Development without Carbon:

Climate and the Global Economy through the 21st Century

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Cover art: Flooding in Chalco, Mexico, in February 2010, which displaced thousands of people / Flickr-MagisRevista, by Enrique Carrasco S.J.

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Executive summary

Economic development and the eradication of energy poverty are increasingly seen as key components in a comprehensive strategy to prevent dangerous climate change, along with greenhouse gas emission reductions and adaptation measures. But the current crop of climateeconomics models used to guide policymakers assumes very little economic growth in the poorest countries.

This report examines the implications of the no-development assumption that underlies many climate policy targets, and finds that, taking developing countries' right to future emissions as a given, economic development in the poorest countries requires more stringent mitigation actions by their richer neighbors, both to reduce industrialized countries' emissions and to provide funding for emissions reduction measures in the developing world. Projections of slow economic growth in the developing world, in contrast, would tend to create the expectation that the poorest countries will use up a relatively small share of the global 21st century emissions budget, leaving more "emissions space" for the high- and middle-income countries. Assuming that economic development will fail or falter has the effect of weakening the urgent call for rich countries to reduce their emissions.

It is hard to imagine a resolution to international climate negotiations that does not involve sustainable low-or-no-carbon development – here referred to, for simplicity, as "development without carbon." For countries that, to date, have emitted very little, a choice between current economic development and avoiding future climate damage is an impossible dilemma.

This report reviews the literature regarding the connection between energy, poverty, and emissions mitigation; sets out principles for an equitable climate policy; explores three future economic growth and emissions scenarios; presents a case study showing the impact of these three scenarios on Latin America and the Caribbean; and concludes with recommendations for setting climate policy targets.

What is fair?

Much has been written about the equitable allocation of future emissions, but there can be no single, definitive answer to what is right or fair in climate policy.In the emissions projections presented here, climate equity is approached in this way: The poorest countries have the same right to future emissions that richer countries asserted over past emissions. The historical and present-day big emitters have a special responsibility to assure that emissions levels are consistent with avoiding dangerous climate change. This responsibility extends both to lowering their own emissions, and to paying for emissions reductions in poorer countries.

An emissions budget

Goals for greenhouse gas emission reduction are set in relation to expected future emissions in the absence of climate policy, often called business-as-usual emissions. The smaller we think that future emissions will be without climate policy, the smaller our policy actions need to be to counteract those emissions – wishful thinking leads to poor planning. The pace of economic growth in the developing world is a critical, but little discussed, element in determining the overall scale of "21st century cumulative emissions," a (slightly misnamed) measure which adds together all of the annual emissions from 2005 to 2105. The higher the business-as-usual cumulative emissions, the more ambitious climate policy must be to provide a good chance of avoiding dangerous climate change.

The budget for maintaining a 98-percent chance of keeping temperature increases below 2°C (a much discussed policy objective) is approximately 2,700 gigatons (Gt) carbon dioxide-equivalents (CO_2-e) – including both carbon dioxide and other greenhouse gases – of which an estimated 200 Gt have already been emitted. Given this budget, country-level emissions can be viewed as a "zero-sum game":the more that any one country emits, the smaller the emission budget that remains for other countries. If the poorest economies don't grow very much, they won't use up much of the remaining budget – leaving a relatively large emissions budget for the rest of the world.

Three scenarios of future emissions

This report sketches out a framework for incorporating real economic development in future climate-economics analysis by exploring the potential greenhouse gas emissions, and corresponding mitigation obligations, of three stylized futures for developing countries:

- *Without Development:* a business-as-usual (no policy) scenario with the standard economic growth rates found in climate-economics models;
- *Development with Carbon:* a business-as-usual (no policy) scenario with more rapid economic growth rates;
- *Development without Carbon:* a policy scenario with rapid economic growth and significant public measures to reduce emissions.

For ease of analysis, the 174 countries modeled for this report are divided into four income groups: high-income, high-middle-income, low-middle-income, and low-income.

Without Development

The Without Development business-as-usual scenario models standard economic growth with slow, income-driven reductions in emissions per dollar of GDP; there are no policy-driven emission reductions. With the exception of the group of newly industrializing countries – most importantly, India and China – that already have a running start, economic growth is expected to proceed at a slow, steady pace in developing countries. This growth is insufficient to alleviate poverty in the poorest countries by 2105. As a result of low growth and low emissions in the developing world, high-income countries have more 21st century "emissions space" and, therefore, weaker emissions mitigation obligations. The Without Development scenario closely emulates the business-as-usual scenarios used in many of the best-known climate-economics models.

Many emissions forecasts are based on the assumption that at the end of this century,the 45 low-income countries will have average per capita incomes of $6,500 a year – matching those of Tunisia, Belize, or Serbia in 2005 – with incomes in the very poorest countries of about $1,100 a year – matching those of Zambia, Bangladesh, and Haiti. 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 –home to 15 percent of the 2005 global population, and rising to 35 percent in 2105 – are left behind.

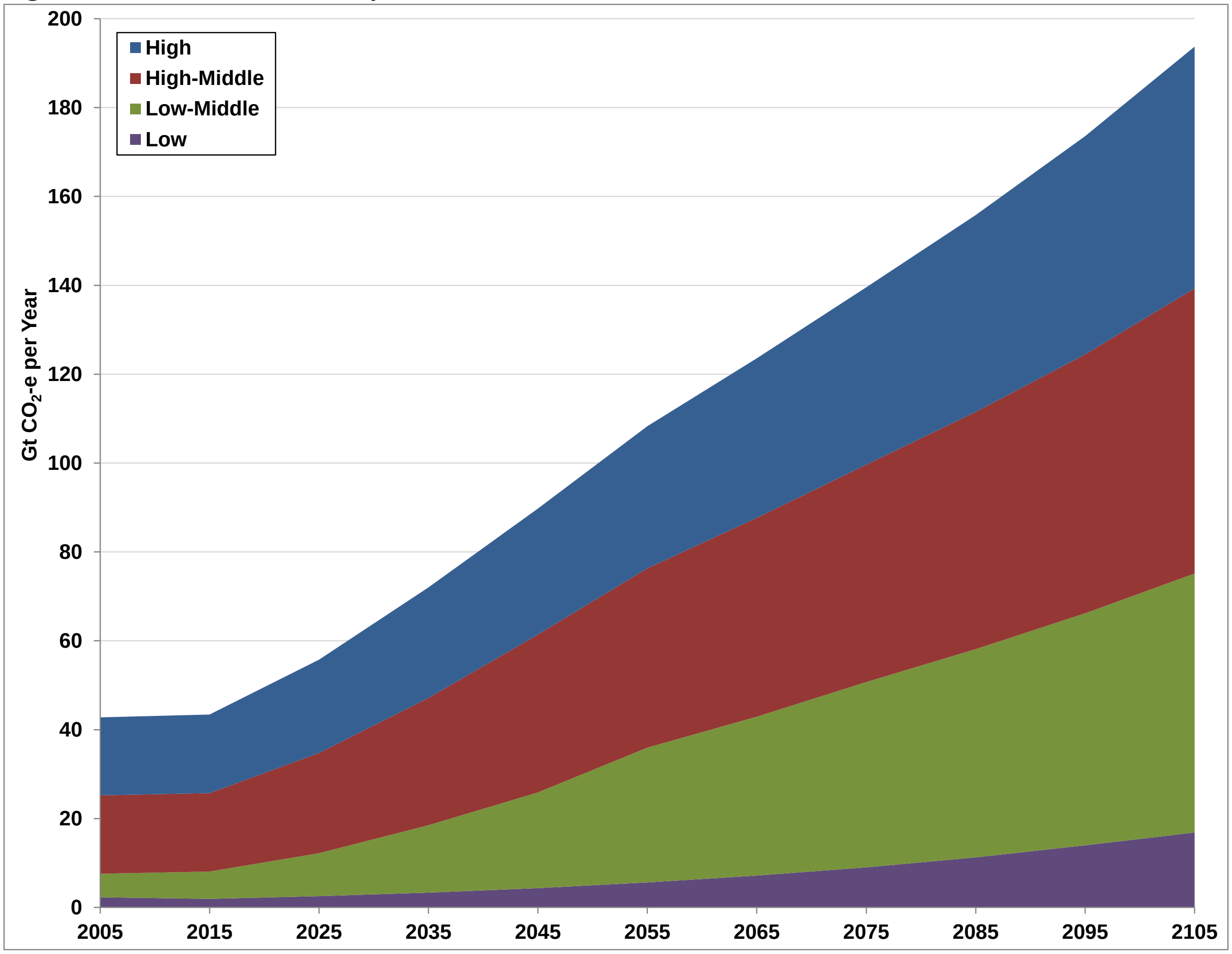
Projections of future annual emissions are based not only on assumptions regarding real GDP growth, but also on expected changes in emissions intensity (or kg of CO_2-e per dollar of GDP). In very general terms – and with many important exceptions – higher per capita income is associated with lower emissions intensity and vice versa. On average, high-income countries' emission intensity is 0.5 kg/$; middle-income countries, 1.2 kg/$; and low-income countries, 2.1 kg/$.

Emissions per dollar tend to fall as technology improves and incomes rise (making relatively more expensive low-carbon technology more affordable). From 1980 to 2005, in most countries, representing 86 percent of today's global GDP and 77 percent of today's greenhouse gas emissions, emissions intensities fell as income rose. A stylized pattern between countries' 2005 per capita income and emissions intensity (each 1-percent increase in per capita income is associated with a 0.34-percent drop in its emissions intensity) is used to model potential future "autonomous" reductions to emissions intensity –

where autonomous reductions, which occur solely as a result of economic development, are contrasted to "policy" reductions, which occur as a result of deliberate policy actions.

