in terms of total emissions, but 73 countries have higher per capita emissions.

Establishing a credible measure of human well-being is less straight-forward. Two measures are commonly used as proxies for well-being in the development literature: gross domestic product (GDP) per capita adjusted for purchasing power parity (PPP)[3] and the Human Development Index (HDI)[4]. PPP-adjusted GDP per capita can be interpreted as average private consumption, but it fails to include access to public goods and other aspects of well-being, both measurable (like long life or educational attainment) and immeasurable (like happiness or the strength of one's community). HDI combines PPP-adjusted GDP per capita with average life expectancy, the literacy rate, and school enrollment[5]; there is a strong correlation between this income measure and the other measures included in HDI. Both PPP-adjusted GDP per capita and HDI are based only on national averages[6] and therefore can impart no information regarding inequalities of ethnicity, gender or region within each nation.

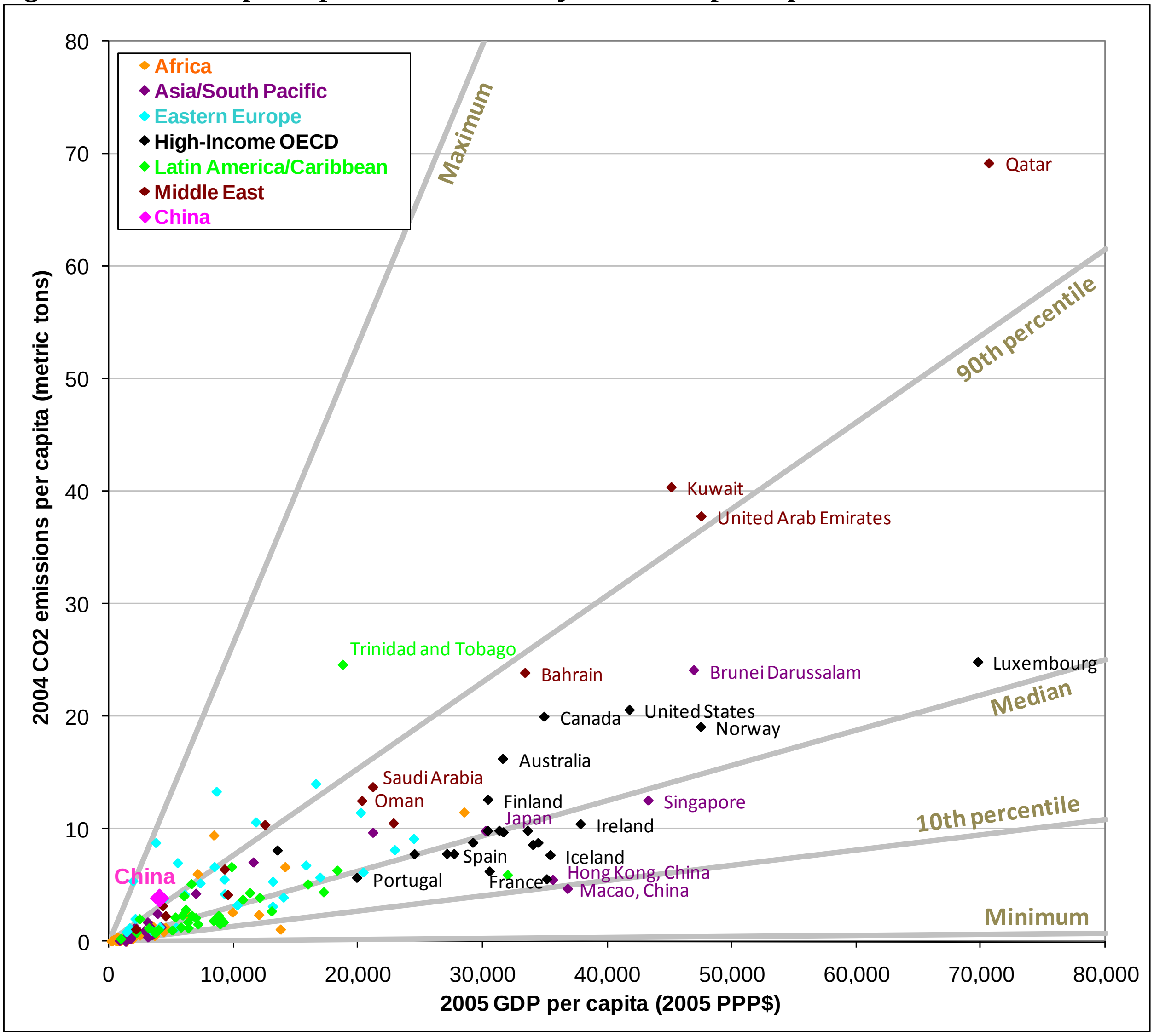
[1] World Bank, World Development Indicators online database.
[2] For a discussion of per capita emissions rights see Baer et al. (2008)
[3] PPP adjustments to GDP per capita are an output of the International Comparison Project (ICP). According the World Bank: "The ICP uses a series of statistical surveys to collect price data for a basket of goods and services. For meaningful inter-country comparisons, the ICP considers the affordability and price level of necessities and luxuries, which exchange rates ignore. Surveys are held every three to five years, depending on the region. The data collected are combined with other economic variables from countries' national accounts to calculate Purchasing Power Parities or PPPs, a form of exchange rate that takes into account the cost and affordability of common items in different countries, usually expressed in the form of US dollars. By using PPPs as conversion factors, the resulting comparisons of GDP volumes enable us to measure the relative social and economic well-being of countries, monitor the incidence of poverty, track progress towards the Millennium Development Goals and target programs effectively." See http://www.worldbank.org.
[4] For more information on the HDI see http://hdr.undp.org/.
[5] PPP-adjusted GDP alone explains 61 percent of the variability in HDI.
[6] Or nation-level projections in the case of life expectancy data.

In this article, the primary measure of well-being will be PPP-adjusted GDP per capita for 2005[7], but several other development indicators will be discussed. Note that GDP per capita alone explains 65 percent of the variability in emissions per capita, indicating a high degree of correlation between income and emissions. (Hereafter, PPP-adjusted GDP per capita will be referred to simply as income per capita.)

Figure 1 is a scatterplot of emissions per capita versus income per capita for 174 countries; China, at 3.9 metric tons of CO_2 emitted annually and $4,088 (PPP) per capita, is highlighted in pink at bottom left. To give some context to the relative positions of each country: mean annual global emissions per capita is 4.3 tons (similar to that of Mexico); mean global income per capita is $8,700 (similar to that of Kazakhstan).

