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Modeling pessimism: Does climate Stabilization require a failure of development?

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ABSTRACT

Climate-economics models often assume that middle-income countries' per capita incomes will catch up with those of today's high income countries, while low-income countries will lag behind. This choice underrates the least developed countries' chance to escape poverty. The consequences in terms of the resulting policy advice are stark: assumed slow growth for the poorest countries means lower projected business-as-usual emissions and, as a consequence, much weaker emissions reduction goals. But what if low-income countries grow more quickly, as China and India have? In the absence of emission reduction policies, fast economic development would mean higher business-as-usual emissions in the future, and would therefore require more ambitious global emissions reductions policies today. This article reviews current practices in modeling income growth in integrated assessment models of climate and economy; provides an empirical illustration of the impact that more optimistic economic development expectations would have on emissions mitigation targets; discusses the kinds of policies necessary to adequately reduce emissions per dollar of economic output in a scenario of robust economic development for the poorest countries; and concludes with recommendations for integrated assessment modelers.

1. Introduction

How big is the climate problem? That depends, in part, on one's assumptions about the inescapably uncertain scale of future economic growth and consequent emissions. If policy makers believe that economic growth will be slow, they should expect future emissions and the climatic changes that result from them to be relatively small. If instead policy makers believe that the global

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economy will expand rapidly, they should expect higher emissions, and therefore should plan for more stringent mitigation policies.

High versus low economic growth may seem, at first, like a bland parameter adjustment, made solely with the goal of more accurate emissions projections and policy goals. In actuality, the choice of growth scenarios is normative and politically laden. When climate-economics models assume that middle-income countries' per capita incomes will catch up with those of today's high income countries, while low-income countries will lag behind, a choice is made to underrate the least developed countries' chance to escape poverty. The consequences in terms of the resulting policy advice are stark: assumed slow growth for the poorest countries means lower projected business-as-usual emissions and, as a consequence, weaker emissions reduction goals.

But what if low-income countries grow more quickly, as China and India have? In the absence of emission reduction policies, fast economic development eclipses income-driven reductions to emissions intensity (where emissions per dollar shrink solely as a result of factors associated with increasing prosperity, and not policy initiatives). The result is higher business-as-usual emissions in the future that require more ambitious global emissions reductions policies today.

This article begins by briefly reviewing current practices in modeling income growth in integrated assessment models of climate and economy, demonstrating that these models assume rates of growth in low-income countries that are not consistent with goals for economic development (a more detailed description of common modeling assumptions is provided in an Appendix to this article). Section 3 provides an empirical illustration of the impact that more optimistic economic development expectations would have on emissions mitigation targets. Section 4 discusses the kinds of policies necessary to adequately reduce emissions per dollar of economic output in a scenario of robust economic development for the poorest countries. A final section brings together recommendations to integrated assessment modelers based on these findings.

2. A review of current practices

Integrated assessment models combine climate and economy projections to arrive at recommendations of the optimal pace of greenhouse gas emissions reductions (see Stanton and Ackerman, 2009; and Stanton, Ackerman, and Kartha, 2009 for a more detailed explanation of these models). In these types of analyses, future emissions are typically modeled as the product of projected gross domestic product (GDP) and emission intensities per dollar of GDP. The pace of economic development can be assessed by comparing the growth rates of GDP per capita—a function of both GDP growth and population growth—among regions within a given model, and in relation to historical trends.

One of the most influential forecasts of future economic growth is published by the International Energy Agency (IEA) in its annual *World Energy Outlook* (*WEO*) (IEA, 2010b). Many models of energy, climate, and economy follow these IEA projections, among them the McKinsey & Co. (2009) marginal abatement pathways[1] and the IEA's own *Energy Technology Perspectives* (IEA, 2010a) and BLUE Map scenario. GDP and population forecasts are described in detail in the Appendix to this article.

In this article, countries are divided into four groups based on their 2005 PPP[2] per capita income, as follows[3]:

- High-income group: 55 countries with 18 percent of the 2005 global population; PPP incomes in 2005 range from $68,500 in Luxembourg to $12,300 in Mexico.

[1] McKinsey (2009) follows the *World Energy Outlook 2007* (IEA, 2007).

