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Development and greenhouse gas emissions deviate from the 'modernization' theory and 'convergence' hypothesis

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ABSTRACT: Projections of future climate change partly depend on the assumptions made for future emissions of greenhouse gases (GHG). These emissions are typically represented through an emissions scenario that posits a particular trajectory of development for the global society over the time of the projection. Since GHG emissions have a substantial impact on climate change, a relevant issue is what theories provide a good framework for addressing the drivers of GHG. We address 2 key research questions in this context: (1) Are carbon emissions attributable to structural change? If so, is it necessary to focus on the trajectories of carbon intensity or also on total emissions? (2) Does the development path of developing countries follow that of industrialized nations (convergence hypothesis) or is it suppressed in some areas and augmented in others due to world hierarchy and heterogeneity? Two development theories that have been applied to understand the drivers of GHG emissions are the modernization theory (MT) and the world economy theory (WET). In this paper, we use a statistical cluster analysis of economic data at the country level to test these theories and explore the convergence hypothesis with respect to GDP and GHG emissions. Results show no evidence of convergence among countries' welfare and emissions in the near term as a consequence of the MT. These results suggest that caution should be exercised in using the MT as basis for developing future emissions scenarios and that more attention should be paid to the WET.

KEY WORDS: CO_2 emissions · Socioeconomic drivers · Development · Scenario · Climate change · Cluster analysis

1. INTRODUCTION

Projections of future climate change partly depend on the assumptions made for future emissions of greenhouse gases (GHG). These emissions are typically represented through a 'storyline' or emissions scenario that posits a particular trajectory of development for the global society over the time of the projection (IPCC 2000). Since GHG emissions have a substantial impact on climate change, a relevant issue is what theories provide a good framework for addressing the drivers of GHG. Besides providing some basis for particular climate projections, appropriate theories can also suggest broad principles for modifying GHG emissions. Two development theories that have been applied to understand the drivers of GHG emissions are the modernization theory (MT) and world economy theory (WET). In this paper, we use a statistical cluster analysis of economic data at the country level to test these theories with respect to GHG emissions.

According to the MT; although the environmental impacts of economic growth increase in early stages of development and affluence (measured by income per capita), impacts stabilize and then decline as economies mature through structural change or modernization (Gibbs 2000, Jung et al. 2000, Stern 2003, Bertinelli & Strobl 2004). This process is depicted by an inverted U-shaped curve, also known as the environ-

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mental Kuznets curve (EKC). The shape is the result of individual countries passing through stages of development, from agriculture to industry and then to services. The process, known as 'convergence', assumes all countries to follow the trajectory of the Kuznets curve and eventually end up with a mature economy with less environmental impacts.

Conversely, WET assumes that only a small number of nations may successfully move up in the international hierarchy of development (Roberts & Grimes 1997). Rather than converging towards similar mature economies, the WET implies a world that will continue to be hierarchical and heterogeneous. This heterogeneity of development must also be associated with different capacities for managing environmental problems.

A common set of future scenarios that is widely used in simulations of future climate (Ref IPCC AR4) emphasizes the convergence hypothesis (IPCC 2000, Fisher et al. 2007). The discussion of convergence or the lack thereof is relevant to climate change for at least 2 reasons. (1) Less convergence commonly yields more GHG emissions, which may be explained by slower growth of the total factor productivity (TFP), slower capital turnover, and less technological congruence resulting in low adoption of low-emission technologies in developing countries (Fisher et al. 2007). This feature will influence mitigation policies, as emissions could be higher than under a convergent situation. (2) The IPCC WGII (Parry et al. 2007) found that the capacity to adapt to a changed climate is influenced by such developmental factors as access to economic and natural resources, social networks, entitlements, institutions and governance. Under a convergent state, many nations will be able to cope with the impacts of climate change. Without convergence, more nations will have difficulties adapting to the local effects of global warming.

Is structural change, resulting in a less 'carbon-intensive' economy, the key to curb carbon emissions; or do we also need to focus on the trajectories of total emissions? Do developing countries follow the development path of industrialized nations; or is the world hierarchical and heterogeneous? This paper aims to answer these questions by clustering countries according to developmental and economic variables. This clustering is an alternative to more traditional partitions such as developed versus developing countries, and Annex versus non-Annex nations[1]. By considering carbon emissions for each cluster, it is possible to assess whether the Kuznets curve is a useful model to understand carbon emissions or if there are other important dynamics in total carbon emissions. As a broader assessment of the evidence for convergence, future tendencies in gross domestic product (GDP), GDP per capita and carbon dioxide emissions can also be examined in each cluster.

2. DATA AND METHODS

2.1. Data

The database compiled and distributed by the World Bank (2007) is the source for country level and annual data in this study. Although the period of record is from 1960 through 2006, and 208 countries are listed, there is a substantial amount of missing data, such that it is only feasible to consider a subset of countries. Scholars tend to agree on the relevance of the following factors as determinants of carbon emissions: population dynamics, affluence as measured by GDP per capita, and technology, as measured by carbon intensity and levels of modernization (York et al. 2003a,b). Based on this, we focus on the following variables: GDP per capita (Year 2000 US $) (GDPcap) as an indicator of affluence, percentage of the population aged between 15 and 65 yr (PopMid) for demographic dynamics, percentage of the population living in urban environments (PopUrb) for levels of modernization, and total carbon emissions for impacts. Carbon emission per capita (CO_2cap) was derived from the total emissions of CO_2 equivalent and the population. The choice of independent variables is also based on practicality. These variables are reported for many countries, thus reducing the potential for missing data. Although it is possible to use statistical variable selection techniques to identify subsets of variables that are good predictors of a dependent variable (e.g. CO_2 emissions), these methods require larger sample sizes than can be provided by country-level data. Prescribing a fixed set of variables that have theoretical justification is preferable in this case. The reader is referred to the World Bank (2007a) for precise definition of these variables.

The primary subset of countries that was considered includes those with a 2003 population >10 million and a complete set of variables for 2003. These criteria result in a subset of 72 countries. The countries omitted from our analysis only accounted for 7.8% of the total population and 7.1% of the CO_2 emissions in 2003.