In the business-as-usual, Without Development scenario, there are no policy-induced emissions reductions; the only changes to emissions intensity are based on the autonomous-emissions-reduction pattern. Twenty-first-century cumulative emissions reach 10,800 Gt CO_2-e, with low-income countries contributing just 6 percent of this total (see Figure ES-1; annual emissions for each income group are the lines dividing the areas, and cumulative emissions are the colored areas).

Figure ES-1: Without Development annual CO_2-e emissions, 2005-2105



The 21[st]century cumulative emissions budget for keeping temperature increases under 2°C is 2,700 Gt CO_2-e. Assuming little or no emission mitigation policy in the Without Development scenario, low-income countries are expected to emit about a cumulative 700 Gt in the 21[st] century, leaving 2,000 Gt for richer countries. A policy gap of 8,800 Gt exists between target cumulative emissions in high and middle-income countries, and expected business-as-usual emissions. Meeting this policy gap through emissions reductions would require substantial policy-driven decreases in emissions-intensities.

Development with Carbon

What if low-income countries experienced genuine economic development? In 1985, India's real per capita income 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. Extended standard growth projections 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 21st century per capita income growth expected for Haiti by climate-economics models, on average just 2.0 percent per year reaching $7,200 in 2105.

What would happen to emissions if Haiti (and every low-income country) were able to follow India?

Faster economic growth in the Development with Carbon scenario brings all countries out of poverty, but the pace of reductions in emissions per dollar remains slow and, again, is driven by income growth rather than policy. This scenario represents an alternate vision of business-as-usual.

With faster economic growth in the Development with Carbon scenario, incomes converge around the world. Twenty-first-century cumulative emissions reach 20,700 Gt CO_2-e, 21 percent of which originates in the poorest countries. In this scenario, low-income countries emit a cumulative 4,400 Gt in the 21st century exceeding the entire global 2,700 Gt budget. The policy gap for richer countries' emissions reduction is 16,300 Gt.

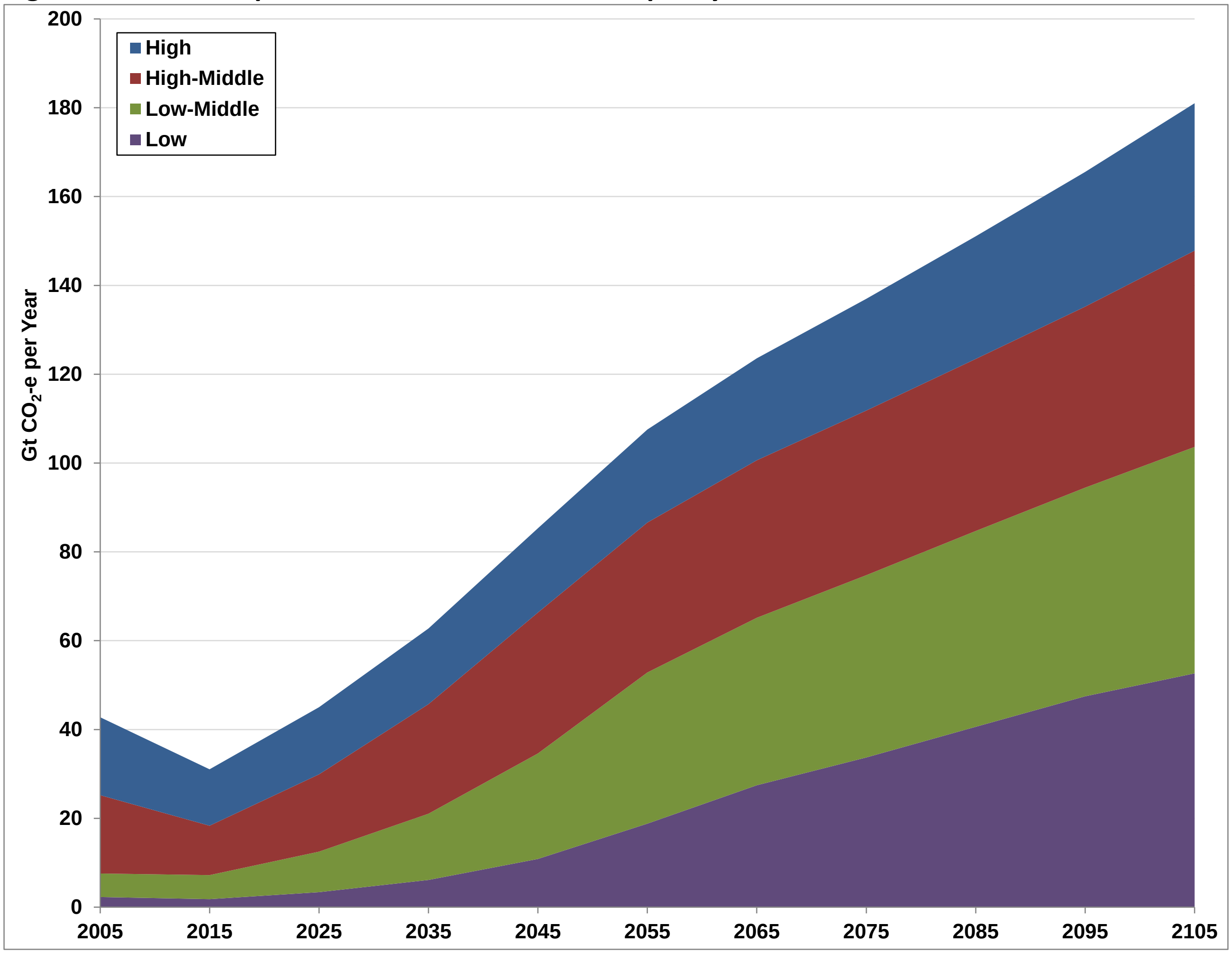
The relative size of the policy gaps in the Without Development and Development with Carbon scenarios demonstrates the potential scale for miscalculation caused by overly-pessimistic economic development projections. In the standard growth, Without Development scenario, richer countries face an 8,800 Gt CO_2-e policy gap; in the faster growth, Development with Carbon scenario, this gap is almost doubled. Using standard growth assumptions to form climate policy is a risky proposition: If economic development is successful, climate policy will fail.

Development without Carbon

In the Development without Carbon scenario, the same faster economic growth is coupled with strong decarbonization policies in developing and developed countries alike. Funding from high-income countries helps to assure that economic development drives a reduction in emissions intensity at every income level. Enhanced emissions reductions are modeled as stronger responses to per capita income growth than predicted from autonomous-intensity-reduction alone. Two levels of policy response are modeled: "mild policy," with a 0.40-percent intensity drop for every 1 percent increase in per capita income (this rate includes both autonomous and policy-induced reductions); and "strong policy," with 0.53-percent intensity drop for every 1 percent increase in per capita income.

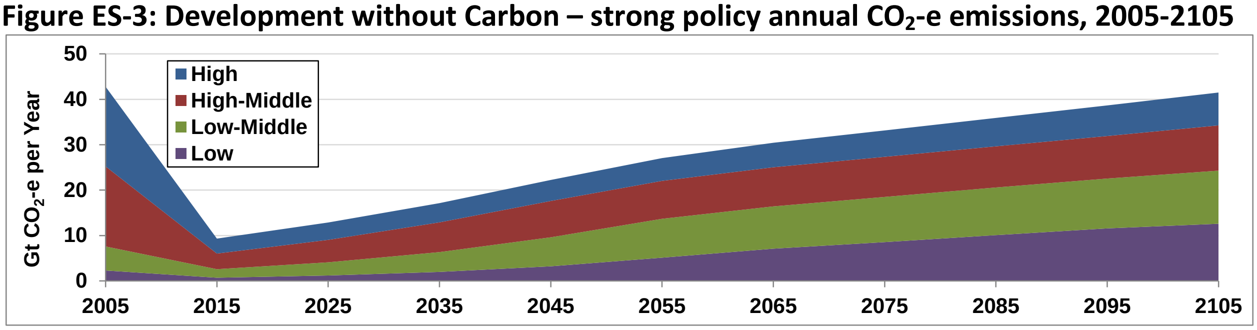
Using the mild policy assumption, 21st century cumulative emissions reach 10,200 Gt CO_2-e, with 2,200 Gt from low-income countries; the remaining policy gap for middle and high-income countries is 9,700 Gt (see Figure ES-2).

Figure ES-2: Development without Carbon – mild policy annual CO_2-e emissions, 2005-2105



Using the strong policy assumption, 21st century cumulative emissions reach 2,700 Gt CO_2-e, with 600 Gt from low-income countries (see Figure ES-3).This rate of emission-intensity reduction was chosen such that the Development without Carbon scenario with strong policy assumption keeps emissions within their 21st century budget for staying below 2°C, leaving no additional policy gap.