[2] All money values in this article are expressed in real PPP 2005 U.S. dollars. The purchasing power parity (PPP) conversion factor adjusts per capita GDP to reflect international differences in domestic prices for the same goods, which are usually lower in poorer countries. For a more detailed definition, see the World Bank Development Education Program glossary: http://www.worldbank.org/depweb/english/beyond/global/glossary.html.

[3] This classification differs slightly from the one used by the World Bank (http://data.worldbank.org/about/country-classifications/country-and-lending-groups) which is based on incomes for an earlier year and a different upper bound for the low-income group. A small number of countries have been removed from the dataset due to missing data for GDP, population, or emissions, resulting in a slightly lower 2005 world total than reported by the World Bank. The dataset used here includes 176 countries.

- High-middle-income group: 53 countries, including China, with 38 percent of population; incomes range from $12,200 in Chile to $4,000 in Syria.
- Low-middle-income group: 23 countries, including India, with 29 percent of population; incomes range from $3,900 in Paraguay to $2,100 in Pakistan.
- Low-income group: 45 countries with 15 percent of population; incomes range from $1,900 in Uzbekistan to $202 in the Republic of the Congo.

Thirty-four of the low-income countries are in Sub-Saharan Africa, representing 66 percent of the group's population in 2005 and 84 percent in 2105. One country, the Sudan, is in North Africa. Another nine low-income countries are in Asia and the Pacific, including Bangladesh, which by itself accounts for 16 percent of the low-income countries' current population. The final country in this group is Haiti, by far the poorest country in the Americas; the most recent World Bank data indicate that Haiti's per capita income—$1,016 in 2005—shrank to $996 in 2010, no doubt in part due to the tragic and ongoing aftermath of its 2010 earthquake.[4]

In the model used for this article, GDP per capita is projected by decade from 2005 to 2105 as the ratio of real GDP and population, where population follows the medium variant of the United Nations Department of Economic and Social Affairs' (UNDESA's) 2010 revision (see Appendix). For the period from 2005 to 2035, real GDPs (in PPP terms) are the *WEO 2010* projections. After that point, countries have continued GDP growth at their 2020–2035 *WEO 2010* rate until their per capita output exceeds $20,000. Countries with per capita output between $20,000 and $35,000 are assigned a 2.0 percent rate (in the WEO projections, the only country with GDP per capita greater than $20,000 that exceeds this rate of growth is Canada). Once a country reaches real GDP per capita of $35,000 it is assigned a 1.5 percent long-term real GDP growth rate, chosen as a rough average of the WEO's projected rates for high-income countries. The GDP per capita projections generated from these assumptions are referred to throughout this article as the "standard" or *WEO 2010* extended projections.

As Table 1 demonstrates, these standard WEO-based GDP projections are at the high end of the ranges used in the Energy Modeling Forum's (EMF) 2009 comparison of twelve climate-economics models[5] and the Potsdam Institute for Climate Impact Research's (PIK) 2010 five-model comparison,[6] and closer to the middle of the range used in the IPCC's SRES emissions scenarios.[7] Both the EMF and PIK model comparisons project lower world GDP per capita. In many of the EMF models with high GDP growth this difference is due, in part, to high population projections for China and India. SRES projections are designed to represent a diversity of possible socio-economic futures and therefore include a larger range of per capita incomes.

The *WEO 2010* extended GDP per capita projections show limited convergence over time, leaving a big gap between incomes in the richest and poorest countries (see Table 1). When disaggregated projections are applied to individual countries (see Appendix), the ratio of per capita income in high-income countries to that in low-income countries shrinks from 27–1 today down to 20–1 in 2105 (see Fig. 1). Average per capita income in high-income countries grows four times larger; in high-middle income countries, 14 times larger; and in low-middle income countries, 21 times larger—but economic development in low-income countries lags behind. Average per capita income in the poorest countries grows just six-fold, from $1,100 in 2005 to $6,500 in 2105.

The 45 countries with the lowest average incomes (the low-income group) are expected to have much more rapid population growth than the rest of the world and to have real per capita GDP growth rates that average 1.6 percent per year over the century (compared to 2.7 percent for high-

[4] The World Bank, *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4#.

[5] Energy Modeling Forum (2009). EMF model inputs are reported in 2005 US$ MER terms. These values are converted to PPP terms using the ratio of 2005 global GDP (PPP, 2005 US$) to 2005 global GDP (MER, 2005 US$), 1.24. Increasing 2105 GDP (MER) estimates by this amount very likely overestimates GDP (PPP)—the ratio of PPP to MER GDP would tend to decrease with income convergence.