2.2. Clustering of countries

Our statistical approach to clustering is different from the usual methods used in carbon emissions forecasting. The 2 main approaches are partitions based on region or income. For example, the Special Report on

[1]Under the Kyoto Protocol, emission restrictions were made for the rich countries of Annex 1 — the biggest greenhouse gas producers, and also the countries most able to cut emissions. Targets range from an 8% cut for the EU to a 10% increase for Iceland

Emissions Scenarios (SRES) as published by IPCC (IPCC 2000, 2007b) groups countries into 4 geographic regions: (1) OECD-1990, (2) Reforming Economies (central and eastern Europe and former Soviet Union, REF), (3) Asia, and (4) Africa, Latin America and Middle East (ALM). The industrial region (IND) corresponds to the SRES regions OECD90 and REF, and the developing region (DEV) corresponds to the SRES regions ASIA and ALM.

The economic criteria commonly used to measure the level of development and affluence of a nation are income per capita (GDP), life expectancy, and the rate of literacy. The World Bank for instance, classifies national economies according to their 2006 gross national income (GNI) per capita, calculated using the World Bank Atlas method. The groups are: (1) low income, ≤\$905; (2) lower middle income, \$906 to \$3595; (3) upper middle income, \$3596 to \$11 115; and (4) high income, ≥\$11 116 (World Bank 2007).

Both World Bank and SRES classifications have been the primary divisions used by the 3 working groups of the climate change research community (IPCC 2000, IPCC 2007a). Yet, those classifications have at least 3 limitations when used to explore the linkages between development and global warming:

(1) In the developed-nations group, the SRES classification combines countries with such diverse development pathways and emissions trajectories as the OECD90 region and countries undergoing economic reform (REF); it includes — in the developing-nations group — countries with such diverse levels of development as China, Korea and Thailand on the one hand, and Fiji, Malawi and Ethiopia on the other. As shown by Huang et al. (2008), the collapse of the REF countries' economies during the 1990s resulted in great decreases in GHG emissions; while the OECD90 nations contained a subgroup with increasing carbon intensity, and a second subgroup contained a decreasing trend.

(2) The use of such criteria as developing and developed or industrialized nations might be inaccurate and even misleading (D. Satterthwaite pers. comm.). Many so-called developing nations are actually not developing. The use of industrialization as a criterion is also misleading, as certain Asian and Latin American countries are among the world's major industrial producers and several have higher proportions of their labor force in industry than North America and most of Europe (D, Satterthwaite pers. comm.).

(3) It is not clear what criteria the World Bank applied in dividing countries into income groups, e.g. deciding that the low income group ends at ≤\$905, and not at ≤\$1000.

To overcome these limitations and provide a more robust basis for grouping countries, we used some co-variables that drive emissions trajectories as classification criteria, and applied hierarchical clustering (Everitt 1993) to generate groups of similar countries. We used a small set of standardized variables, deemed in the literature as key in explaining the variations in national emissions trajectories (Fisher et al. 2007, York et al. 2008), namely log GDP per capita, urban population and population aged 15 to 65 yr.

The hclust function in the R statistical environment (R Development Core Team 2008) was used for these calculations. Briefly, each country is assigned to its own cluster and then the algorithm proceeds iteratively, at each stage joining the 2 most similar clusters, continuing until there is just a single cluster. The criterion for similarity is related to the Euclidean distance among members compared to the distance between cluster means, and only depends on the values of the 3 standardized variables. As in any clustering exercise, the number of clusters is arbitrary. We choose to use 8 clusters from this algorithm as a compromise between having enough clusters to represent a diversity of countries, while maintaining reasonable sample sizes within each cluster. The split from 7 to 8 clusters was particularly judged to be a meaningful refinement.

Fig. 1 shows the hierarchical clusters coded by a common color on pairwise scatter plots of the 3 standardized clustering variables. The cluster attributes are described as 'the haves' (green group), the 'have somes' (black, pink, and orange groups), and the 'have nots' (turquoise, red, and blue groups). A high level of correspondence exists between the 8 clusters and the World Bank classification of countries (see Table A1). Countries grouped under the 8 clusters and those excluded due to population size and/or missing data are shown in Tables A1 and A2, respectively.

The clustering algorithm creates a partition of just 7 clusters by combining Groups III (pink, the 'have somes') and VI (green, the 'haves'), but creates 9 clusters by subdividing Group VI to create 2 additional groups — the first comprised of Canada, France, Germany, Italy, Japan, South Korea, the Netherlands, Spain and the United States and, the second, comprised of Czech Republic, Greece, Hungary, Poland and Portugal. Being able to relate clusters of size 7 and 9 to the 8-cluster result through aggregation and splitting is an advantage of hierarchical clustering. A statistical check was made to determine if the clustering could predict carbon emissions. An ANOVA was done to test if the mean trends in carbon emissions across the clusters are equal. Specifically, the 10 yr trend in CO_2cap was determined for each country and the F statistic was compared to the randomization of the countries to the 8 clusters. A p-value of ~0.05 indicates that emission trends are not the same among clusters.