Figure ES-3: Development without Carbon – strong policy annual CO_2-e emissions, 2005-2105



Policy-driven emissions intensity reductions

Without some policy-driven assistance, autonomous intensity reductions are drowned out by economic growth. A successful development-without-carbon strategy requires both economic development –

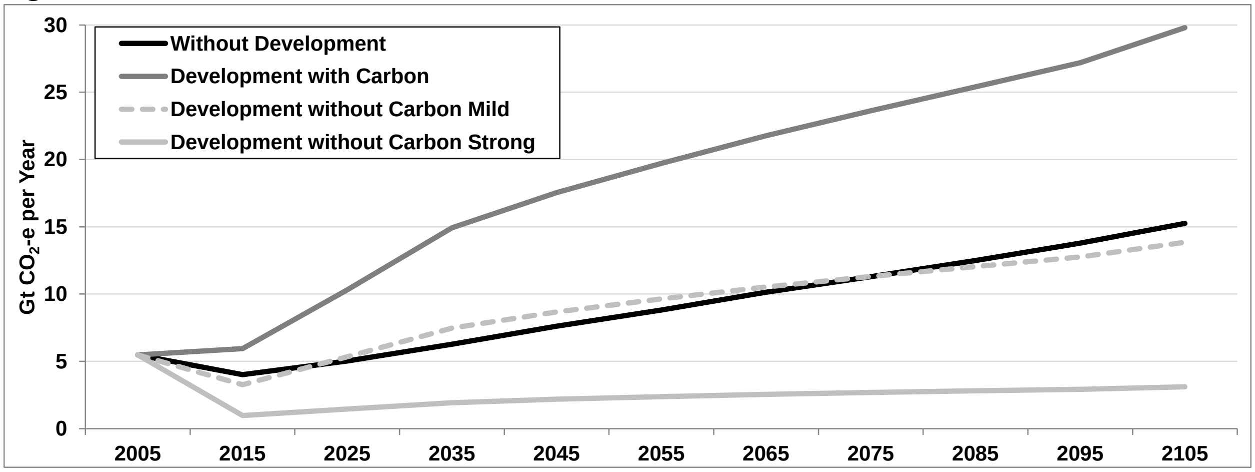
including policies to address energy poverty – and emissions mitigation policy. Climate policy aimed at lowering emissions intensities as incomes grow would need to:

- *Support and enhance trends toward lower emissions intensity as incomes rise:* Without policies 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 intensity to increase with rising incomes.
- *Offer additional support to countries with anomalously high emissions intensities:* Our projections assume that countries with especially high emissions intensities will jump relatively quickly to the expected technology for their income level. This may be unrealistic without financial and technical support.
- *Accelerate innovation in low-cost low carbon technologies:* Low-cost alternative electricity generation and heating and cooking fuels are a critical component of energy poverty reduction and emissions reduction.

Case Study: Latin America and the Caribbean

Per capita incomes, expected economic and population growth rates, and emissions intensities vary widely across the 32 Latin America and the Caribbean countries. In the Without Development business-as-usual scenario, this region emits a cumulative 900 Gt CO_2-e in the 21st century(see Figure ES-4). With faster economic growth in the Development with Carbon business-as-usual scenario, regional 21st century cumulative emissions reach 1,800 Gt CO_2-e. When policy-induced reductions to emissions intensities are modeled, emissions fall despite converging world incomes. In the Mild Policy Development with Carbon scenario, 21st century cumulative regional emissions fall to 900 Gt CO_2-e; in the Strong Policy scenario regional cumulative emissions only amount to 200 Gt.

Figure ES-4: Latin America and the Caribbean annual CO_2-e emissions, 2005-2105



A successful climate policy for Latin America and the Caribbean will require public actions to enhance adherence to the autonomous-intensity-reduction pattern: support for emissions intensity reductions in countries at risk of exhibiting rising emissions per dollar as incomes grow, such as El Salvador, Grenada, and Trinidad and Tobago; support to countries with anomalously high emissions intensities, such as Bolivia, Honduras, Guyana, and Brazil; and financial support for local energy technological innovation as well as unfettered access to low-cost low-carbon technology developed beyond their borders.

Discussion and recommendations

Is there a path forward that balances climate and development (where development includes an end to energy poverty)? At present, most climate-economics models skirt this issue by implicitly treating the economic development of the poorest countries as if it were doomed to failure. This approach is overly simplistic and short-sighted: it either consigns the poor to remain poor for the next few generations at a minimum, or assures a failure of climate policy by failing to anticipate economic development.

Here are a few questions that the next generation of economic analyses should be asking:

Can development derail climate policy? It is possible that, either on their own or with financial support from the international community, the poorest countries could follow India and China on a path to prosperity? Without targeted funding to support emissions intensity reduction while simultaneously alleviating energy poverty, this optimistic economic development scenario seems very likely to result in higher developing-country emissions. Meanwhile, if rich countries set weak mitigation targets for themselves, based on bad economic advice that assumes a pessimistic growth scenario for developing countries, the 21st century emissions budget is sure to be busted.In this manner, successful development (in combination with poor foresight) could indeed derail climate policy.

Can climate policy derail development? A global climate policy powerful enough to force developing countries to slow growth is a little hard to imagine, given the mood and track record of the international negotiations process. In theory, strongly enforced per country or per person emissions caps, enacted without supporting policy to aid reductions in emissions intensity, could slow or even stop economic growth in poor countries. In practice, this outcome is of most use as a counterfactual – a description of a world no one wants or expects. To make strong climate policy and strong economic development compatible will require significant investment in measures to enhance and support income-driven reductions to emission intensity.

What are the poorest countries in the world entitled to? They have every right to continued economic growth, very little history of past emissions, and somewhere between very little and no responsibility to pay for future emissions mitigation. Taking such a pro-development stance seriously in climate-economics modeling requires the examination of the impacts of faster economic growth in developing countries. Even if complete 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.

1.What's at stake

There was a time when climate policy was strictly aboutreducing current greenhouse gas emissions. Over the past decade, mitigation has been paired with adaptation to protect against unavoidable damages from climate change, and those twin prioritieshave dominated international climate negotiations and the academic analyses of climate policy issues. Today, however, a third imperative, the eradication of energy poverty, is elbowing for space in the climate policy agenda. One-fifth of today's global population lacks access to electricity; two-fifths rely on traditional biomass for cooking and heating; and an even larger share has only very limited access to modern energy systems(IEA 2010a). Poverty reductionrequires improved access to modern energy. But without a strong and well-funded policy initiative, eliminating energy poverty is very likely to increase greenhouse gas emissions.

Improved energy access for the poor links climate policy with development policy, drawing attention both to opportunities for harmony – economic development can reduce vulnerability to climate damage, and many climate adaptation initiatives have co-benefits that improve living standards in poor communities – and for dissonance.Without policy intervention, economic development and improved energy access are likely to increase carbon dioxide (CO_2) emissions, but abandoning those goals to hold down emissions is neither fair nor politically viable. Thus it is hard to imagine an international climate agreement that does not provide for sustainable low-or-no-carbon development – here referred to, for simplicity, as "development without carbon." Countries that, to date, have emitted very little should not have to choose between economic development and climate protection.

Indeed, the very crux of climate negotiations, arguably, is the meaning of the term "common but differentiated responsibilities" in the Kyoto Protocol(United Nations 1997)and what its implications for rich and poor countries in terms of mitigation and climate finance. Because CO_2, once emitted, persists in the atmosphere for a century or more, many argue that there is a fixed budget for 21st century cumulative emissions – a 100-year global total of emissions that cannot be exceeded while avoiding dangerous climate change(see, for example, German Advisory Council on Global Change 2009). Based on estimates from the CRED model (described later in this report) for 2005 through 2105, the budget for maintaining a 98-percent chance of keeping temperatures increases below a 2°C is approximately 2,700 Gt CO_2-e,[1] of which an estimated 200 Gt had already been emitted by 2011.[2]

Who gets to emit how much? More specifically, how will the economic burden of climate change – mitigation and adaptation costs, together with residual climate damages – be shared among nations? And how will economic growth in developing countries be balanced with global emissions mitigation?

Taking developing countries' right to future emissions as a given (a topic discussed in detail in Section 2 below), economic development in the poorest countries requires more stringent mitigation actions by their richer neighbors, both to reduce industrialized countries' emissions and to provide funding for emissions reduction measures in the developing world. The opposite, of course, is also true: Projections of slow economic growth in the developingworld would tend to create the expectation that the poorest countries will use up a relatively small share of the global 21st century emissions budget, leaving more "emissions space" for the high and middle-income countries. Assuming that economic development will fail or falter has the effect of weakening the urgent call for rich countries to reduce their emissions.

[1] CO_2-equivalent (CO_2-e) emissions include non-CO_2 greenhouse gases (such as methane) measured in CO_2 equivalents.

[2] For a detailed description of the CRED model, see Ackerman, Stanton and Bueno (2011a). For comparison, in Lowe et al.'s (2011) scenarios of the long-run emissions necessary for the Copenhagen Accord pledges to have a 50/50 chance of staying below 2°C, cumulative 21st century emissions were 3,000 Gt CO_2-e.

Climate, poverty, energy

Improved access to modern energy resources is essential to development (CCD 2009; UNEP 2011). The traditionalfuels used by the poorcan be expensiveas a share of their incomes, or require a great deal of labor (e.g. gathering firewood), and they often carry terrible health costs, especially for women and children, as with unimproved biomass cooking and heating fuels (Saghir 2005). Time spent gathering fuel and performing manual labor that could be replaced by mechanical power (food grinding, threshing) also prevents women and girls from engaging in employment and education (UNDP 2005; Keam and McCormick 2008).The co-benefits of improved access to modern energy sources include enormous reductions in indoor air pollution and decreased pressure on ecosystem health (Lambe and Johnson 2009; CCD 2009).

The importance of energy access to development, and of development to reducing climate damage vulnerabilities,is well established, but one interconnection has been relatively unexploreduntil recently. What impact will development have on emissions mitigation efforts? Several recent publications remark on this disconnect, sometimes suggesting that the reputation of biomass as a “carbon neutral”fuel – now debunked as the role of black carbon has become better understood(Gustafsson et al. 2009) – may go part way towards explaining the dearth of analysis(CCD 2009). After all, countries with very low energy use and a well-known reliance on a “green” fuelwould hardly be seen as priority targets forthe limited emissions mitigation funds available(Sagar 2005).

There is an expanding literature aimed at closing this research gap by exploring the interconnections between increasing energy access, alleviating rural poverty, and mitigating climate change, sometimes called the “energy-poverty-climate” nexus (Casillas and Kammen 2010).A statement by Rajendra Pachauri, chair of the Intergovernmental Panel on Climate Change (IPCC), has been widely cited in this regard: “Providing an adequate supply of energy to the poor should be a key priority. Without it there can be no talk about eliminating poverty in the world.”[3]Climate policy is incomplete without a low-carbon solution to energy poverty.