[6] Edenhofer et al. (2010).

[7] Nakicenovic et al. (2000). Converted from 1990 to 2005 dollars using the U.S. Consumer Price Index, http://www.bls.gov/cpi/.

Table 1
Socio-economic growth in climate-economics models.
Source: See text for data sources. Data are for 2100 or 2105 depending on the model. Average annual growth is shown for the 100-year period.[a]

Model	2100/2105 Real GDP		2100/2105 Population (billions)	2100/2105 Real GDP per capita	
	(trillions 2005 US$ PPP)	Average Annual Growth		(2005 US$ PPP)	Average Annual Growth
Extended WEO 2010					
World	$537	2.3%	9.8	$54,000	1.8%
China	$101	3.0%	0.9	$106,000	3.3%
India	$102	3.8%	1.6	$65,000	3.4%
United States	$65	1.7%	0.5	$139,000	1.2%
European Union	$63	1.6%	0.5	$128,000	1.6%
OECD	$176	1.6%	1.4	$124,000	1.4%
Non-OECD	$362	2.9%	8.4	$43,000	1.8%
EMF 12-model comparison					
World	$258–$528	1.8–2.5%	8.7–10.6	$22,000–$46,000	1.3–2.1%
China	$27–$115	2.8–4.0%	1.1–1.7	$15,000–$76,000	1.2–4.3%
India	$18–$63	3.1–4.4%	1.5–2.6	$14,000–$29,000	2.6–3.5%
United States	$40–99	1.2–2.0%	0.3–0.5	$96,000–$150,000	1.0–1.5%
European Union	$40–$67	1.2–1.4%	0.4–0.6	$68,000–$127,000	1.2–1.6%
PIK 5-model comparison					
World	$236–$446	1.8–2.5%	9.2	$21,000–$39,000	1.4–2.1%
IPCC SRES emissions scenarios					
World	$350–$820	2.1–3.1%	7.0–15.1	$24,000–$116,000	1.4–2.9%
OECD	$84–$185	1.0–1.8%	0 9–1.5	$87,000–$167,000	1.0–1.6%
Non-OECD	$231–634	2.1–3.1%	5.9–13.6	$17,000–$107,000	2.2–4.2%

[a] In the data reported for the EMF 12-model comparison (Energy Modeling Forum 2009), the FUND model's population projections for India are implausibly small and appear to have been recorded erroneously. This apparent error is excluded from the range presented above.

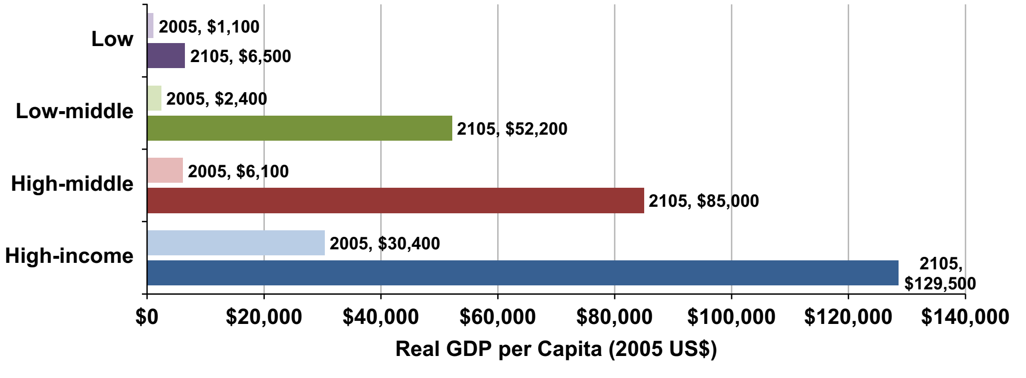

Fig. 1. Real GDP per capita (PPP) by income group in 2005 and 2105, standard growth.
Source: Author's calculations; see text for data sources.

middle-income countries and 3.1 percent for low-middle-income countries). According to UNDESA's medium-variant population projections, these 45 countries will contribute 73 percent of global population increase during the 21st century, growing from 0.9 billion people to 3.5 billion people.

Table 2
Scenario assumptions.