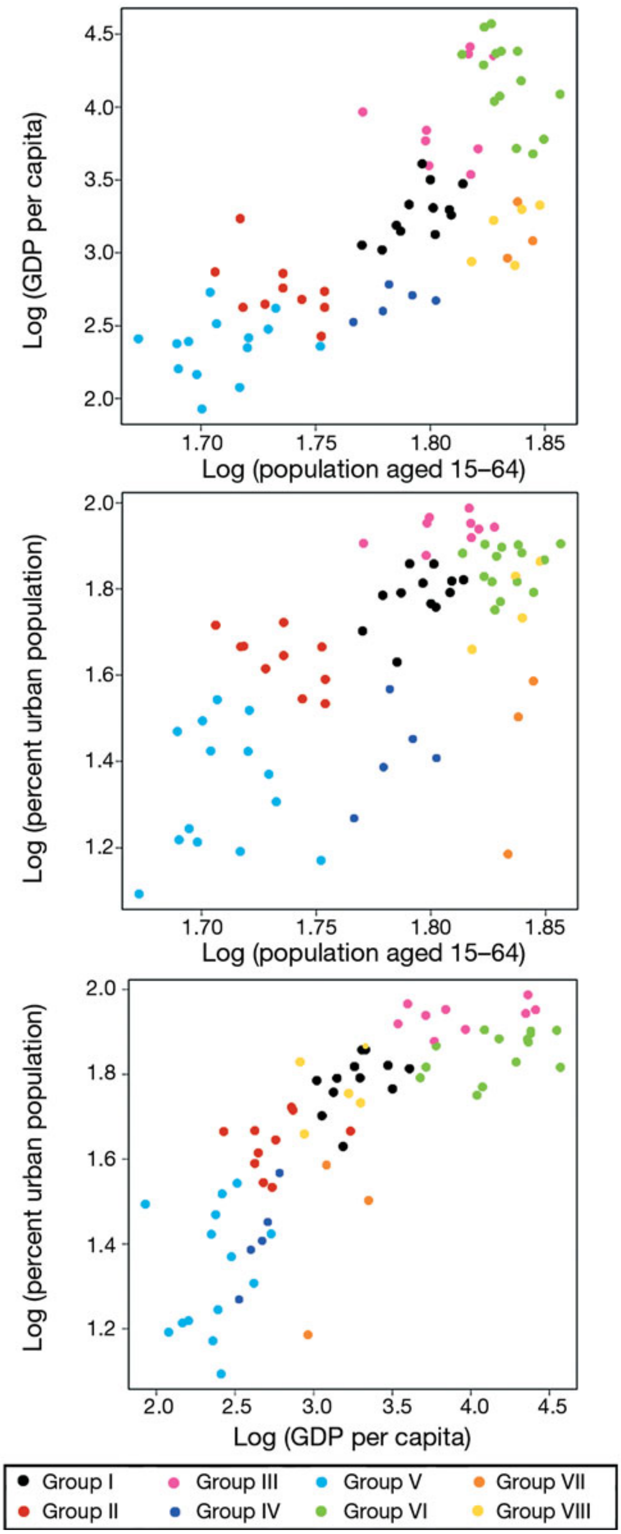

Fig. 1. Hierarchical clusters coded by a common color on pairwise scatter plots of the 3 standardized clustering variables GDP per capita, 15 to 65 population, and percentage of urban population (hierarchal clustering leaves a total of 72 countries). 'Haves': Group VI; 'have some': Groups I, III, VII, and VIII; 'have nots': Groups II, IV, and V

One interesting aspect of the clustering results is the grouping of countries with regional and/or cultural similarities (e.g. Colombia, Ecuador and Peru under Group I), even when these were not explicitly included among the variables for clustering. Moreover, even cluster members that are geographically separated often have other basic commonalities such as large petroleum exports (e.g. Saudi Arabia, Mexico and Venezuela under group III). Further examples of the advantages of using 3 variables for clustering are also notable. The blue 'have not' group is not separated from the turquoise cluster when only GDP per capita and percent of urban population are used. However, with the addition of the percentage of the population aged 15 to 65 yr, these two groups become delineated. On hindsight, separation into these two groups makes sense with regard to cultural and regional considerations.

As an alternative way of choosing clusters, we investigated the use of K-means clustering (Hartigan & Wong 1979) using the 8 hierarchical cluster centers as starting points for the algorithm. Four of the clusters remained the same, 3 had only small changes among members, but the last cluster had some significant shifting between clusters 6 and 8. One potential advantage of the K-means clustering is that it moves Indonesia into the group of other Asian countries. When random starting clusters were used, the K-means algorithm produced more distinctly different clusters but even in this case, the major grouping of countries suggested in the hierarchical clustering was preserved. Although there was some shuffling of cluster membership based on different clustering algorithms, we choose to use the hierarchical method because the nesting of clusters simplified the choice of cluster number. In general, the 3 variables used for clustering tend to be evenly spread, thus dividing these data into clusters may result in some ambiguity. There will always be some countries that are near boundaries between clusters that could be moved between groups with modest changes in the clustering algorithm.

3. EMISSIONS AND DEVELOPMENT

MT and WET have explored the nature of the relationship between development and carbon emissions, and whether developing nations will follow the development paths of industrialized countries. MT recognizes that development has generated negative environmental impacts, such as global warming. Yet, it states that economic development can also be the source of the solution. Two explanations for this are structural change/shift that occurs at the macroeconomic level (that leads to less carbon intensive societies), and such technological innovations as energy efficiency, renewable energy sources and — in the future — CO_2 capture and storage, all of whose use is induced by market mechanisms (Grossman & Kruger 1995, Huang et al. 2008). As a result of structural change and technological innovations, the environmental impacts of economic growth increase in the early stages of development, but stabilize and then decline as economies mature. The process, also known as the EKC, is depicted by an inverted U-shaped curve.

A key second statement of the MT is that the Kuznets curve is the result of individual countries passing through stages of development and eventually converging to a mature economy. This is due to the change in sectors such as agriculture and fishery to manufacturing industries and their further transformation into service industries as an economy develops. Industrialization, combined with scientific and technological progress, leads to modernization and to a series of processes (e.g. rural migration to urban areas, improvements of living conditions in cities) driving urbanization (Jung et al. 2000), and allowing countries to deal with their environmental problems through technological innovations.

Convergence has 2 carbon-relevant implications: First, income convergence between developed and developing countries is assumed to occur (Fisher et al. 2007) and with it, convergence in carbon emissions. A rich discussion on economic growth and convergence provided the economic background for the series of assumptions on the long-term convergence of income (as measured by GDP per capita) found in the scenario literature (Fisher et al. 2007, their Section 4.2). Second, by following the development path of industrialized countries, developing countries reduce their environmental problems through technological innovations associated with decreasing carbon intensity (Jung et al. 2000; Stern 2003, Bertinelli & Strobl 2004).

The WET also considers carbon intensity as an important test of the threshold in the relationship between development and environment (Roberts & Grimes 1997). However, it argues that the EKC is not a consequence of individual nations passing through certain stages of development. It is rather the result of a small group of wealthy countries becoming more affluent, powerful and efficient. The WET posits that the world economy is marked by a hierarchy of regions or groups of countries, interlinked by unequal exchanges of capital and resources, which make possible the functioning of the whole economic system (Braudel 1984). Within a small group of core areas — 'the haves' in our classification — is the major concentration of trade, technological innovations, energy and material consumption as well as carbon emissions (Romero Lankao 2004). Fairly developed middle nations and zones, the 'have somes' in our clustering, contain only some of the benefits, assets and carbon footprints of the core. Some of them constitute the runner-up areas. The huge peripheries, or 'have-nots' in our grouping, rank low in the hierarchy, and have a tiny share of trade, technological innovations, energy consumption and carbon emissions. The peripheries may be located within a nation's boundary or are part of overseas economic zones and empires. Peripheries function as resource-exporting hinterlands, linked to and impacted by core regions through different mechanisms: trade and political domination aimed at finding markets for industrialized goods, supplying cores with raw materials, and in recent decades, offering chances for relocation of carbon-intense activities considered environmentally negative to the cores (Galeano 1978, Ponting 1991). Peripheries are relatively more vulnerable to the impacts of a global warming they did not contribute to as much as did core regions (Romero Lankao 2007).