[7] World Bank, World Development Indicators online database.

Figure 1: Emission per capita versus PPP-adjusted GDP per capita



Emissions intensity is the ratio of per capita emissions to per capita income; graphically, in Figure 1 countries aligned along any ray from the origin share the same emissions intensity. The median emission intensity – close to that of Portugal, Japan and Singapore – is 0.3 tons for every $1,000 of income. The 90th percentile of emissions intensities is 0.8 tons per $1,000, while the 10th percentile is 0.1 tons. The area of the graph near and above the 90th percentile of emissions intensities is populated almost exclusively by countries of the Middle East, other OPEC[8] members, and the transition economies of Eastern Europe and the former Soviet Union. With the exception of the two Chinese cities for which data is collected in the international dataset – Hong Kong and Macao – countries near or below the 10th percentile are crowded into the bottom left-hand corner of the graph: only countries with very low incomes have very low emissions intensities. Indeed, only one country in the lowest decile by emissions intensity, Gabon, has an income per capita greater than $3,300.

In the regression analysis shown in Table 1, four variables explain 80 percent of the variance in emissions per capita (although average annual temperature was not statistically significant, a point addressed in detail below):[9]

- For every $1,000 increase in income per capita there is a 0.38 ton increase in emissions per capita
- Eastern European and former Soviet transition countries have 3.0 tons higher emissions per capita than non-transition countries
- For every $1,000 increase in oil production per capita there is a 0.8 ton increase in emissions per capita

Table 1: Regression analysis for 174 Countries
Dependent variable: CO_2 emissions per capita (metric tons)
Independent variables: GDP per capita (PPP 2005$1000); average annual temperature in country capital (degrees Celsius); transition country (dummy); and oil production per capita (2005 US$1000)

	Coefficient	*Significance [a]*		
Per capita GDP (PPP$1000)	**0.3819**	**	**Number of observations**	**174**
Temperature (°C)	**0.0713**		**R-squared**	**0.803**
Transition country (dummy)	**3.0240**	**		
Per capita oil production ($1000)	**0.8249**	**		
constant	**-2.1259**			

a) * indicates significance at the 95% level; ** indicates significance at the 99% level

[8] Organization of Petroleum Exporting Countries
[9] Data are from the World Bank, World Development Indicators online database except for temperatures of capital cities, http://www.worldclimate.com/.

Nearly all countries above the 90th percentile in emissions intensity have oil production that is more than 10 percent of GDP and/or are ex-Soviet transition countries. China has the 8th highest emissions intensity, 0.9 tons per $1,000 income per capita, only surpassed by: Uzbekistan (2.7 tons per $1,000); Turkmenistan (2.3); Kazakhstan (1.5); Trinidad and Tobago (1.3); Ukraine (1.2); South Africa (1.1); and Syria (1.0). Among the top decile by emissions intensity only China and South Africa (with 9.4 tons and $8,400 per capita) are neither highly dependent on oil production nor ex-Soviet transition economies. Uzbekistan, Turkmenistan, Kazakhstan, Ukraine, and other transition countries tend to have outsized industrial infrastructures in relation to current GDP, a legacy of large-scale state-driven manufacturing under the Soviet Union and its satellites.

Table 2 adds an additional significant variable to this regression, fossil fuels as a share of energy production (included separately because there are observations for only 127 countries).[10] With the addition of the fossil fuel share of energy, the trend in emissions intensity (that is, the coefficient for income per capita) is slightly reduced: the impact of every $1,000 increase in income per capita is a 0.35 ton increase in emissions per capita. Coincidentally, that is the same as the estimated impact for a 10 percentage point increase in the fossil fuel share of energy production.

Table 2: Regression analysis for 127 Countries
Dependent variable: CO_2 emissions per capita (metric tons)
Independent variables: GDP per capita (PPP 2005$1000); average annual temperature in country capital (degrees Celsius); transition country (dummy); oil production per capita (2005 US$1000); and fossil fuels as a share of energy production (%).

	Coefficient	*Significance*[a]		
Per capita GDP (PPP$1000)	**0.3466**	**	**Number of observations**	**127**
Temperature (°C)	**0.0713**		**R-squared**	**0.850**
Transition country (dummy)	**2.3851**	*		
Per capita oil production ($1000)	**1.0321**	**		
Fossil fuel share of energy	**0.0348**	*		
constant	**-4.0132**			

a) * indicates significance at the 95% level; ** indicates significance at the 99% level

In this more limited data set, only Hong Kong has a low emissions intensity but a high fossil fuel share of energy, 97 percent. In general, city states (like Singapore) and the Chinese cities included in the international data have lower than the expected emissions per capita and higher than the expected income per capita. These anomalous results often point to high population density, abundant public transportation and a service-based

[10] Data are from the World Bank, World Development Indicators online database except for temperatures of capital cities, http://www.worldclimate.com/.

economy (Leung and Lee 2000) Like most high-emissions intensity countries, China produces the vast majority, 84 percent, of its energy from fossil fuels.[11]

[11] Note that China, as defined in this international dataset, does not include Hong Kong and Macao. Data are from the World Bank, World Development Indicators online database.

High-income countries with low emissions intensities tend to produce a higher share of energy from renewables and nuclear: France, Iceland, Sweden and Switzerland all fit this pattern. Among high-income OECD[12] countries, Iceland and Sweden have the lowest fossil fuel reliance. Seventy-three percent of Iceland's energy comes from geothermal and hydroelectric generation. Sweden generates 13 percent of its energy from renewables (excluding biomass) and 36 percent from nuclear.[13]

One-third of global emissions are residential in origin[14] – primarily from heating and cooling – but, unexpectedly, the coefficient for average annual temperature is positive and insignificant in these regression analyses. The relationship between emissions per capita and temperature is complex: colder countries use more heat and therefore have higher emissions; but countries that are both warm and rich often have high rates of air conditioning use, and therefore very high residential emissions. The regression reported in Table 3 replaces the explanatory variable temperature with an interaction term that multiplies temperature by income per capita.[15] A high value for this interaction variable indicates a warm, rich country where air conditioning is likely to be widely used.

Table 3: Regression analysis for 174 countries, with interaction term
Dependent variable: CO_2 emissions per capita (metric tons)
Independent variables: GDP per capita (PPP 2005$1000); interaction term: average annual temperature in country capital (degrees Celsius) multiplied by GDP per capita (PPP 2005$1000); transition country (dummy); and oil production per capita (2005 US$1000).