Scenario	Scenario type	Economic growth	Emission intensity reductions
Without Development	Business-as-usual	Standard	Slow
Development with Carbon	Business-as-usual	High	Slow
Development without Carbon	Policy	High	Fast

The result of combined standard real GDP growth and population growth is per capita income that rises slowly in today's low-income countries, and much more quickly in middle-income countries. Generalizing across the climate-economics models reviewed here, emissions forecasts assume that at the end of this century the 45 low-income countries as a group will have real average per capita incomes of $6,500 a year—matching those of Tunisia, Belize, or Serbia in 2005. The bottom end of national average incomes in this low-income group ranges as low as $1,100 a year—matching those of Zambia, Bangladesh, and Haiti today. In these forecasts, middle-income countries' 2105 per capita income surpasses high-income countries' 2005 levels, and the development gap between middle and high-income countries is greatly reduced. But the 45 poorest countries—15 percent of 2005 global population rising to 35 percent in 2105—are left behind.

3. Modeling income convergence

The integrated assessment models reviewed here tend to presuppose a slow pace of economic growth in most developing countries. This section presents a simple, scenario-driven modeling exercise for the purpose of illustrating the impact of very slow development assumptions on the policy recommendations derived from climate-economics analysis. End of the century per capita GDP and cumulative 21st century greenhouse gas emissions are estimated for three stylized futures (see Table 2):

- *Without Development*: This business-as-usual scenario models standard economic growth with slow reductions in emissions per dollar of GDP; there are no policy-driven emission reductions.
- *Development with Carbon*: Faster economic growth brings all countries out of poverty, again with no policy-driven emissions reductions. This scenario represents an alternate vision of business-as-usual.
- *Development without Carbon*: Fast economic growth is coupled with strong decarbonization policies in developing and developed countries alike.

Standard economic growth refers to the extended *WEO 2010* projections described above. In high economic growth scenarios the following changes are made to the standard growth assumptions: all GDP per capita growth rates in all periods are set to 5.0 percent per year in countries with incomes below $20,000, 3.0 percent per year in countries with incomes between $20,000 and $35,000, and to 1.5 percent in countries with incomes above $35,000. (Using standard growth, *GDP* grows at 1.5 percent in countries with average incomes above $35,000; using high growth, *GDP per capita* grows at 1.5 percent for average incomes over $35,000.) Slow and fast emissions intensity reductions are described in the next section.

3.1. Modeling changes in emissions intensity

Projections of future annual greenhouse gas emissions are based not only on assumptions regarding real GDP growth, but also on expected changes in emissions intensity (or emissions per dollar of GDP). In 2005, emissions intensities ranged from 23 kg CO_2-e per dollar (kg/$) in the Central African Republic and the Republic of the Congo (both dominated by non-CO_2 emissions) to 0.2 kg/$

in Switzerland and Norway.[8] In very general terms—and with many important exceptions—higher per capita income is associated with lower emissions intensity and vice versa. On average, high-income countries' emission intensity in 2005 was 0.5 kg/$; middle-income countries, 1.2 kg/$; and low-income countries, 2.1 kg/$.

Emissions intensities are not expected to stay steady over time. Instead, emissions per dollar tend to fall as technology improves and incomes rise (making relatively expensive low-carbon technology more affordable). From 1980 to 2005, emissions intensities fell with rising income in 44 out of the 53 high-income countries and in all but six OECD countries.[9] Overall, during this period emissions intensities fell as income rose in 108 out of the 174 countries modeled for the historical period, representing 86 percent of today's global GDP and 77 percent of today's greenhouse gas emissions.

The assumption that emissions intensities will decrease over time is well entrenched in climate-economics modeling; the mechanisms and causes of that reduction much less so (a topic revisited below). According to the IPCC's Special Report on Renewable Energy Sources and Climate Change Mitigation (Chapter 9, Sathaye et al., 2011), "economic growth can largely be decoupled from energy use by steady declines in energy intensity as structural change and efficiency improvements trigger the 'dematerialization' of economic activity" (p.16–17). Sathaye et al. caution, however, that successful reduction of emissions intensity in rich countries has been due in part to the outsourcing of energy-intensive industries to poorer countries.