In the following sections, we explore some of the key drivers of carbon emissions, namely economic growth and structural change resulting in a less carbon-intensive economy; the relationship between size of the economy and total emissions; and whether development of the world is convergent or hierarchical and heterogeneous.

3.1. Threshold versus total emissions

The discussion on the applicability of the EKC to GHG emissions is often contentious (Huang et al. 2008). Some cross-national and cross-sectoral studies have found that the Kuznets hypothesis is supported by empirical evidence when applied to the exploration of the relationship between levels of development and such pollutants as toxic chemicals, sulphur dioxide, and particulates (Stern 2003, Bertinelli & Strobl 2004), but not for pollutants of global impacts such as carbon dioxide. Roberts & Grimes (1997) found that the relation between national carbon intensity and level of economic development has changed from essentially linear in 1965 to essentially curvilinear in 1990. The tendency to an essentially curvilinear relation is still valid for the year 2003 (Fig. 2). As also reported by Roberts & Grimes (1997) for 1990, the green group or the 'haves' showed a net improvement (decrease) in carbon intensity in 2003 (Fig. 2). The pink group or the 'have somes' also showed some improvements.

More recent studies found that while the carbon intensity of the global economy improved (i.e. decreased) by 1.3 % yr^{-1} during 1970–2000, it has dete-

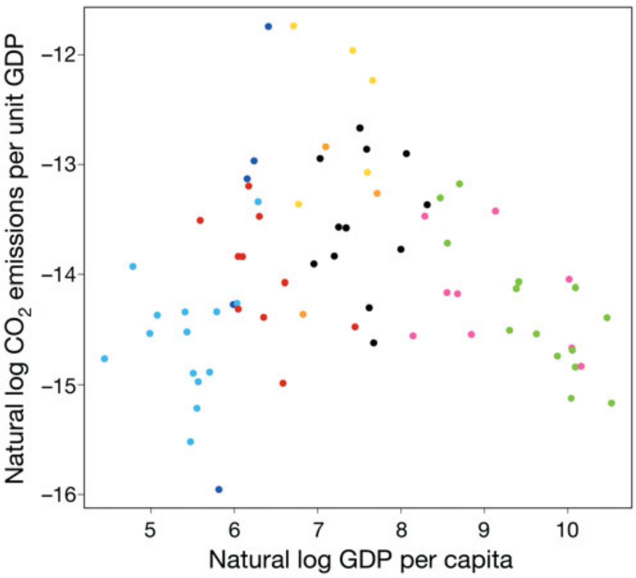

Fig. 2. Relationship between carbon intensity (kt per unit GDP, US$) and economic development (2003). Colors as in Fig. 1

riorated (i.e. increased) by 0.3% yr^{-1} since 2000 (Canadell et al. 2007, Raupach et al. 2007). Furthermore, emissions are tracking above the most intense fossil fuel scenario established by the IPCC SRES (IPCC 2000), the A1FI-A1 fossil fuel intensive, and moving away from stabilization scenarios of 450 and 650 ppm.

Another picture emerges when the total carbon budget, instead of carbon intensity, is given focus since the former affects the capacity of the carbon pools to absorb GHG emissions (Canadell et al. 2007). Proponents of the EKC have been criticized for not paying due attention to the scale effect and the size of a country's economy. In raw quantity, carbon dioxide emissions and energy consumption are closely correlated with the size of a country's economy. Although the relations between total emissions and the size of a country's economy (as measured by total GDP in constant US $) have been weakening since the 1960s, both are still linearly related: r^2 = 0.907, 0.649, and 0.697 for 1960, 1990, and 2003, respectively (Table A3). As to the overall effect, even with structural or technological changes aimed at improving the carbon intensity of the economy, total GHG emissions have increased globally at 1.3% annually during the period 1990–1999 and at 3.3% annually from 2000–2006 (Canadell et al. 2007). In the 'haves' or green group that is assumed by the MT to promote such requirements for structural change with more efficient infrastructure and stringent pollution controls, total GHG emissions have also increased by 1.04% annually in 1990–1999 and by 1.19% annually in 2000–2003 (Fig. 3).

York et al. (2003a) pointed out that not only affluence, but also the structure of an economy (measured by the percentage of GDP not in the service sector), and its levels of urbanization (indicated by the percentage of the population living in urban areas) have impacts opposite to those proposed by the MT. Increases in urbanization correlate with increases in energy consumption and CO_2 emissions per capita (see Fig. 4). This implies that high-income, more industrialized and more urbanized economies have higher emissions and energy footprints than lower-income, less industrialized and less urbanized economies.

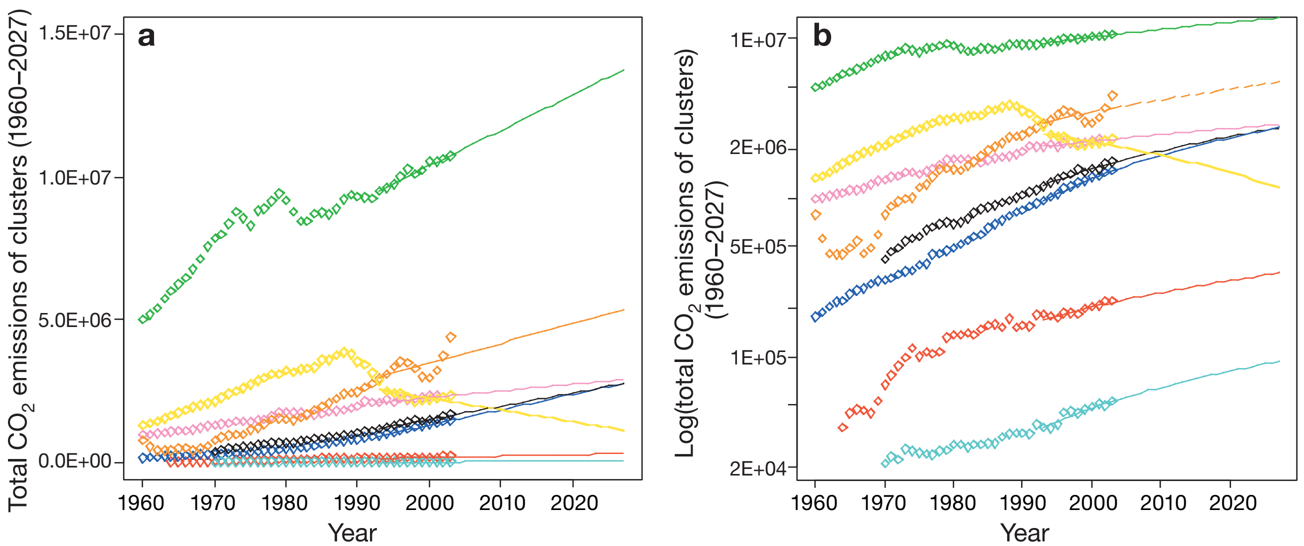

Fig. 3. Recent to near future tendencies in (a) total and (b) logged total CO_2 emissions (kt) by cluster. Colors as in Fig. 1