	Coefficient	*Significance [a]*		
Per capita GDP (PPP$1000)	0.2691	**	Number of observations	174
Temperature (°C)* per capita GDP (PPP$1000)	0.0074	**	R-squared	0.813
Transition country (dummy)	2.7838	**		
Per capita oil production ($1000)	0.6812	**		
constant	-0.6685			

a) * indicates significance at the 95% level; ** indicates significance at the 99% level

[12] Organization for Economic Cooperation and Development
[13] Data are from the World Bank, World Development Indicators online database.
[14] World Resources Institute, Climate Analysis Indicators Tool, http://cait.wri.org/, 2000 data.
[15] Data are from the World Bank, World Development Indicators online database except for temperatures of capital cities, http://www.worldclimate.com/.

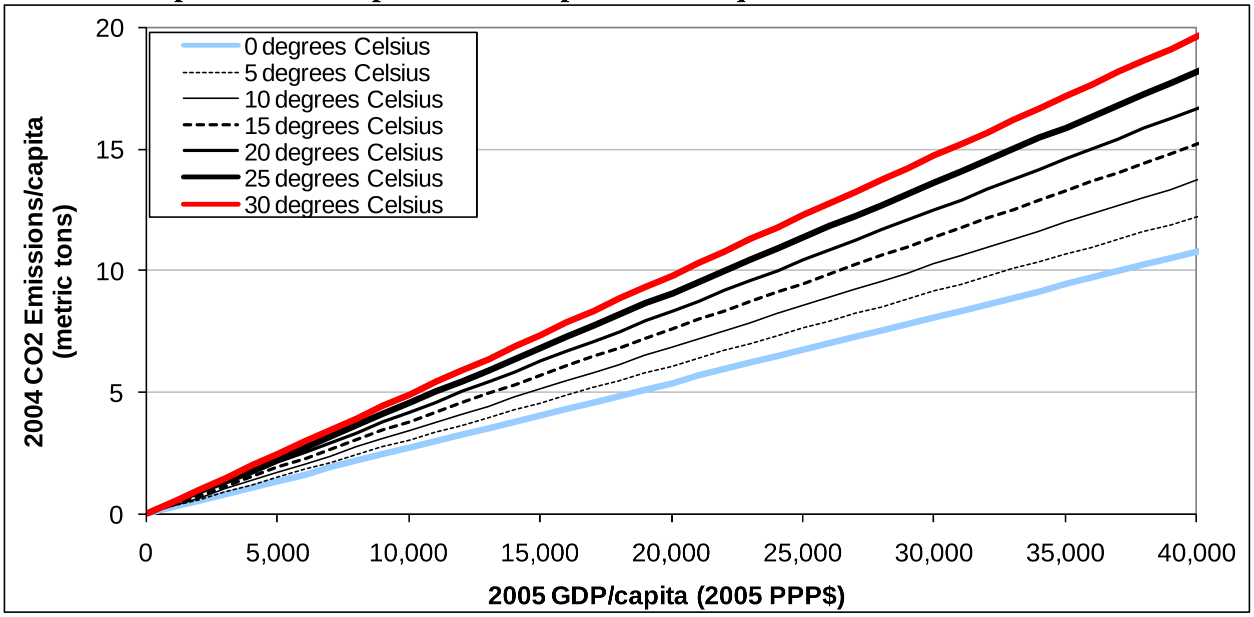
The estimated relationship between emissions, income, and temperature shown in Table 3 (ignoring other variables, and rounding off the estimated coefficients) can be expressed as:

(1) Emission/capita = GDP/capita * (0.3 + 0.007*Temperature)

where emissions per capita are measured in metric tons and GDP per capita in thousands of PPP-adjusted dollars.

Higher temperature is associated with higher emissions across the full range of countries, but part of the emissions per capita versus income per capita relationship is sensitive to temperature and part is insensitive. When average annual temperature is 0ºC, for every $1,000 increase in income per capita there is a 0.3 ton increase in emissions per capita, but when temperature is 30ºC, for every $1,000 increase in income per capita there is a 0.5 ton increase in emissions per capita. Differences in emissions based on temperature are real, at high incomes, but are dominated by differences based on income: Expected emissions per capita for a 30ºC country with $30,000 in income per capita is 15 tons, compared to 0.5 tons for a country with the same temperature but $1,000 in income per capita. Figure 2 represents this relationship as a set of temperature isoquants.[16]

Figure 2: Stylistic Representation:
Emissions/capita v. GDP/capita with Temperature Isoquants



[16] Assuming a non-transition economy with zero oil production.