The final impact on emissions themselves is, however, ambiguous. Higher incomes both raise GDP and lower emissions intensity, so the impact on emissions—the product of GDP and emission intensity—is uncertain. The former linkage—higher incomes raise emissions—is often referred to as the *scale effect*, while the latter—higher incomes lower emissions—represents the combination of two linkages, both of which work to reduce emissions intensities: the *technique effect* caused by technological improvement; and the *composition effect* caused by changes to the sectoral composition of the economy (see Tsurumi and Managi, 2010, among others). In principle, it is possible for either the scale effect or the technique-composition effects to dominate.

Emissions for future years are projected here using either of two methods: slow or fast. In both methods, emissions are modeled as the product of real national GDP (PPP) and national emissions intensity (CO_2-e emissions per dollar of GDP) for each country in the dataset. Base-year 2005 emissions are total greenhouse gases—including non-CO_2 gases—from the World Resources Institute's Climate Analysis Indicators Tool.[10]

The "slow" reduction in emissions intensity assumes that from 2045 onward, each country's emissions intensity is the smaller of its 2005 intensity, or the projection from a cross-section analysis of emissions intensity versus income. A linear transition is assumed from 2005 to 2045 intensity levels. From 2045 forward slow emissions-intensity reductions are projected as follows:

$$\ln Intensity_k = a + (b * \ln Income_k)$$

where k is the country, and a and b are the intercept and coefficient, respectively, of a log–log regression of 2005 national GDP per capita on 2005 national emissions intensity: a is 2.77 and b is -0.34. Both a and b are statistically significant at the 99-percent confidence level; the regression has an adjusted R-squared value of 0.31. Empirically, there is a clear relationship between countries' 2005 per capita income and emissions intensity: on average, a 1-percent increase in per capita income is correlated with a 0.34-percent drop in its emissions intensity.

[8] Calculated as 2005 total greenhouse gas emissions, including non-CO_2 gases (World Resources Institute's Climate Analysis Indicators Tool. CAIT 8.0. http://cait.wri.org/), divided by 2005 PPP GDP (*World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4).

[9] Historical CO_2 emissions intensities were calculated using World Bank GDP data (from the *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4) and CAIT emissions data (World Resources Institute's Climate Analysis Indicators Tool. CAIT 8.0. http://cait.wri.org/). The historical dataset is slightly smaller than the set of countries with World Bank GDP data for 2005. There is some, but not complete, overlap between OECD and high-income countries per the World Bank data; among high-income countries, emissions intensities grew with incomes in Barbados, Greece, Israel, New Zealand, Oman, Portugal and Qatar. Among OECD countries, emissions intensities grew with incomes in Chile, Greece, Israel, New Zealand, Portugal and Turkey.

[10] CAIT 8.0. http://cait.wri.org/.

Assuming that this cross-section relationship applies over time, this can be viewed as a pattern for potential future autonomous reductions to emissions intensity, which occur solely as a result of economic growth. That pattern is referred to here as the "income-driven" intensity-reduction pattern. Income-driven reductions can be contrasted to policy reductions, which occur as a result of deliberate policy actions. (Note that this may be a conservative assumption with regard to emissions projections. If emissions intensity is less sensitive to incomes than predicted, or if in some countries, it follows an inverted U-shaped path—at first increasing with economic development but eventually decreasing after a threshold per capita income is reached[11]—cumulative emissions will be higher.)

"Fast" emissions-intensity reductions are projected in an identical manner, save for one change: the parameter b is modeled at -0.68, doubling the "slow" reduction pace of income-driven intensity reduction. Multiples of parameter b higher than 2 do little to further reduce the emissions intensity—in effect, an elasticity of emissions intensity with respect to income of -0.68 brings national emissions intensities very close to their minimum values (in accordance with the statistical relationship presented above) and, indeed, close to zero. Here, no argument is made about the likelihood of this rapid pace of emissions reductions (although some countries have met or exceeded it in the recent past, see Section 4 below); the "fast" pattern of reductions is presented rather as an illustration of the speed at which intensities must fall to achieve the 21st century budget for avoiding dangerous climate change.

As a simple model of an ambitious climate policy, this "fast-reduction" relationship represents a global standard in which countries must by a given date conform to a schedule of allowable emissions intensity per dollar of per capita income. (Before that date, this model assumes that countries are, with perfect foresight, reducing emissions linearly to achieve a target emissions intensity set according to their future per capita income.) A policy target date set far into the future allows countries with emissions intensities higher than the accepted pattern a long period during which their emissions per dollar, although dropping, are higher the most other countries. In policy circles, this effect is often referred to as "grandfathering," when regulations include allowances for future emissions based on each agent's past emissions.