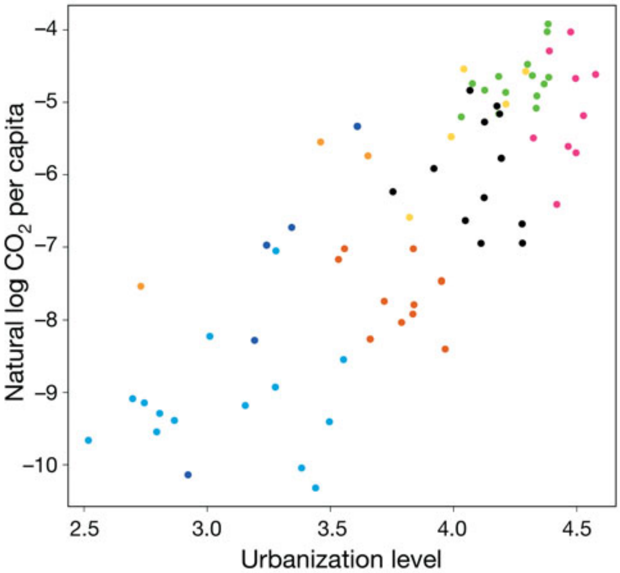

Fig. 4. Relationship between CO_2 emissions (kt) and urbanization levels. Colors as in Fig. 1

3.2. Scenarios narratives and the convergence hypothesis

As already mentioned, a broad discussion exists within the climate change community on 'the nature of economic processes and whether developing countries will follow the development pathways of industrialized countries with respect to energy use and GHG emissions' (Fisher et al. 2007). A component of this discussion relevant to this paper is the weight given to the convergence hypothesis within the scenarios literature. Below we review the major scenarios and their use of convergence.

Rather than predicting future developments, scenarios describe plausible trends. However, it is reasonable to expect scenarios to portray the transition from recent and present trajectories to the long-term logic with some degree of plausibility (van Vuuren & O'Neill 2006). This is because large inconsistencies with historical trajectories and/or near-term expectations would imply that all of the scenario logic is unlikely and even implausible. Moreover, an insufficient fit between scenarios and historical data or short-term trends can undermine the credibility of the scenarios (van Vuuren & O'Neill 2006). Two groups of narratives within the scenarios literature are pertinent here: the SRES scenarios (IPCC 2000) developed by and for the IPCC, and the scenarios families known as GEO-3, developed by the Global Environment Outlook (GEO) (UNEP 2004).

The SRES (IPCC 2000) focuses on 6 scenario storylines, grouped into 4 scenario families. They differ in several aspects, e.g. how global regions interrelate, how new technologies diffuse, and how regional economic activities evolve. Two axes define the assumptions of the 4 families: emphasis on continuing globalization (marked as '1') versus regional identity (marked as '2'); and prominence of economic development (marked as 'A') versus social and environmental factors (marked as 'B'). The A1 scenario family describes a world of very rapid economic growth, a population that declines after mid century, and the rapid introduction of new technologies. The A2 scenario family describes a very heterogeneous world. Economic development is mostly regionally orientated, while technological change is more fragmented (IPCC 2000, 2007c). In the B1 scenario family, global solutions to economic, social and environmental sustainability as well as to equity are prominent. The B2 scenario family describes a world that emphasizes local solutions to economic, social and environmental sustainability (IPCC 2000, 2007). A common feature of these scenarios is the assumption on the long-term convergence of income and total CO_2 emissions between developed and developing nations (Table 1).

To classify scenarios, GEO uses classes defined by essentially different social visions and variants, which represent a range of possible outcomes within each class. Three broad classes are Conventional World, Barbarization and Great Transitions, respectively characterized by fundamental continuity with current development pathways, essential but unwanted social change, and favorable social transformation (UNEP 2004). The 2 variants of the Conventional World class share the premises of convergence of developing countries towards the development models of industrialized countries. The Market Forces variant, a market-driven development, differs from the A1 scenario in that economic growth in this variant is accompa-

Table 1. SRES marker scenarios. Dates (nearest 5 yr) when developing region (DEV) countries reach 1990 levels of industrial region (IND) countries, and when they reach parity (and overtake) projected IND country levels. Modified and based on IPCC 2000, their Table 4.19. mex: market exchange rate

	A2	B2	A1B	B1
Reaching 1990 IND levels				
GDP (mex)	~2030	~2020	~2015	~2020
GDP (mex) per capita	>2100	~2080	~2050	~2060
Annual CO_2	~2000	>2000	~2000	~2005
CO_2 per capita	–	–	–	–
Overtaking IND				
GDP (mex)	~2060	~2035	~2030	~2035
GDP (mex) per capita	–	–	–	–
Annual CO_2	~2000	~2005	~2000	~2005
CO_2 per capita	–	–	–	–

nied by less convergence (Table 2). The Policy Reform variant adds incremental policy adjustments, which steer conventional development towards environmental and poverty reduction goals. It strengthens management systems and the diffusion of environmentally friendly technologies. The Fortress World variant of Barbarization scenarios features a world descending towards fragmentation, extreme inequality (in contrast to convergence) and widespread conflict. It includes an authoritarian response to the threat of breakdown and is a world in which the elites, entrenched in protected enclaves, safeguard their privileges by controlling an impoverished majority and managing critical resources. Great Transitions classes explore visionary solutions to the sustainability challenge: a new development paradigm distinguished by planetary solidarity, and new values and institutions (UNEP 2004).