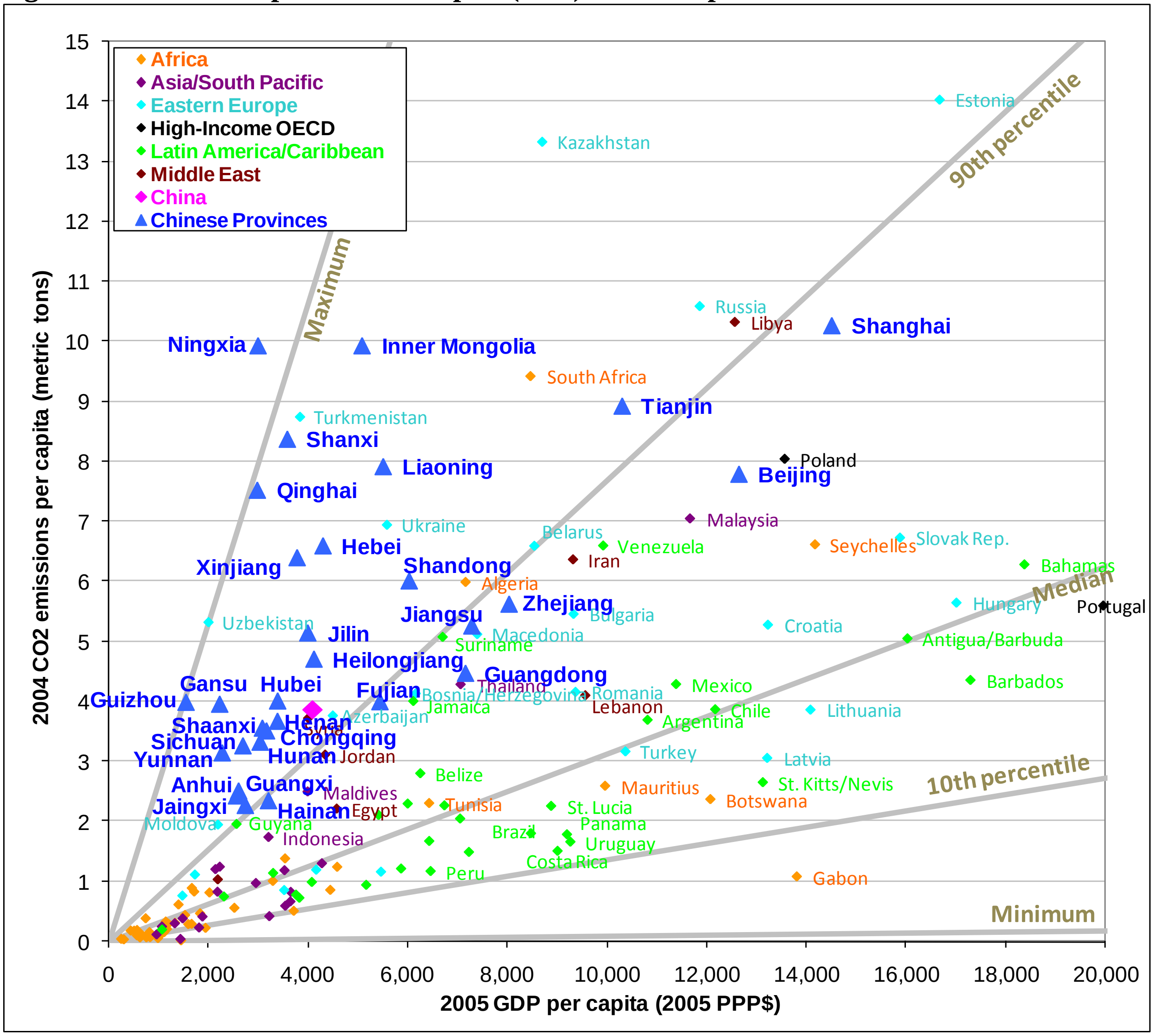
3. Chinese Provinces in a Global Context

With 5.3 million people, the least populous Chinese province, Qinghai, has a larger population than 68 of the countries in the international dataset used in this article.[17] Figure 3 demonstrates the relative emissions intensities of Chinese provinces in a global perspective. Of 30 provinces, 23 are above the 90th percentile by emissions intensity in the international dataset.[18]

Few countries share the Chinese provinces' high emissions intensity, and even fewer combine this trait with a similar range of income per capita: South Africa and a handful of ex-Soviet transition countries (see Figure 3). Most of the provinces with somewhat lower emissions intensities can be paired with countries that share a very similar emissions per capita and income per capita: Hainan resembles Indonesia; Fujian, Bosnia and Herzegovina; Guangdong, Thailand; Jiangsu, Macedonia; Zhejiang, Bulgaria; and Beijing, Poland. Only Shanghai has no close analog. It has both the highest emissions per capita (10.3 tons) and the highest income per capita ($14,500 in PPP-adjusted 2005$) among the Chinese provinces; its closest matches in terms of emission intensity are Iran ($9,300), Venezuela ($9,900), and Bahrain ($33,500).

[17] Tibet is excluded from this analysis for lack of data. Hong Kong and Macao are also excluded.
[18] To compare Chinese provinces with nations, emissions per capita were imputed by adjusting China's 3.9 tons per capita in proportion to the ratio of each province's energy consumption per capita to China's in standard coal equivalents; similarly, PPP-adjusted Gross Regional Product (GRP) per capita is China's income per capita weighted by the ratio of each GRP per capita to China's GDP per capita in Yuan. Chinese provincial data are taken from the China Statistical Yearbook 2007, http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm. Of course, this method assumes that the energy production mix and purchasing power parity are consistent across all provinces. For a comparison with other sources of emissions per capita data for Chinese provinces see the Appendix to this article.

Figure 3: Emission/capita v. GDP/capita (PPP): Chinese provinces



As reported in Table 4, among Chinese provinces the trend in emission intensity (the coefficient for income per capita) is higher than in the international dataset:[19]

- For every $1,000 increase in income per capita there is a 0.5 ton increase in emissions per capita (compared to 0.38 tons in the international dataset)
- For every 1°C increase in average annual temperature there is a 0.2 ton decrease in emissions per capita

[19] Chinese provincial data are taken from the China Statistical Yearbook 2007, http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm.

- For every 1000 ton increase in coal reserves per capita there is a 1.3 ton increase in emissions per capita

Table 4: Regression analysis for 30 Chinese Provinces
Dependent variable: CO_2 emissions per capita (metric tons)
Independent variables: GRP per capita (PPP 2005$1000); average annual temperature in province capital (degrees Celsius); and per capita coal reserves (1000 tons).

	Coefficient	*Significance* [a]		
Per capita GDP (PPP$1000)	**0.5248**	**	**Number of observations**	**30**
Temperature (°C)	**-0.1891**	**	**R-squared**	**0.792**
Per capita coal reserves (1000 tons)	**1.2862**	**		
constant	**5.1819**			

a) * indicates significance at the 95% level; ** indicates significance at the 99% level

The relationship between temperature and income per capita is more straight-forward in the dataset of Chinese provinces: colder provinces have higher emissions. Taking the constant term into consideration, and ignoring the income and coal reserve effects:

(2) Emission/capita = 5.2 - 0.2*Temperature + …

The average annual temperatures of Chinese provinces (taken as that of their capital cities) range from 5ºC in Heilongjiang to 25ºC in Hainan. For a province with an average annual temperature of 5°C, the expected contribution from temperature to emissions per capita is 4.2 tons; for a province with a temperature of 25°C, the contribution is 0.2 tons. While no data on air conditioner use and ownership across Chinese provinces is available, it seems plausible to assume that use of this expensive convenience is more limited in China than in countries with higher incomes but similar average annual temperatures. As air conditioning use in China rises along with rapid income growth, residential emissions are likely to increase, especially in warmer provinces.

Per capita coal reserves are an additional significant determinant of the variance in per capita emissions among Chinese provinces. The only provinces below the 90^{th} percentile by emissions intensity in the international dataset – Hainan, Fujian, Guangdong, Jaingsu, Zhejaing, Beijing and Shanghai – all have low per capita coal reserves; the provinces with the highest emissions intensity are among those with the highest per capita coal reserves.