The further into the future the policy target date is set, the less equitable—from the point of view of countries with low historical emissions—the distribution of future emissions. Four policy target dates were modeled: 2045, 2065, 2085, and 2105. Of course, under both the slow and fast emissions-intensity reductions, the later the policy target date, the higher the cumulative emissions. Scenarios' success in reducing emissions may be judged against Bowen and Ranger's (2009) estimated budget for keeping global average temperature increases below 2 °C: 2,000 Gt CO_2-e emitted cumulatively during the 21st century, including both CO_2 and other non-CO_2 greenhouse gases.[12]

3.2. Findings

The Without Development emissions projections (see Table 3, which assumes a 2045 policy target date throughout) are slightly above the high end of the range used in climate-economics models' business-as-usual scenarios (indicating that these models, which have similar income per capita projections, employ even more optimistic assumptions of income-driven reductions to emissions intensity). In this scenario, twenty-first-century cumulative emissions reach 11,150 Gt CO_2-e, with low-income countries contributing just 6 percent of the total. Twenty-first century cumulative emissions range from 4,700 to 9,100 Gt CO_2-e in the EMF and PIK model comparisons, and SRES emissions scenarios.[13]

[11] See Lindmark (2004).

[12] Estimates in Bowen and Ranger (2009) range from 1,908 to 2,684 Gt CO_2-e. See also Allen et al. (2009); Gohar and Lowe (2009), Lowe et al. (2011), and Meinshausen et al. (2009).

[13] EMF, PIK, and SRES emissions are reported in CO_2 (excluding non-CO_2 gases). These values have been converted to CO_2-e by adding a cumulative 1,100 Gt CO_2-e in non-CO_2 greenhouse gas emissions during the 21st century following the methodology used in the CRED model (Ackerman, Stanton, and Bueno 2011). EMF model comparison: 5,100 to 9,100 Gt CO_2-e; PIK model comparison: 5,000 to 7,000 Gt; and SRES emissions scenarios: 4,700 to 9,100 Gt.

Table 3
Scenario results with 2045 policy target date.
Source: Author's calculations.

	2105 GDP per capita (PPP 2005 US$)		Cumulative 21st century emissions (Gt CO_2-e)		
	Without Development	**Development with and without Carbon**	**Without Development**	**Development with Carbon**	**Development without Carbon**
High income	$128,500	$158,600	3,350	3,840	590
High-middle income	$85,000	$92,200	4,150	4,700	870
Low-middle income	$52,200	$71,700	2,940	3,820	370
Low income	$6,500	$55,300	720	2,900	220
World	$54,400	$83,000	11,150	15,270	2,060
Mitigation target			9,150	13,270	60

Table 4
Cumulative 21st century emissions (Gt CO_2-e) with varying policy target dates.

	Policy target date			
	2045	**2065**	**2085**	**2105**
Development with Carbon	15,270	16,090	17,710	20,480
Development without Carbon	2,060	4,070	7,350	12,270

In the Development with Carbon and Development without Carbon scenarios incomes converge. With faster economic growth per capita incomes reach $158,600 per year in high-income countries, $92,200 in high-middle-income countries, $71,700 in low-middle-income countries, and $55,300 in low-income countries in 2105. The end of the century ratio of high-income to high-middle-income countries per capita income is 1.7–1; and for high to low-middle-income countries, 2.2–1. The ratio of high to low-income countries is 2.9–1 with faster economic growth, compared to 20–1 with standard growth.

With the 2045 policy target date, in the Development with Carbon scenario, twenty-first-century cumulative emissions reach 15,270 Gt CO_2-e, 19 percent of which originates in the poorest countries. In this scenario, low-income countries emit a cumulative 2,900 Gt in the 21st century, exceeding the entire global 2,000 Gt budget for avoiding dangerous climate change. In the Development without Carbon scenario, economic growth remains high in the poorest countries, but policy measures supplement income-driven emissions-intensity reductions, outrunning economic growth. Cumulative 21st century emissions are limited to 2,060 Gt CO_2-e, including 220 Gt emitted by the low-income group.