Other recent reports come to this same conclusion from a slightly different vantage point. The Economic Commission for Latin America and the Caribbean’s report on the economics of climate change in Latin American and the Caribbean (ECLAC 2010)concludes that a “sustainable, adaptive, low-carbon, socially inclusive development strategy must … bedesigned and implemented. This strategy must be based on an awareness that forms of economic growth that do not take into account climate-related phenomena and considerations of equality will carry a high level of risk that is quite likely to prove to be unsustainable in the long run”(p.103).Even in developing countries with relatively strong economic growth, there is a need to balance solutions to energy poverty with emissions mitigation.

In the poorest countries, scarce resources may impose a choice between immediate development needs and the longer-term threat of climate change (IEA 2010b).Climate protection requiresnear-complete decarbonization worldwide, but it does not require that every country pay for its own emissions mitigation. If the cost of both innovation and implementation necessary to decouple economic growth from emissions growth is not shared – with rich countries assuming the responsibility for a large share of the burden – the viability of global low-emissions trajectories may be called into question. The IPCC’s Special Report on Renewable Energy Sources and Climate Change Mitigation (Chapter 9, Sathaye et al. 2011) asserts that investment in renewable energy can decouple the correlation between rising incomes and rising greenhouse gases, while improving energy access for the poor.Lambe and Johnson(2009), in contrast,question whether any country has ever truly decoupled economic expansion from growth in

[3] “Vienna Energy Conference calls for shift to low-carbon green industries,” United Nations Industrial Development Organization, June 22, 2009. Available at http://www.unido.org/index.php?id=7881&tx_ttnews[tt_news]=360&cHash=b32ae1b88f.

energy consumption without outsourcing its most polluting industries. The relationship between perceived decoupling and the importation of goods and services containing embedded energy and emissions isunder-explored.

Key questions that emerge from this literature are:How can developing countries achieve economic growth without increasing emissions? What national and global policies can effectively link development and climate policies? And how can secure, affordable, sufficient, low-carbon energy sourcesbe assured? If we assume that developing countries will achieve significant economic growth over the next century, the emissions intensity of this growth becomes critical to the success of global mitigation policies. If China were to maintain its current emissions intensity (measured in kg of CO_2-e released per dollar of gross domestic product (GDP)) through a few more decades of rapid growth, its per capita emissions would come to resemble those of the highest (per capita) emitters today: Bahrain, Kuwait, and the United Arab Emirates(Stanton 2011; see also Olivier et al. 2011). If, on the other hand, China – together with all of the low and middle-income countries – is able, through its own efforts and financial support from the high-income countries, to lower its emissions intensity even as its economy grows, climate policy has a chance for success.

An emissions budget

Goals for greenhouse gas emission reduction are set in relation to expected future emissions in the absence of climate policy, often called business-as-usual emissions. The lower, or more optimistic, the business-as-usual forecast of future emissions, the less urgency there is for mitigation policy, and the more lax emission reduction goals can be. (Put another way, the smaller we think that future emissions will be without climate policy, the smaller our policy actions need to be to counteract those emissions – wishful thinking leads to poor planning.) The pace of economic growth in the developing world is a critical, but little discussed, element in determining the overall scale of "21st century cumulative emissions," a measure which adds together all of the annual emissions from 2005 to 2105. And cumulative emissions are one of the most important indicators of the likelihood of limiting the increase in global average temperatures to 2°C, a well-established climate policy goal.[4]

Business-as-usual emission projections are based on expected economic growth and expected changes to emissions intensity. Projections of emissions under a given mitigation scenario begin with the business-as-usual trajectory, then show the effect of slowing economic growth and accelerating emissions intensity reductions. The higher the business-as-usual emissions, the more ambitious climate policy must be to provide a good chance of achieving the 2°C objective.

SEI's CRED model indicates that the emissions budget for keeping global average temperature increases below 2°C is about 2,700 Gt CO_2-e emitted cumulatively during the 21st century, including both CO_2 and other non-CO_2 greenhouse gases such as methane and nitrous oxide.[5]Given such a budget, country-level emissions can be viewed as a "zero-sum game." In other words, the more that any one country emits, the less that remains for other countries. If the poorest economies don't grow very much, they won't use up much of the remaining budget – leaving more for today's industrialized global North and the newly industrializing countries in the global South. The assumption of slow economic growth in the poorest countries has the effect of lowering expectations for emissions reductions in the rest of the world. An example will help to illustrate this concept.

Imagine if the lowest income countries' economies were expected to grow so quickly over the next 85 years that their emissions would total 2,600 Gt CO_2-e from 2005 to 2105, leaving just 100 Gt for richer countries to emit – a very small budget that would require extremely steep emissions reductions. If, on the other hand, the least developed countries were expected to have slow economic growth, they might emit

[4] See Allison et al. (2009), German Advisory Council on Global Change (2009).
[5] See Ackerman, Stanton and Bueno(2011a).

only 100 Gt CO_2-e, leaving a 2,600 Gt budget for richer countries. In this second scenario, there would be much less pressure on richer countries to lower their emissions, and their target level of annual emissions could be much higher. What we *think* about developing countries economic growth and future emissions affects how big of an emissions budget richer countries can claim for themselves. (Of course, this assumes that developing countries have a right to certain amount of emissions – a topic discussed in detail in Section 2 below.)

Assuming slow economic growth in the poorest countries would mean a larger emissions budget – and weaker targets for emissions reductions – for the rest of the world. What do actual climate-economics models assume about economic development?

Three scenarios of future emissions

As this report will demonstrate, many of the climate-economics models that analyze outcomes of various future emissions scenarios presuppose a slow pace of economic growth in most developing countries. That assumption ignores connections between climate, poverty, and energy. It bypasses core issues in current climate negotiations – developing countries' right to development, and all countries' common but differentiated responsibilities for mitigation. Throughout the report, countries are divided into four "income groups" for ease of analysis, based on real per capita incomes in PPP terms[6], as follows (see the Appendix for an explanation of these classifications):

- High-income group: 55 countries with 18 percent of today's population; incomes range from $68,500 in Luxembourg to $12,300 in Mexico
- High-middle-income group: 53 countries, including China, with 38 percent of today's 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 today's population; incomes range from $3,900 in Paraguay to $2,100 in Pakistan
- Low-income group: 45 countries with 15 percent of today's population (rising to 35 percent by 2105); incomes range from $1,900 in Uzbekistanto $202 in the Republic of the Congo. Thirty-four of these countries are in Sub-Saharan Africa, representing 66 percent of the group's population today 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.[7]

This reportsketches out amore comprehensive framework for future climate-economics analysisby exploring the potential greenhouse gas emissions, and corresponding mitigation obligations, of three stylized futures for developing countries: Without Development; Development with Carbon; and Development without Carbon.

Without Development:This business-as-usual scenario models standard economic growth with slow reductions in emissions per dollar of GDP that correspond with each country's GDP per capita growth; there are no policy-driven emission reductions. With the exception of the group of newly industrializing countries – most importantly, India and China – that already have a running start, economic growth

[6]All money values in this report are expressed in 2005 U.S. dollars.The purchasing power parity (PPP) conversion factor adjusts per capita GDP to reflect differences in domestic prices for the same goods – which are usually lower in poorer countries. Thus 50 cents may be $1 in PPP terms, if in that country, it buys what $1 would buy in the United States. For a more detailed definition, see the World Bank Development Education Program glossary: http://www.worldbank.org/depweb/english/beyond/global/glossary.html.
[7] The World Bank, *World dataBank,* http://databank.worldbank.org/ddp/home.do?Step=3&id=4#.

proceeds at a slow, steady pace in developing countries. This growth is insufficient to alleviate poverty in the poorest countries by 2105. As a result of low growth and low emissions in the developing world, high-income countries have more 21st century "emissions space" and, therefore, weaker emissions mitigation obligations.The Without Development scenario closely emulates the business-as-usual scenarios used in many of the best-known climate-economics models.

Development with Carbon: Faster economic growth in the Development with Carbon scenario brings all countries out of poverty, but the pace of reductions in emissions per dollar remains slow and, again, is driven by income growth rather than policy. This scenario represents an alternate vision of business-as-usual. Emission reduction policies formed using the Without Development scenario as a baseline will be insufficient if the Development with Carbon future comes to pass.

Development without Carbon: Fast economic growth is coupled with strong decarbonization policies in developing and developed countries alike. Funding from high-income countries helps assure that economic development drives a reduction in emissions intensity at every income level. The result is success in greatly reducing the risks of climate change, coupled with success in alleviating poverty worldwide.

The following section explores the meaning of common but differentiated rights and responsibilities in climate policy, providing support for the proposition – taken as a given throughout the remainder of this report – that poor countries have a right to economic development, and rich countries have a responsibility to fund mitigation and adaptation measures both at home and abroad. Sections 3, 4, and 5 of this report – *Without Development*, *Development with Carbon*, and *Development without Carbon*, respectively – present expected emissions under each of these scenarios, along with analysis of the implications of each such future. (A detailed Appendix lays out the assumptions and data behind the model used in this report.) The report concludes with policy recommendations and a discussion of key elements necessary to portray a joint climate and development policy in climate-economics models.

2. What is fair?

There are two normative principles at work in the discussion of development without carbon: equity requires development; and equity requires common but differentiated responsibilities. (A third principle, that equity is a social good and an appropriate goal for public policy is here taken as a given.) The principle that equity requires development is enshrined in the Millennium Declaration, adopted by the General Assembly in the United Nations in 2000, which opened with this assertion:

> We recognize that, in addition to our separate responsibilities to our individual societies, we have a collective responsibility to uphold the principles of human dignity, equality and equity at the global level. As leaders we have a duty therefore to all the world's people, especially the most vulnerable and, in particular, the children of the world, to whom the future belongs.(United Nations 2000)

The Declaration goes on to lay out a set of commonly held objectives for development and poverty eradication, stating:

> We will spare no effort to free our fellow men, women and children from the abject and dehumanizing conditions of extreme poverty, to which more than a billion of them are currently subjected. We are committed to making the right to development a reality for everyone and to freeing the entire human race from want.