4. Measuring Development in China and Abroad

Countries with higher emissions per capita also have higher standards of living, not just in terms of private consumption (or PPP-adjusted GDP per capita) but also as measured by life expectancy and literacy (see Table 5).[20] China's emissions per capita place it in the first decile above the median, where the average income per capita among countries in this group is $8,500, average life expectancy is 71 years, and the average literacy rate is 89 percent. (China is a good match to other countries in this group for all data categories considered here; the life expectancy in China is 73 years and the literacy rate is 91 percent.) For countries below China's emissions per capita, the trend is clear: greenhouse gas emissions are highly correlated with the level of development. Above China's level of emissions per capita, improvements in life expectancy and literacy slow, but gains in income per capita remain strong.

Table 5: International Dataset:
Emissions and Development Measures by Emission per Capita Decile

Countries grouped by decile of emissions per capita	Mean CO2 Emissions/ capita (tons)	Mean GDP/capita (PPP)	Mean Life Expectancy (years)	Mean Literacy rate (%)	Mean Cumulative emissions/ capita (tons)
Lowest	0.1	841	52	51	2
Second	0.2	1,181	54	54	6
Third	0.6	2,610	62	75	21
Fourth	1.1	4,343	67	85	44
Fifth	**1.8**	**5,899**	**71**	**87**	**51**
Sixth	**3.3**	**8,538**	**71**	**89**	**100**
Seventh	**5.3**	**15,425**	**75**	**94**	**240**
Eighth	**7.6**	**19,313**	**75**	**97**	**338**
Ninth	**10.3**	**24,310**	**73**	**95**	**475**
Highest	27.6	38,223	76	95	680

Note: Cumulative emissions are for 1850 to 2005.

[20] Data are from the UNDP Human Development Report, http://hdr.undp.org/, World Resources Institute, Climate Analysis Indicators Tool, http://cait.wri.org/, and the China Statistical Yearbook 2007, http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm.

Table 6: Chinese Provinces:
Emissions and Development Measures by Emission per Capita Decile

Chinese provinces grouped by global decile of emissions per capita	Mean CO2 Emissions/ capita (tons)	Mean GDP/capita (PPP)	Mean Life Expectancy (years)	Mean Literacy rate (%)	Count of provinces in group
Lowest					0
Second					0
Third					0
Fourth					0
Fifth	2.3	2,736	69	92	1
Sixth	3.4	2,966	70	87	13
Seventh	5.2	6,103	74	90	6
Eighth	7.4	5,465	71	91	6
Ninth	9.8	8,224	73	89	4
Highest					0

Note: Cumulative emissions are for 1850 to 2005.

Table 6 sorts Chinese provinces by emissions per capita decile in the international dataset. Only one Chinese province, Jiangxi, has emissions per capita below the world median; Jiangxi has the sixth lowest average life expectancy, but the 11th highest literacy rate among the 30 provinces. Most provinces join China as a whole in the first decile above the median. The four Chinese provinces with the highest emissions per capita are Shanghai (10.3 tons), Ningxia (9.9), Inner Mongolia (9.9), and Tianjin (8.9). Although the emissions intensity of Chinese large Eastern city-provinces – Beijing (7.8 tons), Shanghai, and Tianjin – are much higher than that of cities like Singapore, Hong Kong and Macao, the basic relationship seen in the global data remains the same within China: cities have higher incomes than larger regions with the same emissions per capita. Chongqing, China’s large Western city-province, is an exception with much lower income per capita ($3,200), emissions per capita (3.5 tons), life expectancy and literacy than Beijing, Shanghai and Tianjin.

5. Re-Examining the Environmental Kuznets Curve

A key question in understanding the relationship between emissions and development is this: As countries develop, and income per capita grows, is a constant emissions intensity maintained? Even with constant emissions intensity, developing countries’ contribution to atmospheric concentrations of greenhouse gases will grow in relation to that of industrialized countries as incomes rise. If, however, emissions intensity grows as income grows, future emissions may dwarf business-as-usual projections. Taking an international mandate for poverty reduction as a given,[21] if global emissions are to decrease over time two things will be necessary: first, rich countries must decrease their emissions intensity;

[21] See for examples the literature on the United Nations’ Millenium Development Goals, http://www.un.org/millenniumgoals/.

and second, low-income and middle-income countries must find a way to increase their income per capita while maintaining or reducing emissions intensity.

By far the strongest determinant of emissions per capita is PPP-adjusted GDP per capita. As noted above, it alone explains nearly two-thirds of the international variation in emissions intensity. One possible form for the relationship of emissions to income is a so-called Environmental Kuznets Curve (EKC), which posits U-shaped pollution levels that first rise and then fall as income per capita increases.[22] The message of the EKC is that negative environmental impacts may increase with development but further development will serve to reduce pollution. In essence, environmentalism is a luxury good that a richer, better educated populace will purchase either collectively (through a policy response or by importing pollution-intensive goods from elsewhere) or individually.

The linear regression reported in Table 1 (above) can only describe a linear relationship between emissions per capita and income per capita; graphically the trend line representing that relationship is nearly indistinguishable from the ray describing the median emissions intensity in Figure 1 above. Table 7 reports on a log-log regression, where the natural logarithm of emissions per capita is regressed against the natural logarithm of income per capita.[23] The coefficient of a log-log relationship can be interpreted as a ratio between two percentage changes. Here the estimated coefficient implies that for every 1 percent increase in income per capita there is a 1.13 percent increase in emissions per capita.

Table 7: Regression analysis

Dependent variable: natural logarithm of CO_2 emissions per capita

Independent variables: natural logarithm of PPP-adjusted GDP per capita; average annual temperature in country capital (degrees Celsius); transition country (dummy); and oil production per capita (2005 US$1000).