Both SRES and GEO-3 scenarios groups have common features: the way in which the tension between economic growth and environmental limits is resolved; and the commonalities between some storylines (e.g. the SRES-A1 and the GEO-3 Market Forces, Table 2). Yet, some differences exist. For example, the SRES scenarios do not consider the implications of international equity and poverty (UNEP 2004). While equity deteriorates in 2 GEO scenarios, namely the Market Forces and Fortress World (UNEP 2004), the SRES scenarios assume a narrowing of the income ratio between developed and developing countries in all scenarios, the narrowing ranging from <0.5% in the A2 scenario family to <2% in the A1 family (Table 1) (Fisher et al. 2007, see also Toth & Wilbanks 2004). Furthermore, the SRES scenarios provide dates when GDP and emissions in developing countries will reach and even overtake those that prevailed in industrial countries in 1990 (IPCC 2000; Table 1).

Table 2. Scenarios compared. Adapted from UNEP (2004). The table first appeared in the United Nations Environment Programme's (UNEP) Global environment outlook scenario framework (2004). Background paper for the third global environment outlook report (GEO-3)

Global scenario group	Framework	
	SRES	GEO-3
Conventional Worlds		
Market Forces	A1	Market Forces
Policy Reform	B1	Policy Reform
Barbarisation		
Breakdown		
Fortress World	A2	Fortress World
Great Transitions		
Eco-communalism	B2	
New Sustainability Paradigm		Great Transitions

The discussion on convergence is relevant to carbon emissions for 2 reasons. As found by sensitivity analysis, less convergence usually yields more GHG emissions. For example, in the B2 scenario, an income ratio of 7 (between 11 world regions, in market exchange rates) corresponds to CO_2 emissions of 14.2 Gt C in 2100, while shifting this income ratio to 16 would lead to CO_2 emissions of 15.5 Gt C in 2100. Similar results were also obtained for the A2 scenario (Fisher et al. 2007). Poor countries and communities can be especially vulnerable to the impacts of climate change. If convergence is not realized, then those countries will lack the financial and human resources to cope with climate change.

4. RESULTS AND DISCUSSION

We used our clustering of countries to determine recent to near future tendencies in GDP, GDP per capita and CO_2 emissions (Figs. 3, 5 & 6, respectively). These extrapolations were created using a least squares fit to estimate parameters for the annual trends of GDP, GDP per capita and CO_2 emissions for each cluster from 1960–2006 and linearly extending the estimates to 2027. Instead of testing for curvilinear or other relationships, 20 yr linear projections were used due to the ease in interpreting the slope as a simple summary of growth. We emphasize that these slopes are a summary of the recent growth in the clusters and that the linear extrapolation is more useful in emphasizing differences among the clusters rather than providing an absolute prediction of future growth. The goal is to see whether these projections are consistent with the idea of convergence as suggested by the SRES (Table 1, see also van Vuuren & O'Neill 2006), or whether income disparities increase, as assumed by at least 2 of the narratives of the GEO-3 logic, the Market Forces and the Fortress World (Table 2).

Figs. 5 & 6 do not show convergence between industrialized and developing countries as assumed by both the MT and the SRES literature. Instead, they illustrate a huge development gap (as measured by GDP and GDP per capita) between the 'haves' and the other 6 clusters of 'have somes' and 'have nots'. The pink 'have somes' is the only group poised to constitute the runner-up area, at least in terms of GDP per capita. This finding supports the WET's statement that development is hierarchical rather than being stage-based (Braudel 1984, Roberts & Grimes 1997, Romero Lankao 2004). Only a few countries have historically been able to move up in the world economy, and the same is currently happening, with only some nations (the pink 'have somes') being able to join the 'haves' group.

When compared with Fig. 2, Fig. 3 shows one of the ironies of modernization. The 'haves' in our classification are the ones with a net improvement/decrease in carbon intensity (Fig. 2). Yet, as suggested in the literature (Stern 2003, Bertinelli & Strobl 2005), the same green cluster has been less successful in curbing its total carbon emissions. This group's share of total GHG emissions is the highest and has steadily increased in recent decades. For the 43 yr spanning 1960–2003, its contribution to total carbon emissions is 52.5 %. Moreover, a big difference exists between the emissions trajectories of the 'haves' nations on the one hand, and the 'have somes' and 'have nots' nations on the other (Fig. 3a). Therefore, instead of converging as suggested by the SRES (Table 1) and the MT, the 3 indicators (GDP, GDP per capita, and CO_2 emissions) diverge. Three other groups have increased their total emissions: the orange 'have somes' including countries such as China and Thailand, the black 'have somes', including such nations as Iran and South Africa, and the blue 'have nots', including such countries as India and Vietnam (Fig. 3).

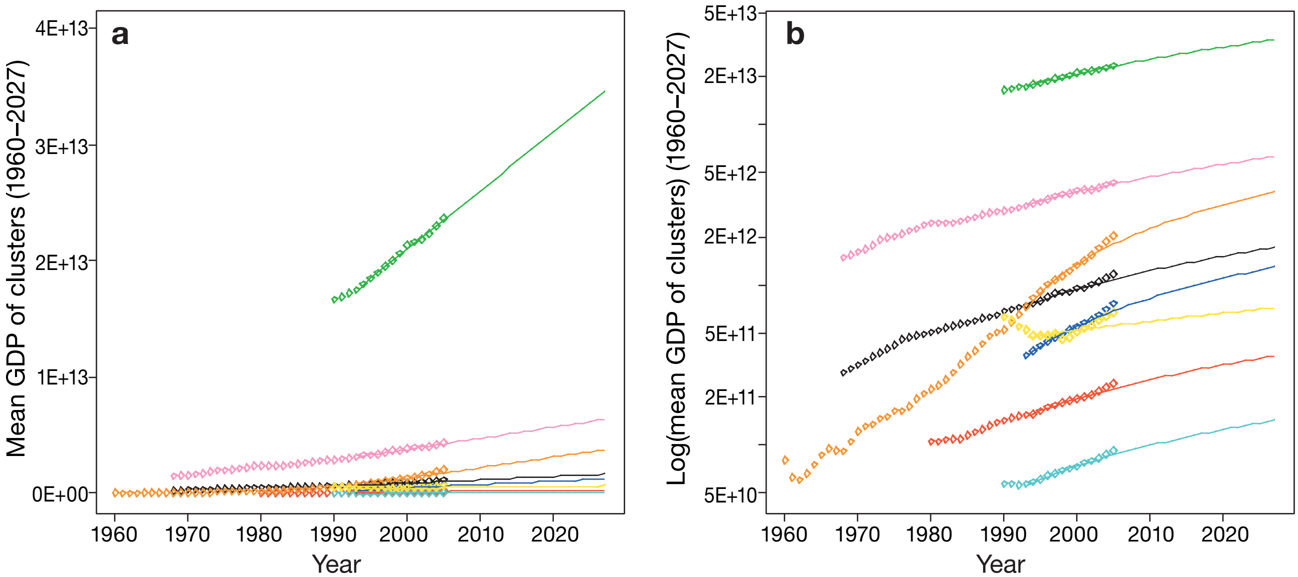

Fig. 5. Recent to near future tendencies in (a) mean and (b) logged mean GDP (US$) by cluster. Colors as in Fig. 1