The United Nations, together with the Organization for Economic Cooperation and Development (OECD), the World Bank, and the International Monetary Fund, went on to establish a set of eight Millennium Development Goals (MDGs)[8] that incorporate measurable indicators for progress. The MDGs include the eradication of extreme poverty, a substantial reduction in child mortality, and the objective that environmental sustainabilitybe integrated with development; many of the MDGs targets – officially set in 2000 – are meant to be achieved by 2015. According tothe 2011 MDG progress report (United Nations 2011), the world is on target to meet some of the goals, while on others, it is lagging behind. For the poorest of the poor, obstacles to development have proved intractable, and the MDGs will remain aspirations long after 2015 has come and gone.

The importance that a clean and healthy environment has in achieving development goals is akey thread in the MDG literature. Rockström et al.(2005) argue that environmental sustainability has an important role in the achievement of all the MDGs, and the IPCC's Special Report on Renewable Energy Sources and Climate Change Mitigation (Chapter 9, Sathaye et al. 2011)describes numerous synergies between renewable energy and sustainable development. Moreover, development is widely seen as a way to reduce vulnerability to climate change(see UNDP n.d.; Davidson 2003)– a premise that explains the coincidence of so many climate adaptation goals with development goals.

Development without carbon starts with development, best described as progress towards MDG targets or measured in terms of human development (UNDP 2011), but very often summed up in terms of the growth of per capita income in PPP terms (see footnote 7).Critiques of per capita GDP as a summary measure of development abound, but have failed to dethrone it, at least in the field of economics. (See Sen 1999; UNEP 2011, among many other important works, for a more nuanced discussion.) Economic development is central – but not sufficient – to improving the quality of life in poor communities. If development is a right, then so too is economic growth up to some threshold.

A second normative principle upholds the development with carbon approach: Equity requires common but differentiated responsibilities in climate policy.This principle was first articulated in the 1992 Rio Declaration on Environment and Development, which stated: "In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command"(United Nations 1992) The Kyoto Protocol to the United Nations Framework Convention on Climate Change echoed this language, and declared that:

1. The largest share of historical and current global emissions of greenhouse gases originated in developed countries.
2. Per capita emissions in developing countries are still relatively low.
3. The share of global emissions originating in developing countries will grow to meet social and development needs. (United Nations 1997)

These assertions are based on a long-run view that acknowledges that not every person, or every country, has had an equal responsibility for causing the climate problem. The high-income countries emitted 62 percent of cumulative global emissions in the period from 1980 to 2007; the middle-income countries, 35 percent; and the low-income countries just 2 percent. In 2005, CO_2-e emissions per person ranged from 70.5 tons in Qatar to 0.4 tons in Burundi and Rwanda. On average, high-income countries emitted 15.6 tons per person; high-middle-income, 7.4 tons; low-middle-income, 3.3 tons, and low-income, 1.5 tons(WRI 2010). If anyone has a right to continued greenhouse gas emissions, surely it is the group that has emitted the least to date.

[8] To learn more about the MDGs, go to http://www.un.org/millenniumgoals.

An equitable climate policy cannot make the same requirements of developing countries that it does of industrialized countries (Modi et al. 2005). The recent Copenhagen Accord reaffirmed this basic principle, and established the Green Climate Fundas a financial mechanism to support mitigation and adaptation in developing countries(for documents on the design of the Green Climate Fund, see UNFCCC 2011).

Though the MDGs do not include a direct mandate to reduce energy poverty, a subsequent literature following on the MDGs has made this relationship clear (Rockström et al. 2005). The United Nations' own Millennium Project has called for energy services to be placed on par with other MDGs, noting that lack of access to energy services impedes the eight original MDGs(Modi et al. 2005). More recently, the Commission on Climate Change and Development (CCD 2009)has drawn out the connections between emissions mitigation and the eradication of energy poverty in detail, concluding:

> The increase in public attention to climate change during the past decade has thus sometimes obscured the need to increase energy consumption in developing countries in order to raise their living standards and thereby improve their adaptive capacity. This tendency has been countered by the recognition that developing countries and especially [less developed countries] have the right to use their emission space in any future climate agreement for significant increases in energy consumption while industrial countries rapidly decrease their emissions.(CCD 2009, p.63)

There can be no single, definitive answer to what is right or fair in climate policy, and much has been written about the equitable allocation of future emissions. One of the simplest, most transparent approaches to climate equity allocates emissions on an equal per capita basis, where each country's emission budget is the sum of its residents' individual emission rights (Agarwal and Narain 1991; Narain and Riddle 2007). Some proposals assert developing countries' right to emit up to the current average per capita emissions in industrialized countries, agreeing to lower the former in step with the latter (Singh 2008). Others stress the importance of basing policy on individual, rather than average national emissions, excusing individuals with emissions lower than the per capita target from engaging in any mitigation activities (Chakravarty et al. 2009).

Prominent among emission allocation proposals is the Greenhouse Development Rights (GDRs) framework(Baer et al. 2008), which sets a global emissions budget and then distributes the abatement costs necessary to staying within that budget on the basis of two factors: a country's ability to pay – taking income distribution within countries into consideration – and the country's responsibility for past and current emissions. When all global mitigation measures are assumed to be paid out of a common fund, the question of where in the world emissions (or emissions reductions) will take place becomes secondary to the question of how much each country will contribute to the common pool of funding.

Using the GDRs approach, emissions reductions will begin wherever the costs of abatement are especially low, with the cheapest abatement measures, anywhere in the world, addressed first and the most expensive last.[9] Low-income countries have little or no responsibility to pay into the abatement funding pool because any contribution is unaffordable to the portion of their populations living in poverty, and because their historical greenhouse gas emissions have been infinitesimal.As countries develop, so does their contribution, but in proportion to the share of their population with incomes above a minimum acceptable standard of living.

The Climate and Regional Economic Development (CRED) model (Ackerman, Stanton and Bueno 2011b; Ackerman, Bueno, et al. 2011)takes a similar approach, paying abatement costs out of a common pool and assigning contributions to that pool based on average per capita consumption in a country or

[9] See Vogt-Schilb and Hallegatte (2011) for a discussion of exceptions to this "marginal abatement cost curve" approach.

region. CRED is a welfare-optimizing integrated assessment model that allows for cross-regional investment between rich and poor countries. Following the mainstream economic principle of diminishing marginal returns, increasing incomes in poor countries does a lot more to raise social welfare than does increasing incomes in rich countries. In CRED's optimal climate policy, therefore, high-income regions contribute the bulk of funds in the common abatement pool and simultaneously invest in poverty reduction in low-income regions.

All of these emissions allocation systems share a few common principles:

- The allocation of future emissions should follow some normative, rule-based standard for equity.
- Poorer countries have a special right to future emissions.
- Richer countries have a special responsibility for paying for mitigation.

This report ignores the finer details of who has a right to exactly how much of the 21st century cumulative emissions budget, and approaches climate equity in this way: The poorest countries, and the segment of the world's poorest population living in middle- and high-income countries, have the same right to future emissions that richer countries asserted over past emissions. The historical, and present day, big emitters have a special responsibility to assure that 21st century cumulative emissions stay below the2,700 Gt CO_2-e target. This responsibility extends both to lowering their own emissions, and to paying for emissions reductions in poorer countries.

3. Without Development

The first scenario explored in this report is based on a forecast of the "business-as-usual" emissions that are expected in the absence of an effective climate policy. The model used in this report projects Without Development scenario emissions using "standard" economic and population growth data. Standard projections for real GDP (PPP) growth extend International Energy Agency (IEA) forecasts for 2035 through 2105, with the assumption that high growth rates will slow down over time; these growth rates are very similar to the rates used in a wide range of climate-economics models. Population projections follow the medium variant in the United Nations Department of Economic and Social Affairs (UN-DESA) *World Population Prospects, 2010 Revision.*[10](The data and methodology used to model the Without Development, Development with Carbon, and Development without Carbon scenarios are described in detail in the Appendix.)

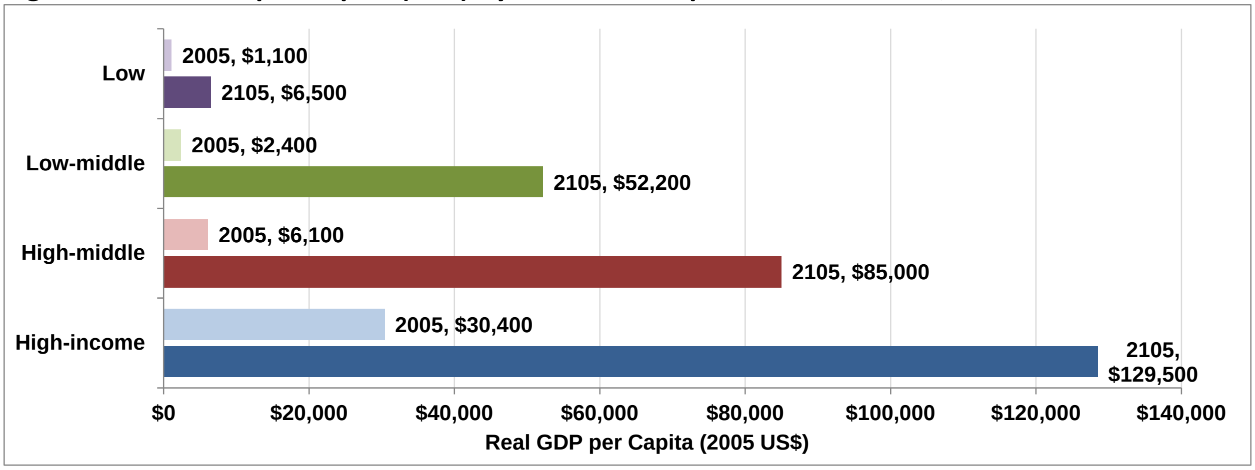
In the Without Development scenario, per capita incomes (defined as real GDP per person in PPP terms) show a limited convergence over time, leaving a big gap between incomes in the richest and poorest countries. The ratio of per capita income in high-income countries to that in low-income countries shrinks from 27-to-1 today down to 20-to-1 in 2105. High-income countries' average per capita income grows four times larger; high-middle income countries', 14 times larger; and 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) populations are expected to grow much more rapidly than in 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-middle-income countries and 3.1 percent for low-middle-income countries). According to UN-DESA's 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.