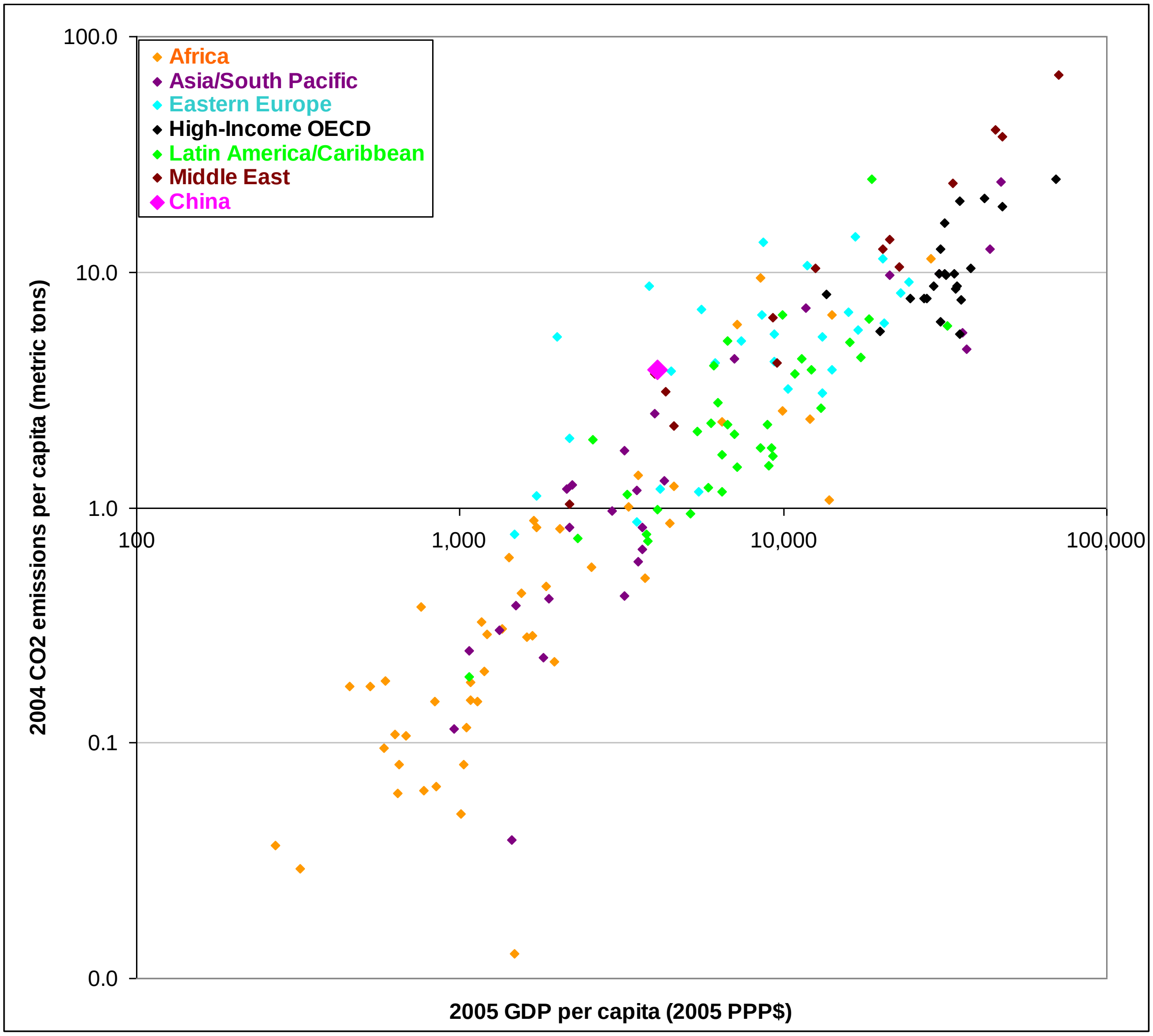
	Coefficient	*Significance*[a]		
Log per capita GDP (PPP$)	**1.1303**	**	**Number of observations**	**174**
Temperature (°C)	**-0.0044**		**R-squared**	**0.853**
Transition country (dummy)	**0.6308**	**		
Per capita oil production ($1000)	**0.0376**	**		
constant	**-9.2468**			

a) * indicates significance at the 95% level; ** indicates significance at the 99% level

[22] For a good summary of issues surrounding the Environmental Kuznets Curve see (Torras and Boyce 1998).

[23] Data are from the World Bank, World Development Indicators online database except for temperatures of capital cities, http://www.worldclimate.com/.

Figure 4: Logarithm of Emission/capita v. Logarithm of GDP/capita (PPP)