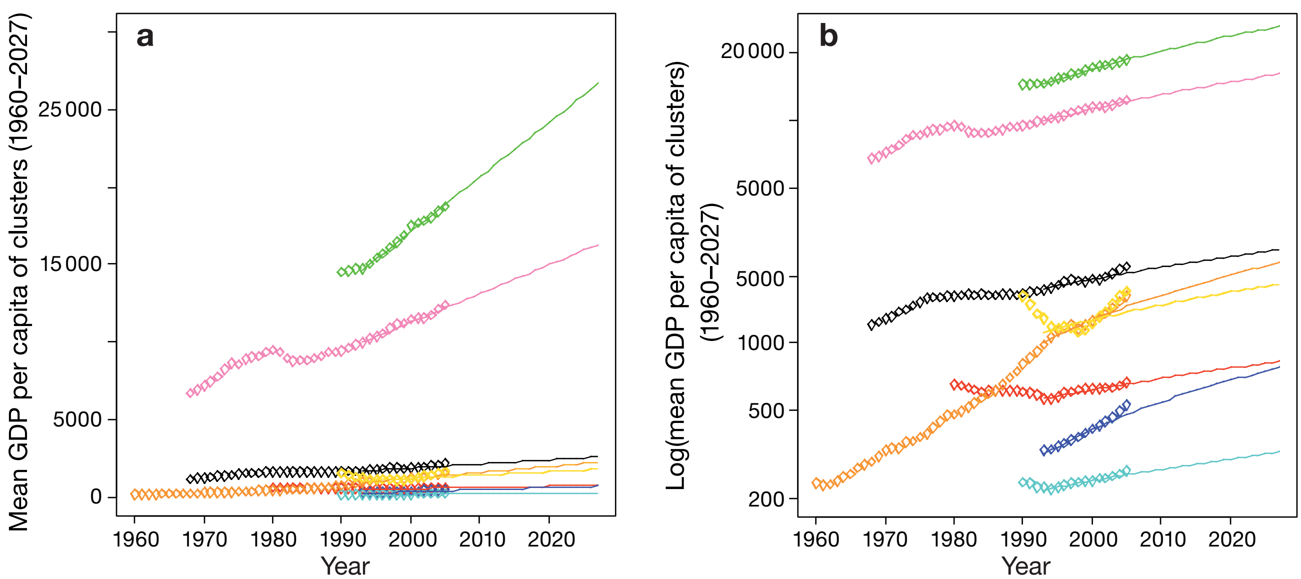

Fig. 6. Recent to near future tendencies in (a) mean and (b) logged mean GDP (US$) per capita by cluster. Colors as in Fig. 1

Figs. 3, 5 & 6 also show that there is no convergence between developed and developing countries as suggested in Table 1. Thus, the SRES scenarios do not necessarily portray the transition from recent and present trajectories to the future logic in a way that is consistent with the data. The historical trajectories of change in GDP, GDP per capita and total CO_2 emissions are inconsistent with the idea that developing countries will reach parity and even overtake projected industrial country levels, as suggested in Table 1. Instead, these trajectories are consistent with 2 GEO narratives: the Market Forces variant where economic growth results in a more skewed income distribution, and the Fortress World where the world moves towards extreme inequality (Table 2).

5. CONCLUDING REMARKS

In this paper we explored (a) whether structural change is a key requirement in reducing carbon emissions; (b) whether we also need to focus on the trajectories of total emissions, and (c) whether developing countries follow the development path of industrialized nations, or whether development is suppressed in some areas and augmented in others due to world hierarchy and heterogeneity. In support of findings by other scholars (Roberts & Grimes 1997), we conclude that countries, in fact, reach a threshold at which the intensity of carbon emissions begins to drop (Fig. 2). For wealthier countries (the 'haves' and even some 'have somes' in our clustering), this is partly the result of the introduction of more efficient technologies and more stringent pollution controls. Nevertheless, the full applicability of the EKC has been questioned by other scholars (e.g. Canadell et al. 2007, Raupach et al. 2007, York et al. 2008).

The capacity of terrestrial and ocean processes to absorb carbon is naturally dependent on the total amount emitted. Therefore, analysis also needs to focus on total carbon emissions, which have increased globally from 1.3% yearly during the 1990s, to 3.3% during 2000–2006. This is not surprising given that there was little incentive (e.g. increases in fuel prices) to reduce GHG emissions in the 1990s. Total carbon emissions have also increased considerably in the 'haves' and the 'have somes' and even the 'have-nots' countries (i.e. in the green, orange, black and blue clusters). We illustrate here that although the relationship between total emissions and size of a country's economy (as measured by total GDP in constant US $) has been weakening since the 1960s, they are still linearly related.

Rather than supporting the idea of countries passing through stages of development and eventually reducing their pollution through structural change (i.e. the convergence hypothesis), both Figs. 5 & 6 suggest that only a small number of nations have, at least since 1960, successfully been able to notably increase their levels of affluence as measured by GDP and GDP per capita. Thus, poverty and affluence are different facets of the same global economic system, rather than diverse points on a common economic trajectory. Other scholars report that the 'haves' cluster of nations has been successful in addressing local and regional environmental problems. We find here that they have been less successful in curbing total carbon emissions

Furthermore, Figs. 3, 5 & 6 show that the recent to near future tendencies in GDP, GDP per capita and CO_2 emissions are not consistent with the idea of convergence as suggested by the SRES. Instead, income disparities are likly to increase as assumed by at least 2 of the narratives of the GEO-3 logic: the Market Forces and the Fortress World. The inconsistency seems to be large enough to make part of the SRES logic implausible or at least unlikely. We suggest that the narratives based on the GEO logic be applied when exploring plausible futures of carbon-relevant change in development paths.