[10] See http://esa.un.org/wpp/unpp/panel_population.htm.

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. The ratio of high-income to high-middle income countries' per capita income falls from 5.0-to-1 today to 1.5-to-1 in 2105, and the ratio of high-income to low-middle-income countries' per capita incomes falls from 12.5-to-1 today to 2.5-to-1 in 2105 (see Figure 1).

Figure 1: Real GDP per Capita (PPP) by Income Group in 2005 and 2105, Standard Growth



Source: Author's calculations; see text for data sources.

Generalizing across the climate-economics models reviewed in the Appendix to this report, emissions forecasts assume that at the end of this century the 45 low-income countries will have average per capita incomes of $6,500 a year – matching those of Tunisia, Belize, or Serbia in 2005 – with incomes in the very poorest countries of about $1,100 a year – matching those of Zambia, Bangladesh, and Haiti. 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.

Projections of future annual emissions are based not only on assumptions regarding real GDP growth, but also on expected changes in emissions intensity. The model used in this report estimates that today's emissions intensities range from 23 kg CO_2-e per dollar (kg/$) in the Central African Republic and the Republic of the Congo to 0.2 kg/$ in Switzerland and Norway. 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 is 0.5 kg/$; middle-income countries, 1.2 kg/$; and low-income countries, 2.1 kg/$. (See the Appendix for methodology and data sources.)

In the Without Development scenario modeled here, in the unlikely event that each country's emissions intensity remained unchanged over time, cumulative 21st century emissions would exceed 23,000 Gt CO_2-e, only 7 percent of which would come from the low-income countries.(Recall that the global 21st century cumulative emissions budget for keeping temperature increases below 2°C is 2,700 Gt.) Most business-as-usual emission scenarios used in climate-economics models add up to cumulative 21st century emissions of less than 10,000 Gt CO_2-e,indicating that the models assume decreasing emissions intensities over time (see Appendix).

Emissions intensities are notexpected to stay steady over time. Emissions per dollar tend to fall as technology improves and incomes rise (making relatively more 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 in this slightly smaller dataset and all but six OECD countries. Overall, during this period emissions intensities fell as income rose in 108 out of 174 countries modeled with historical data for this report, representing 86 percent of today's global GDP and 77 percent of today's greenhouse gas emissions.[11]

The assumption that emissions intensity will decrease over time is well entrenched in climate-economics modeling; the mechanisms for and causes of that reduction much less so (a topic revisited in Section 5). 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…However, despite the decreasing energy intensities (i.e., energy consumption per unit of GDP) observed over time in almost all regions, declines in energy intensity historically often have been outpaced by economic growth and hence have proved insufficient to achieve actual reductions in energy use"(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.

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. 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 in this report as the "autonomous-intensity-reduction" pattern. Autonomous reductions can be contrastedto "policy" reductions, which occur as a result of deliberate policy actions.[12] (Note that this is 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[13] – cumulative emissions will be higher.)

In the Without Development scenario, there are no policy-induced emissions reductions; the only changes to emissions intensity are based on the autonomous-emissions-reduction pattern as modeled for each country (see above). Twenty-first-century cumulative emissions reach 10,800 Gt CO_2-e., with low-income countries contributing just6 percent of this total (see Figure 2; annual emissions for each income group are the lines dividing the areas, and cumulative emissions are the colored areas). These emissions projections are at the high end of the range of projections 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-drive reductions to emissions intensity). In the CRED model's business-as-usual scenario, for example, 21st century cumulative emissions amount to 8,900 Gt CO_2-e and temperatures have a 50-percent probability of exceeding 3.3°C of warming by 2105.

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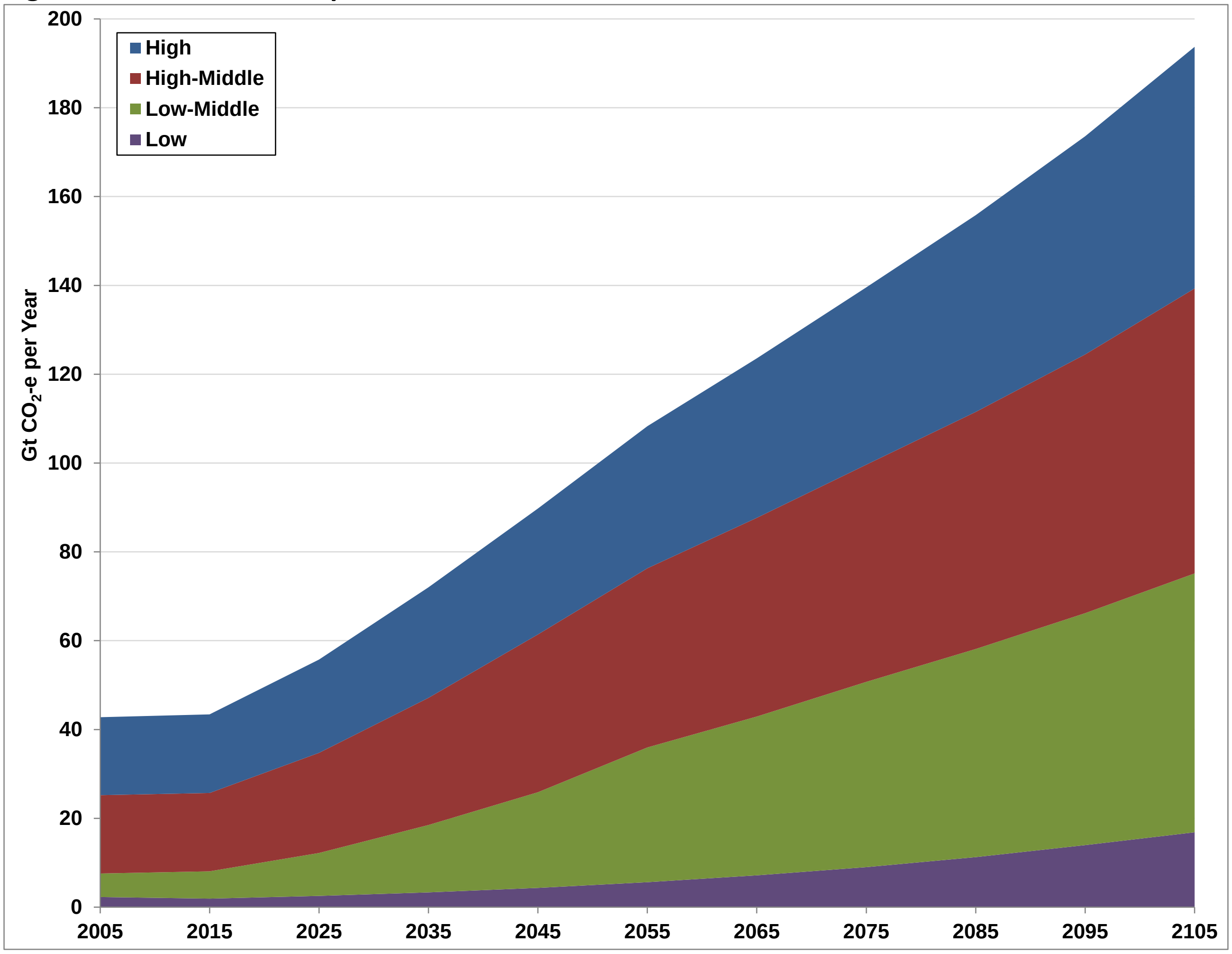
[11] Historical CO_2 emissions intensities were calculated using World Bank GDP data (from the *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4) and CAIT emissions data (WRI 2010). There is some, but not complete, overlap between OECD and high-income countries per the World Bank 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.

[12] In the model used for this report, emissions intensities are assumed to be lower than or equal to 2005 levels. Countries with higher than expected emissions intensities move to their expected levels in the first period. Countries with lower than expected emissions intensities stay at their 2005 levels until their per capita income catches up with their emissions intensity. This assumption is discussed in more detail in a subsequent section.

[13]See Lindmark (2004).

Figure 2: Without Development Annual CO_2-e Emissions, 2005-2105



Source: Author's calculations; see text for data sources.

The 21st century cumulative emissions budget for keeping temperature increases under 2°C is 2,700 Gt CO_2-e. Assuming little or no emission mitigation policy in the Without Development scenario, low-income countries are expected to emit about a cumulative 700 Gt in the 21st century, leaving 2,000 Gt for richer countries and a policy gap of 8,800 Gt between expected business-as-usual emissions (10,800 Gt) and target cumulative emissions (2,000 Gt) in high- and middle-income countries. Meeting this policy gap through emissions reductions would require substantial policy-driven decreases in emissionsintensities.

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 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?

Imagine if low-income economies were to grow more quickly with the same lack of policy-driven emission reductions.Faster economic development and greater emissions from the lowest-income countries (together with developing countries' assumed right to economic development and common but differentiated mitigation responsibilities) would call for still more ambitious emission reductions in high-and middle-income countries. Sections 4 and 5 of this report explore the impact of faster economic growth on developing country emissions in detail.

4. Development with Carbon

What if low-income countries experienced 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.[14]Standard growth projections 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 the21st century per capita income growth expected for Haiti by climate-economics models, on average just 2.0 percent per year reaching $7,200 in 2105.