The importance of the policy target date (and, therefore, the degree of grandfathering of past emissions intensities) to cumulative 21st century emissions is displayed in Table 4. In the Development without Carbon scenario, with its fast pace of emissions-intensity reductions, only the 2045 policy target date succeeds in keeping emissions close to the 2,000 Gt budget for keeping temperatures below 2 °C.

Table 5 puts the 2045 policy target date scenarios' emissions in what may be a more familiar context, reporting the results for the United States and India, in addition to the income groups, as points of reference. Per capita emissions, higher in richer countries today, would grow in every region in the Without Development scenario while still maintaining that basic pattern. The Development with Carbon scenario results in per capita emissions that are still higher in almost every country. In the Development without Carbon scenario, per capita emissions must be ratcheted down in every region to stay within the emissions budget; in per capita terms, these reductions are smallest in the case of the lowest-income countries.

Under the Development with Carbon scenario, speeding up growth but keeping the pattern of income-driven emissions-intensity reductions the same, results in an enormous increase to

Table 5
Per capita emissions by scenario with 2045 policy target date.
Source: Author's calculations.

	Per capita emissions in 2005 (tons CO_2-e /person)	Per capita emissions in 2105 (tons CO_2-e/person)		
		Without Development	Development with Carbon	Development without Carbon
High income	15.0	38.3	44.3	0.8
High-middle income	7.3	29.1	31.0	0.7
Low-middle income	2.9	21.1	26.3	0.6
Low income	2.4	4.8	22.1	0.6
World	6.7	19.6	28.5	0.6
United States	22.9	40.7	49.2	0.8
India	1.7	24.7	26.4	0.6

cumulative 21st century total emissions (shown in Table 3), and an increase in annual per capita emissions in every income group (shown in Table 5). If climate-economics models are under-estimating economic growth in low-income countries, expected business-as-usual cumulative emissions are too low, and emission reduction targets in richer countries will be grossly insufficient to meet policy goals. If successful, rapid development were modeled (as in the Development with Carbon scenario), the gap between business-as-usual emissions and the allowable budget (2,000 Gt)—and, consequently, the global target for emissions reductions—would be 13,270 Gt. When, instead, conventional, weak development is modeled (as in the Without Development scenario), the target for emissions reductions falls to 9,150 Gt.

Pessimistic economic development assumptions in climate-economics models have the effect of lowering high-income and emerging economies' goals for emissions reductions. Poor foresight leads to poor planning.

4. Policy measures to reduce emissions intensity

Without some policy-driven assistance, real economic development drowns out income-driven emissions-intensity reductions.[14] A successful development-without-carbon strategy requires both economic development—including policies to address energy poverty—and emissions mitigation policy. Climate policy needs to support and accelerate income-driven intensity reductions by improving countries' adherence to the income-driven pattern, offering additional support to countries with anomalously high emissions intensities, and driving the innovation of low-cost low carbon technologies forward in order to speed up emissions reduction.

Policy measures to improve adherence to the income-driven intensity-reduction pattern include supporting emissions-intensity reduction in countries at risk of exhibiting rising emissions per dollar as incomes grow. The experience of El Salvador, where per capita GDP was $4,400 in 2005, is illustrative. El Salvador's per capita GDP (PPP) grew 30 percent from 1985 to 2005, while its emissions intensity more than doubled from 0.09 kg CO_2/$ in 1985 up to 0.19 kg/$ in 2005. El Salvador's emission intensity in this period may be interpreted as being on the upswing of an inverted U-shaped path, or so-called Environmental Kuznets Curve (EKC).[15] In the EKC pattern, countries are expected to see emissions, or other forms of environmental degradation, rise and then fall as their income per capita grows.[16]

[14] See Chapter 9 in Sathaye et al. (2011).
[15] Historical CO_2 emissions intensities calculated using World Bank GDP data (from the *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4) and CAIT emissions data (WRI, 2010).
[16] For more on the Environmental Kuznets Curve, see Grossman and Krueger (1995).

Without policy measures designed to connect energy poverty reduction and other forms of economic development with emissions reduction, there is a strong potential for low-income countries' emissions intensities to increase with rising incomes, as they did in El Salvador, among many other examples. The EKC, which is sometimes used to suggest an inevitable relationship between development and environmental quality, however, has been widely critiqued. Conflicting empirical results show that the relationship, when and where it exists, may not be robust, and some research suggests that the pattern may be caused by an induced policy response (Dasgupta et al., 2002; Munasinghe, 1999; Torras and Boyce, 1998).