The present findings have several implications for the science of climate change. As suggested by sensitivity analysis, less convergence frequently yields more GHG emissions and increased carbon emissions result in increases in global temperatures. Thus, divergence needs to be associated, not only with the carbon cycle and the mitigation side of the climate change debate, but also with increased climate impacts (the adaptation side). Figs. 5 & 6 suggest that some of the developing countries will not join a convergent development group. Therefore, their populations and economic activities will not have the availability of resources, entitlements, social networks and governance structures deemed particularly important by the IPCC Working Group II Fourth Assessment for them to adapt to the impacts of climate change (Parry et al. 2007).

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Appendix 1

Table A1. Countries grouped by clustering based on 2003 data for GDP per capita, urban population, and population aged 15 to 65 yr and World Bank income classifications (World Bank 2007). Economies are divided into income groups according to 2006 GNI per capita, calculated using the World Bank Atlas method. The groups are: low income, ≤US$905; lower middle income, US$906– US$3595; upper middle income, US$3596–$11 115; and high income, ≥US$11 116

	World Bank income classification
Group I (black)	**'have-somes'**
Algeria	Lower-middle
Colombia	Lower-middle
Ecuador	Lower-middle
Egypt, Arab Rep.	Lower-middle
Iran, Islamic Rep.	Lower-middle
Malaysia	Upper-middle
Morocco	Lower-middle
Peru	Lower-middle
Philippines	Lower-middle
South Africa	Upper-middle
Syrian Arab Republic	Lower-middle
Turkey	Upper-middle
Group II (red)	**'have-nots'**
Angola	Lower-middle
Cameroon	Lower-middle
Cote d'Ivoire	Low
Ghana	Low
Guatemala	Lower-middle
Nigeria	Low
Pakistan	Low
Senegal	Low
Sudan	Low
Zimbabwe	Low
Group III (pink)	**'have-somes'**
Argentina	Upper-middle
Australia	High (OECD)
Belgium	High (OECD)
Brazil	Upper-middle
Chile	Upper-middle
Mexico	Upper-middle
Saudi Arabia	High (non-OECD)
United Kingdom	High (OECD)
Venezuela, RB	Upper-middle
Group IV (blue)	**'have-nots'**
Bangladesh	Low
Cambodia	Low
India	Low
Uzbekistan	Low
Vietnam	Low
Group V (turquoise)	**'have-nots'**
Burkina Faso	Low
Congo, Dem. Rep.	Low
Ethiopia	Low
Kenya	Low
Madagascar	Low
Malawi	Low
Mali	Low
Mozambique	Low
Nepal	Low
Niger	Low
Tanzania	Low
Uganda	Low
Yemen, Rep.	Low
Zambia	Low
Group VI (green)	**'haves'**
Canada	High (OECD)
Czech Republic	High (OECD)
France	High (OECD)
Germany	High (OECD)
Greece	High (OECD)
Hungary	Upper-middle
Italy	High (OECD)
Japan	High (OECD)
Korea, Rep.	High (OECD)
Netherlands	High (OECD)
Poland	Upper-middle
Portugal	High (OECD)
Spain	High (OECD)
United States	High (OECD)
Group VII (orange)	**'have-somes'**
China	Lower-middle
Sri Lanka	Lower-middle
Thailand	Lower-middle
Group VIII (gold)	**'have-somes'**
Indonesia	Lower-middle
Kazakhstan	Upper-middle
Romania	Upper-middle
Russian Federation	Upper-middle
Ukraine	

Table A2. Countries (n = 138) not included in the eight clusters

Afghanistan	Burundi	French Polynesia	Kyrgyz Republic	Netherlands Antilles	Slovenia
Albania	Cape Verde	Gabon	Lao PDR	New Caledonia	Solomon Islands
American Samoa	Cayman Islands	Gambia, The	Latvia	New Zealand	Somalia
Andorra	Central African	Georgia	Lebanon	Nicaragua	St. Kitts and Nevis
Antigua and Barbuda	Republic	Greenland	Lesotho	Northern Mariana	St. Lucia
Armenia	Chad	Grenada	Liberia	Islands	St. Vincent and
Aruba	Channel Islands	Guam	Libya	Norway	the Grenadines
Austria	Comoros	Guatemala	Liechtenstein	Oman	Suriname
Azerbaijan	Congo, Rep.	Guinea	Lithuania	Palau	Swaziland
Bahamas, The	Costa Rica	Guinea-Bissau	Luxembourg	Panama	Sweden
Bahrain	Croatia	Guyana	Macao, China	Papua New Guinea	Switzerland
Barbados	Cuba	Haiti	Macedonia, FYR	Paraguay	Tajikistan
Belarus	Cyprus	Honduras	Maldives	Puerto Rico	Timor-Leste
Belize	Denmark	Hong Kong, China	Malta	Qatar	Togo
Benin	Djibouti	Iceland	Marshall Islands	Rwanda	Tonga
Bermuda	Dominica	Iraq	Mauritania	Samoa	Trinidad and Tobago
Bhutan	Dominican Republic	Ireland	Mauritius	San Marino	Tunisia
Bolivia	El Salvador	Isle of Man	Mayotte	Sao Tome and Principe	Turkmenistan
Bosnia and	Equatorial Guinea	Israel	Micronesia, Fed. Sts.	Serbia and	United Arab Emirates
Herzegovina	Eritrea	Jamaica	Moldova	Montenegro	Uruguay
Botswana	Estonia	Jordan	Monaco	Seychelles	Vanuatu
Brunei Darussalam	Faeroe Islands	Kiribati	Mongolia	Sierra Leone	Virgin Islands (U.S.)
Bulgaria	Fiji	Korea, Dem. Rep.	Myanmar	Singapore	West Bank and Gaza
Burkina Faso	Finland	Kuwait	Namibia	Slovak Republic	

Table A3. Regression of total carbon emissions on total GDP for 1960, 1991, and 2003 (World Bank 2007). Coefficient for GDP estimates (±SE) and significance levels ($^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$) are reported

	Coefficient	r^2	N
1960	$1.087 \times 10^{-6} \pm 5.082 \times 10^{-8***}$	0.9068	47
1991	$5.661 \times 10^{-7} \pm 5.015 \times 10^{-8***}$	0.6487	69
2003	$5.271 \times 10^{-7} \pm 4.159 \times 10^{-8***}$	0.6965	70

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