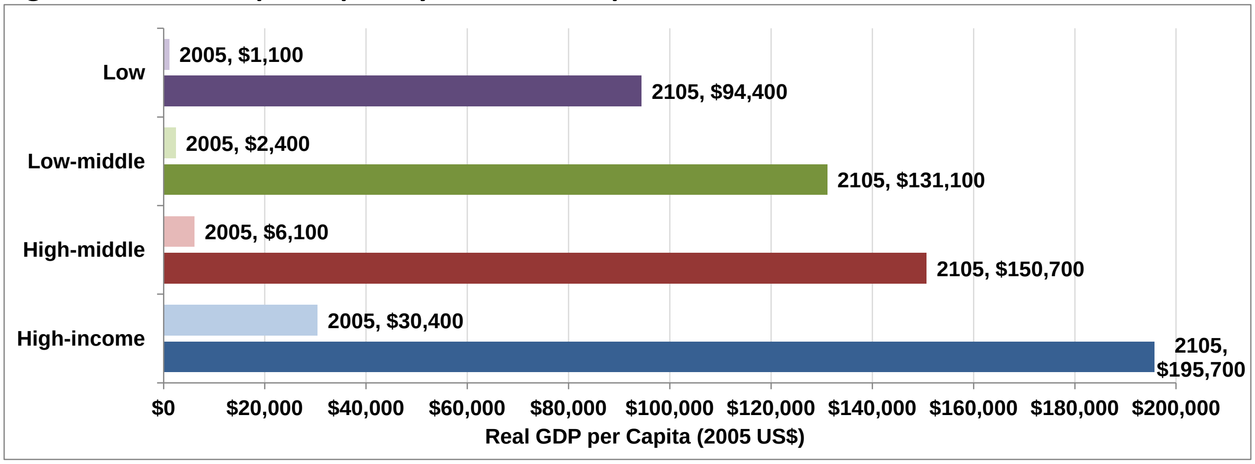
Economic growth is by no means guaranteed, especially in the absence of sufficient international aid, but what if economic development for the poorest countries can and does occur? What if Haiti (and every low-income country) can match the success of India? In the Development with Carbon scenario modeled for this report, more optimistic assumptions about economic development lead to higher expected cumulative greenhouse gas emissions from low-income countries and a smaller 21st century cumulative emissions budget for high- and middle-income countries. This is a business-as-usual – no climate policy – scenario with higher-than-standard economic growth assumptions for developing countries.

Faster economic growth

Future greenhouse gas emissions are estimated as the product of expected GDP and expected emissions intensity (or kg CO_2-e per dollar of GDP). With faster economic growth[15] (using the same UN-DESA medium variant population projections discussed above) per capita incomes reach $195,700 per year in high-income countries, $150,700 in high-middle-income countries, $131,000 in low-middle-income countries, and $94,400 in low-income countries in 2105 (see Figure 3). The end of the century ratio of high-income to high-middle-income countries per capita income is 1.3-to-1; for low-middle-income countries, 1.5-to-1; and for low-income countries, 2.1-to-1, compared to 20-to-1 with standard growth. In the Development with Carbon scenario, incomes converge around the world.

[14]World Bank GDP data (from the *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4).
[15] Modeled as all GDP (PPP) per capita growth rates in all periods set to 7.0 percent per year in countries with incomes below $35,000 and to 1.5 percent in countries with incomes above $35,000.

Figure 3: Real GDP per Capita by Income Group in 2005 and 2105, Faster Growth



Source: Author's calculations; see text for data sources.

Faster economic growth has two countervailing effects on emissions: higher GDP means more emissions, but at the same time,the autonomous-intensity-reduction pattern assures that (if population grows more slowly than GDP) higher per capita income results in a lower emissions intensity and less total emissions.In the Development with Carbon scenario, the scale effect – higher GDP means more emissions – dominates. Twenty-first-century cumulative emissions reach 20,700 Gt CO_2-e, 21 percent of which originates in the poorest countries. In this scenario, low-income countries emit a cumulative 4,400 Gt in the 21st century, exceeding the entire global 2,700 Gt budget.

Without policy-driven emissions intensity reduction measures, accelerated economic growth increases 21st century cumulative emissions in low- and middle-income countries. For success in keeping temperature increases below 2°C, low-income countries would have to bring their cumulative emissions down to the 2,700 Gt CO_2-e budget, and middle and high-income countries would have a 0 Gt emissions budget – leaving these relatively richer countries with a 16,300 Gt policy gap.

The relative size of middle and high-income countries' policy gaps in the Without Development and Development with Carbon scenarios demonstrates the potential scale for miscalculating climate policy targets using overlypessimistic economic development projections. In the standard growth, Without Development scenario, richer countries face a 8,800 Gt CO_2-e policy gap; in the faster growth, Development with Carbon scenario, this gap is almost doubled – 16,300 Gt. Using standard growth assumptions to form climate policy is a risky proposition: If economic development is successful, climate policy based on current business-as-usual projections will fail.

Faster population growth

While population grows in UN-DESA's medium variant long-term projections, developing countryfertility rates drop precipitously over the course of the 21st century. Relatively high fertility rates over the past few decades mean that in many of the world's poorest regions,the share of population under 25 years old is extremely high. Even at low future fertility rates, these populations will continue to grow as the demographic bulge is gradually erased. It is worth considering the impact on emissions projections should UN-DESA's medium variant population projections, based on a steep drop in fertility rates, turn out to have been too low. One point to consider in this regard is the relationship between income levels and fertility rates: There is a strong (51 percent) negative correlation between fertility rates and per capita GDP (PPP) – income is not the only factor influencing fertility, but it is clearly an important one.[16]

Economic development is very likely an important determinant of population growth, but almost all climate-economics models use exogenous population projections that are independent of their economic-growth projections. Population modeling has been a contentious issue in environmental economics, with ideas like Paul Ehrlich's so-called "population bomb" (Ehrlich 1968)leading to callsfor reduced population growth in the developing world(including by coercive means) as a perceived solution to environmental problems. Critics of this notion, including many environmentalists, haveresponded that the real cause of environmental degradation is high per capita resource use in the global North and not high population growth rates in the global South.[17]Treating population growth as exogenous is a simple and defensible way for climate-economics modelers to avoid the appearance of calling for lower population as a way to reduce emissions.

Here's another way to approach this modeling problem.The direction of causation leads from sustainable economic development – including a clean and healthy environment – to lower fertility rates, and not the other way around. Economic development can support basic human dignity, improve living standards, and facilitate better access to education, nutrition, and health care. Amartya Sen emphasizes how patterns of economic development that "enhance gender equity and the freedom of women (particularly education, health care, and job opportunities for women)" are critical to reducing fertility. Lower fertility rates, in turn, enhance the "freedom of people – particularly of young women – to live the kind of lives they have reason to value." Sen concludes: "The solution of the population problem calls for *more* freedom, not less."(Sen 1999, pp.225–226; original emphasis)

If income growth falls behind in the poorest countries – or in the poorest communities in middle and high-income countries –UN-DESA's medium variant population projections may prove too low.And if the "standard"GDP growth may not be consistent with medium variant population growth, it is worthwhile considering the effects of a larger global population, as modeled in UN-DESA's high variant, on emissions projections. Combining the standard economic growth with high population growth drives up emissions in every income group; global cumulative emissions rise from 10,800 Gt CO_2-e with the medium variant, to 14,100 Gt with the high variant.

The bottomline is this, if climate-economics models are underestimating either economic growth or population 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.

5. Development without Carbon

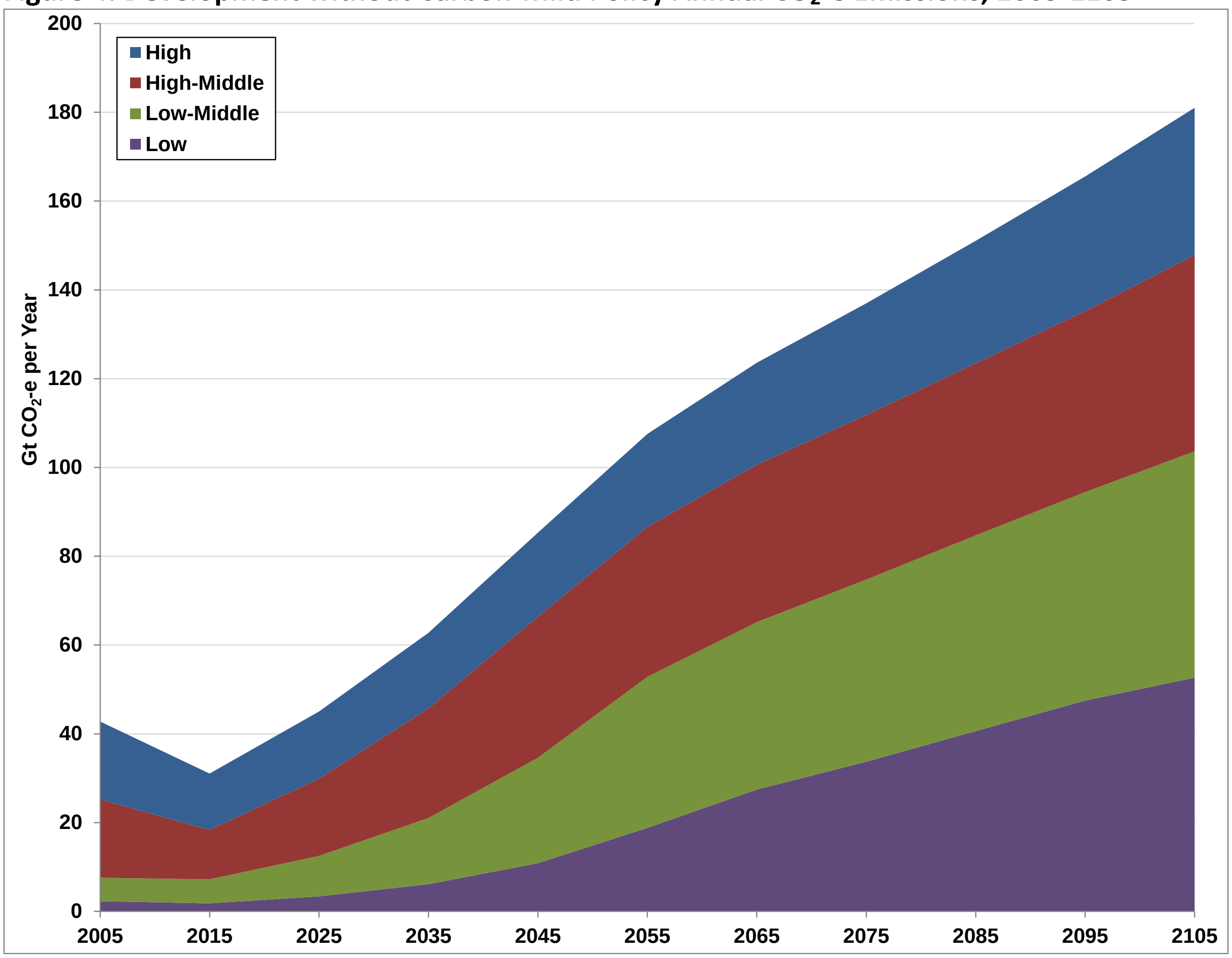
Without some policy-driven assistance, autonomous-intensity reductions are drowned out by economic growth (Chapter 9, Sathaye et al. 2011). A successful development-without-carbon strategy requires both economic development – including policies to address energy poverty – and emissions mitigation policy. Climate policy aimed at lowering emissions intensities as incomes grow would need to support and accelerate autonomous-intensityreduction by improving countries' adherence to the 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.