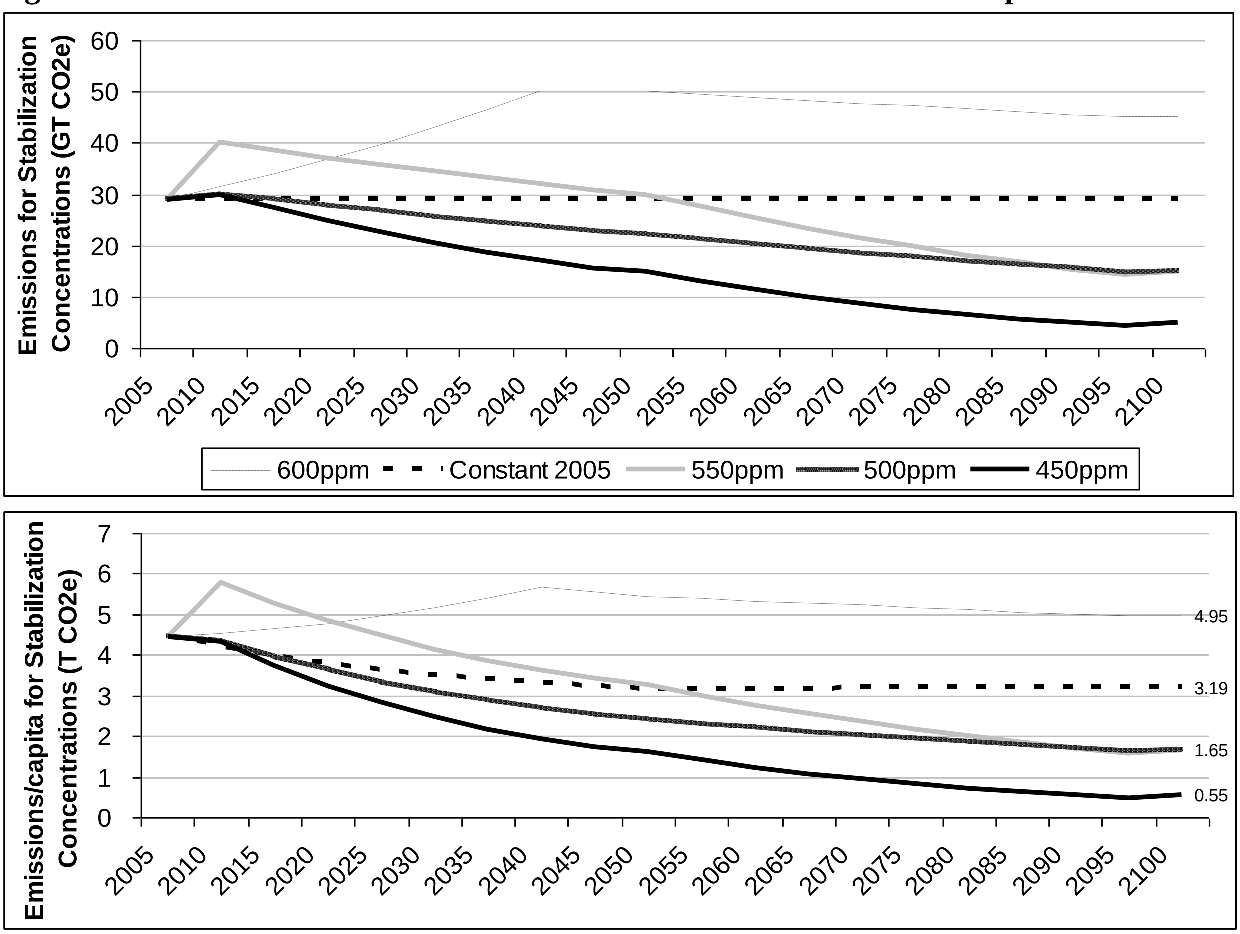


Far from rising and then falling, the relationship between emissions per capita and income per capita is exponential, with emissions increasing at a slightly increasing rate over the set of countries in the dataset: there is no evidence for an EKC for carbon emissions in this dataset. If the trend of this regression can be said to represent the path of countries as they develop (a common argument in the EKC literature), than emissions are growing as income per capita grows, and, at least within the range of today's nations, there is no evidence that after some threshold of wealth, emissions will begin to decrease. Figure 4 shows the graph of emissions per capita versus income per capita in logarithmic scale, with China highlighted in pink.

6. Avoiding Climate Catastrophe: Development Implications

Stabilization targets of 450ppm CO2 or lower have the best chance of keeping the change in change in global annual average temperature below 2°C (IPCC 2007; Stern 2006). Figure 5 pairs Intergovernmental Panel on Climate Change (IPCC) stabilization trajectories, showing total emissions, in the top panel (IPCC 2007) with their global emissions per capita in the bottom panel, based on median United Nations population projections.[24] To hold steady at the 2005 level of total global emissions, per capita emissions will have to shrink from 4.3 to 3.2 tons over the next century to compensate for expected population growth. Note that the speed with which emissions reductions are begun is just as important as the eventual per capita target: The IPCC trajectories for 550ppm and 500ppm both reach 1.6 tons per capita by 2100. The 550ppm trajectory projects rising global emission through 2010; in the 500ppm trajectory, emissions are reduced steadily from 2010 onward.

Figure 5: Stabilization Concentrations: Global emissions and emissions/capita



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[24] United Nations, World Population Prospects: The 2006 Revision Population Database, http://esa.un.org/unpp/.

To achieve a 450ppm or lower stabilization concentration, global per capita emissions must decrease steadily throughout this century, dropping well below 1 ton per capita by 2100. As the world works towards lowering is emissions, there may be both good examples and lessons to be learned among the 57 countries that already have emissions levels lower than 1 ton per capita.

Today, most of the countries with emissions per capita less than 1 ton are the poorest countries with the lowest standard of living in the world – with life expectancies as low as 40 years in Zambia and literacy rates as low as 24 percent in Mali and Burkina Faso – but there are some exceptions to this pattern. The richest countries today with emissions below 1 ton per capita are El Salvador ($5,300 in income per capita) and Swaziland ($4,500). The poorest countries in this group are Burundi and the Democratic Republic of Congo (both $300).

The highest life expectancies among this group are found in Nicaragua and Sri Lanka (both 72 years, the same as China, compared to Japan's 82 years). The transition countries have the highest literacy rates among this group, 100 percent literacy in Georgia and Tajikstan; Samoa is a close third with 99 percent literacy. Some low-emissions countries with anomalous achievements in development have taking a path that few would choose to follow: Reaching near-Western levels of development, and than losing it again (as with former Soviet republics and countries that were highly dependent on economic relations with the Soviet Union). But other examples of low-emissions-intensity development warrant further study with the goal of replicating the success of a Sri Lanka or a Samoa: low emissions per capita but relatively high life expectancy and literacy.

If development is understood not as meeting basic needs but instead as achieving high levels of private consumption, however, examples of high-income countries with very low emissions per capita simply do not exist. To achieve a low stabilization concentration while maintaining high-consumption, Western-style lifestyles, or increasing levels of private consumption in developing countries over time, the development of new technology and a new global energy infrastructure will be essential. No high-income country has emissions lower than 5 tons per capita.

Table 8 reports the countries in the bottom quintile by emissions intensity.[25] At 1.1 tons per capita and $14,000 in income per capita, Gabon has a remarkably low emissions intensity; its life expectancy is low at 56 years, but its literacy rate is relatively high, 84 percent.

In the second decile by emissions intensity (see Table 8), Costa Rica and Uruguay stand out as middle-income, middle-development countries with low emissions, less than 2 tons per capita. Renewables other than biomass contribute a relatively high share of these

[25] Data are from the UNDP Human Development Report, http://hdr.undp.org/, and World Resources Institute, Climate Analysis Indicators Tool, http://cait.wri.org/.

countries energy production: 20 percent for Uruguay and 41 percent for Costa Rica. Among high-income, high-development countries, only Switzerland has an emissions intensity in the lowest quintile; 18 percent of Switzerland's energy production is from renewables and 23 percent from nuclear. Switzerland has a cold climate (limiting air conditioning use), a very small manufacturing sector, and comprehensive system of local and intercity public transporation. Costa Rica, Uruguay and Switzerland all produce no oil and have large service sectors (62, 59, and 70 percent of value-added to GDP from services, respectively). In comparison, China's energy production is composed of just 2 percent renewables, excluding biomass and waste, and 1 percent nuclear, and China's service sector generates only 40 percent of the value added to GDP.[26]

[26] Data are from the World Bank, World Development Indicators online database.