Lindmark (2004) provides examples of both high- and low-income countries that have experienced first rising and then falling CO_2 emissions with income growth, finding that high-income countries are more likely to have a history of an inverted U-shaped, or EKC-like, emissions intensity transitions than are low-income countries. The experience of El Salvador and a number of other low and middle-income countries suggests, however, that an inverted U-shaped emissions-intensity could be a real possibility for these countries as well. In some countries, public policy measures, together with international assistance, may be necessary to make the income-driven intensity-reduction pattern more robust.

Successful emissions intensity reduction policies also will need to offer additional support to countries with anomalously high emissions intensities. The autonomous, income-driven intensity-reduction pattern requires countries with especially high emissions intensities to jump from their current technology to the expected technology for their income level within a few decades. Most countries in which actual intensity exceeds expected intensity are in the low and low-middle-income groups (including many of the ex-Soviet Republics), or are major fossil fuel exporters.

The low-income countries with the highest emissions intensities are the Central African Republic (almost entirely due to methane and nitrous oxide emissions from agriculture) and Cambodia (primarily due to CO_2 emissions from deforestation).[17] Countries with higher than expected emissions intensities may need special assistance or incentives to kick-start income-driven intensity reductions. The examples of the Central African Republic and Cambodia suggest that some low-income countries may need additional technical support in reducing land-use emissions.[18]

Finally, successful global emissions abatement will require policy measures to support the innovation of low-cost low-carbon technology, thereby enhancing the existing income-driven intensity-reduction pattern. Low-cost alternative electricity generation, and heating and cooking fuels are critical components of energy poverty reduction. From 1980 to 2005, twelve countries, including Mozambique, exceeded the "fast" pace of emissions reductions (a 0.68-percent drop in emissions intensity for every 1-percent decrease in income per capita) necessary to the success of the Development without Carbon scenario; 29 countries exceeded the "slow", income-driven pace of emissions reductions.

The low-income countries that have reduced intensities most, in relation to their economic growth, are Burkina Faso and Mozambique. Among middle-income countries, Colombia and Belize provide examples of a strong relationship between increasing per capita income and decreasing emissions intensity. For Mozambique and Colombia, part of this success can be attributed to significant investment in hydro-electric generation; for Burkina Faso and Belize—where land-use emissions dominate—the causes are less clear. Affordable low-carbon technology is crucial to fostering and increasing the pace of the income-driven intensity-reduction pattern, and public policy has an important role to play in supporting and disseminating technological innovations.

5. Discussion and recommendations

Standard projections used in climate-economics models show strong economic growth in many of the middle-income countries over the next century, but much weaker growth in low-income

[17] See CAIT (WRI, 2010).

[18] For a discussion of low-carbon policies for the agriculture sector as it relates to economic development see Norse (2012).

countries. This assumption—that economic development will fail in the poorest countries—results in lower business-as-usual global emissions, allowing emissions reduction targets to be less stringent in richer countries. But what if pessimistic assumptions about economic development turn out to be wrong?

What if low-income countries experience genuine economic development? In 1985, India's real per capita income (in PPP 2005) was $1,035—very similar to that of Haiti before the 2010 earthquake. In 20 years, India's per capita income more than doubled, reaching $2,300 in 2005.[19] Standard growth projections described above have India's per capita income exceeding $9,300 by 2035, and reaching $45,900 by 2085, the result of 3.9 percent average annual growth over the 100-year period. Contrast this to the implied 21st century per capita income growth expected for Haiti by climate-economics models, on average just 2.0 percent per year over the 100-year period, reaching $7,200 in 2105.

Economic growth is by no means guaranteed, especially in the absence of sufficient international aid, but what if economic development for the poorest countries can and does occur? What if Haiti (and every low-income country) can match the success of India and China? In the Development with Carbon scenario modeled for this article, more optimistic assumptions about economic development lead to higher expected cumulative greenhouse gas emissions from low-income countries, higher global business-as-usual emissions, and, therefore, a need for more stringent emissions reductions goals. Even if poverty eradication is regarded as unlikely, climate policy should be designed to allow for the best-case possibility that every Haiti could grow like India.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envdev.2012.05.011.

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