Table 8: Lowest Quintile by Emissions Intensity

Countries in bottom decile by emissions intensity	CO2 Emissions/ capita (tons)	GDP/capita (PPP)	Life Expectancy (years)	Literacy rate (%)	Cumulative emissions/ capita (tons)
Chad	0.01	1,468	50	26	0.7
Cambodia	0.04	1,440	58	74	1.5
Mali	0.05	1,004	53	24	1.3
Uganda	0.07	846	50	67	1.7
Gabon	1.08	13,821	56	84	108.8
Burkina Faso	0.08	1,026	51	24	1.9
Rwanda	0.06	772	45	65	1.7
Burundi	0.03	319	49	59	0.8
Central African Republic	0.06	644	44	49	2.1
Tanzania	0.12	1,049	51	69	2.8
Cameroon	0.22	1,959	50	68	10.1
Nepal	0.11	960	63	49	1.7
Malawi	0.08	648	46	64	2.6
Lao PDR	0.23	1,814	63	69	3.2
Vanuatu	0.42	3,226	69	74	13.3
Comoros	0.15	1,127	64	57	3.4

Countries in second lowest decile by emissions intensity	CO2 Emissions/ capita (tons)	GDP/capita (PPP)	Life Expectancy (years)	Literacy rate (%)	Cumulative emissions/ capita (tons)
Congo, Dem. Rep.	0.04	267	46	67	3.1
Guinea	0.15	1,081	55	30	4.9
Switzerland	5.47	35,182	81	99	324.6
Mozambique	0.11	677	43	39	5.3
Niger	0.09	584	56	29	2.3
Sri Lanka	0.59	3,546	72	91	12.9
Costa Rica	1.50	9,008	79	95	30
Gambia, The	0.18	1,078	59	43	4.5
Sudan	0.29	1,679	57	61	5.7
Zambia	0.20	1,183	41	68	15.6
Ethiopia	0.11	628	52	36	1.3
Cote d'Ivoire	0.28	1,614	47	49	9
Uruguay	1.66	9,266	76	97	81.5
Haiti	0.19	1,068	60	55	4.5
Madagascar	0.15	834	58	71	3.1
Peru	1.17	6,460	71	88	37.9

The development implications of greenhouse gas emissions reductions are two-fold. First, lower emissions are currently associated with a lower standard of living; extraordinary efforts will be required to change this pattern. A combination of the widest access to today's best technologies and policies, with far-reaching and immediate investment in technology innovation will be necessary to keep global emissions per capita below 5 tons – much less bring it below 1 ton by the end of the century – while expanding the number of people at an adequate standard of living. Second, for many developing countries to the cost of emissions reductions will be prohibitive to development; for many transition countries and middle-income countries, like China, these costs could be devastating to the maintenance of current standards of living and could even cause are reversal in the level of development.

At an average cost of $80 per ton[27] of carbon eliminated, the cost of China's abatement from current emissions to 1 ton per capita would be 16 percent of its GDP. With 20 percent of the world's population and 17 percent of world emissions, China's full participation is essential to achieve global emissions reduction goals. For China and many other countries, their ability to reduce emissions will be hobbled by their ability to pay for those reductions. Abatement emissions need not be synonymous with paying for abatement; indeed, freeing abatement from the ability to pay for abatement may be the only way to reach emissions levels below 1 ton per capita without the kind of rapid loss of standard of living experience in Eastern Europe and the former Soviet Union (Baer *et al.* 2008).

7. Conclusions

If China maintains a constant or slightly increasing emissions intensity as its income per capita grows, it will begin to resemble Bahrain, Kuwait or the United Arab Emirates in terms of emissions per capita and income per capita. There are no examples of highly industrialized, high-income countries with as high an emissions intensity as China. Where China's emission intensity is 0.9 tons per $1,000 of income per capita, India's is 0.6 tons, United States 0.5, Japan and Germany 0.3, and Brazil 0.2. If China reaches Japan's income per capita (in PPP terms) while maintaining the same emissions intensity it will emit 32 tons per capita of CO_2 each year; if China reaches U.S. income per capita at this emissions intensity, its emissions will reach 44 tons per capita.

The message here is not that a low stabilization trajectory is inconsistent with global development, rather, that today's industrialized countries do not provide an example of how to achieve a high average standard of living while keeping greenhouse gas emissions low. Even the best current technology cannot square high levels of consumption with emissions lower than 5 or 6 tons per capita. Quick action to implement the best existing technology worldwide is essential – and can be especially effective in countries like China where changes to energy infrastructure are not limited by a lock-in to built

[27] See (McKinsey&Company 2009).

structures – but so too are large-scale investments in innovation in the areas of low-carbon electricity production, low-energy transportation, residential and industrial technology, and carbon capture and storage.

Appendix: Comparison of Emissions per Capita Data

Differences among these data sets are generally within 15 percent and are entirely within 25 percent with the exceptions of Qinghai and Sichuan provinces.

Appendix Table 1: Total carbon dioxide emissions per capita by Chinese province, 2005-2006

	Princeton University[a]	Tsinghua University[b]	Author's Calculations[c]
Anhui	2.87	2.95	2.43
Beijing	7.61	9.56	7.80
Chongqing	3.07	3.23	3.51
Fujian	4.00	4.60	4.00
Gansu	3.74	4.70	3.96
Guangdong	4.03	5.87	4.48
Guangxi	2.45	2.61	2.51
Guizhou	4.60	4.56	3.99
Hainan	2.00	2.21	2.35
Hebei	7.42	7.12	6.60
Heilongjiang	4.73	5.64	4.71
Henan	4.16	4.10	3.68
Hubei	3.83	4.15	4.01
Hunan	3.34	3.72	3.33
Inner Mongolia	12.03	11.39	9.94
Jiangsu	6.02	6.37	5.27
Jiangxi	2.41	2.45	2.27
Jilin	6.41	6.66	5.15
Liaoning	7.89	8.40	7.93
Ningxia	10.42	10.57	9.94
Qinghai	4.10	4.08	7.53
Shaanxi	3.75	4.05	3.56
Shandong	6.56	7.21	6.02
Shanghai	10.84	12.87	10.28
Shanxi	9.89	9.01	8.38
Sichuan	2.30	2.25	3.27
Tianjin	9.95	10.32	8.94
Xinjiang	6.06	6.85	6.41
Yunnan	3.43	3.36	3.15
Zhejiang	5.37	6.70	5.63

Sources:

[a] Personal communication. Jie Li, Princeton University, 2008. Data are for 2005.

[b] Personal communication. Jing Cao, Tsinghua University, 2008. Data are for 2005.

[c] Author's calculations using data from China Statistical Yearbook 2007. Data are for 2006.

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