[16] UNDESA 2005-2015 fertility rates, http://esa.un.org/wpp/unpp/panel_population.htm, and World Bank 2005 GDP per capita (PPP) from the *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4.
[17] See Hartmann (1995).

In the Development without Carbon scenario, faster economic growth, medium-variant population growth, and autonomous-intensity reductions (as modeled in the Development with Carbon business-as-usual scenario) are combined with policy-induced emissions reductions. These enhanced emissions reductions are modeled as stronger responses to income growth than predicted in the autonomous-intensity-reduction pattern of 0.34-percent intensity drop for every 1-percent increase in per capita income. Two levels of policy response are modeled: "mild policy," with a 0.40-percent intensity drop, and "strong policy," with a 0.53-percent intensity drop, for every 1-percent increase in per capita income (these rates include both autonomous and policy-induced reductions).

Using the mild policy assumption, 21st century cumulative emissions reach 10,200 Gt CO_2-e, with 2,200 Gt from low-income countries; the remaining policy gap for middle and high-income countries is 9,700 Gt (down from 16,300 Gt in the Development with Carbon scenario) (see Figure 4).

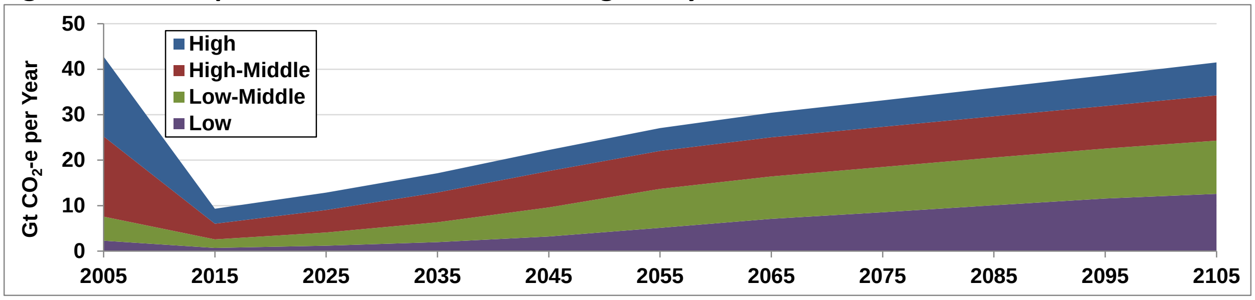
Figure 4: Development without Carbon-Mild Policy Annual CO_2-e Emissions, 2005-2105



Source: Author's calculations.

Using the strong policy assumption, 21st century cumulative emissions reach 2,700 Gt CO_2-e, with 600 Gt from low-income countries (seeFigure 5; note that all emissions graphs in this report have the same vertical scale) – reflecting a deliberate choice in the emissions intensity reduction rate to present a Development without Carbon scenario that could keep emissions within their 21st century budget for staying below 2°C,with no additional policy gap.

Figure 5: Development without Carbon-Strong Policy Annual CO_2-e Emissions, 2005-2105



Source: Author's calculations.

Policy-driven emissions intensity reductions

Policy measuresto improve adherence to the autonomous-intensity-reduction pattern would 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 would appear to be on the upswing of an inverted U-shaped path.[18] 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 intensity to increase with rising incomes.

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 Environmental Kuznets Curve-like, emissions intensity transitions than are low-income countries.[19] The experience of El Salvador and a number of other low and middle-income countries suggests, however, that an inverted U-shaped emissions-intensity is a real possibility for these countries as well. In some countries, public policy measures, together with international assistance, may be necessary to make the autonomous-intensity-reduction pattern more robust.

A second, complementary, approach to emissions intensity reduction policies would offer additional support to countries with anomalously high emissions intensities. The income-driven autonomous-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).[20]Countries with higher than expected emissions intensities may need special assistance or incentives to kick-start income-driven emissions intensity reductions.

Finally, a third set of policy measures would support the innovation of low-cost low-carbon technology, thereby enhancing the existing autonomous-intensity-reduction pattern.Low-cost alternative electricity generation, and heating and cooking fuels are a critical component of energy poverty reduction. Many

[18] 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).
[19] For more on the Environmental Kuznets Curve, see Grossman and Krueger (1995).
[20] SeeCAIT (WRI 2010).

countries exhibited emissions intensity reductions in the 1980 to 2005 period that were faster than the trend used to model the autonomous-intensity-reduction pattern – some with a greater than 1-percent drop in emissions intensity for every 1-percent increase in per capita income. 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. Affordable low-carbon technology is crucial to fostering and increasing the pace of the autonomous-intensity-reduction pattern, and public policy has an important role to play in supporting and disseminating technological innovations.

National and regional planning are some of the most important tools in improving countries' adherence to the autonomous-intensity-reduction pattern, supporting countries with anomalously high emissions intensities, and spurring innovation of low-cost low carbon technologies. Energy policy analysis and climate change mitigation assessment is greatly facilitated by tools like the Long-range Energy Alternatives Planning System (LEAP),[21] which tracks energy consumption, production and resource extraction across economic sectors, as well as emissions of local and regional air pollutants including greenhouse gases. LEAP users include over 3,500 energy analysts, academics, consultants and students from over 150 countries, including more than 30 countries that have used LEAP in the context of UNFCCC national communications. Policy intervention based on detailed long-range energy planning is the key to keeping emissions within their 21st century budget.

[21] To learn more about LEAP, visit http://www.energycommunity.org.

Case Study: Latin America and the Caribbean

With 32 countries and 540 million people, Latin America and the Caribbean accounted for 6.2 percent of the 2005 global population.[22]

- High-income group: six countries with 20 percent of today's regional population; per capita incomes range from $25,900 in the Bahamas to $12,300 in Mexico (which by itself accounts for 98 percent of the population in Latin America and the Caribbean's high-income group). Also in this group: Antigua and Barbuda, Barbados, St. Kitts and Nevis, and Trinidad and Tobago.
- High-middle-income group: 19 countries with 73 percent of today's regional population – Brazil alone accounts for 34 percent of regional population; incomes range from $12,200 in Chile to $4,100 in Guatemala. Also in this group: Argentina, Belize, Colombia, Costa Rica, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Jamaica, Panama, Peru, St. Lucia, St. Vincent and the Grenadines, Suriname, Uruguay, and Venezuela.
- Low-middle-income group: five countries with 5 percent of today's regional population; incomes range from $3,900 in Paraguay to $2,300 in Nicaragua. Also in this group: Bolivia, Guyana, and Honduras.
- Low-income group: Haiti with $1,000 per capita income in 2005 and a population of 9 million; accounts for 1.7 percent of the Latin American and Caribbean population.

Annual growth rates in regional per capita income range from 1.1 percent in Guatemala (high-middle income) to 2.5 percent in Guyana (low-middle income). When countries are grouped by income category, their aggregate growth rates are very similar: high income, 1.8 percent, high-middle income, 2.0 percent, low-middle income, 1.8 percent, and low income 2.0 percent.

Emissions intensities also varied widely from country to country in 2005. Countries with the lowest emissions intensity are St. Vincent and the Grenadines (0.26 kg per dollar of GDP), Costa Rica and the Bahamas (0.27), and St. Lucia (0.28). At the other end of this range, Bolivia (5.82), Honduras (2.82), Guyana (2.80), and Brazil (1.80) have the highest emissions intensities in the region; these four countries also top the list of countries in this region with intensities that are higher than predicted by the autonomous-intensity-reduction pattern.

In the Without Development business-as-usual scenario, Latin America and the Caribbean emit a cumulative 900 Gt CO_2-e in the 21st century, 8 percent of the global total (compared to its 6 percent of the global population). Regional emissions in 2005, 5.5 Gt, grow to 15.2 Gt in 2105(see Figure 6). Latin America and the Caribbean's emissions alone take up one-third of the global budget for keeping temperature increases below 2°C. With faster economic growth in the Development with Carbon business-as-usual scenario, regional 21st century cumulative emissions reach 1,800 Gt CO_2-e, using up more than two-thirds of the global budget. At the end of the century, annual emissions have grown to 29.8 Gt. If faster growth, and real economic development, comes to pass, emissions reductions policies based on Without Development projections will not be enough to avoid dangerous climate change.

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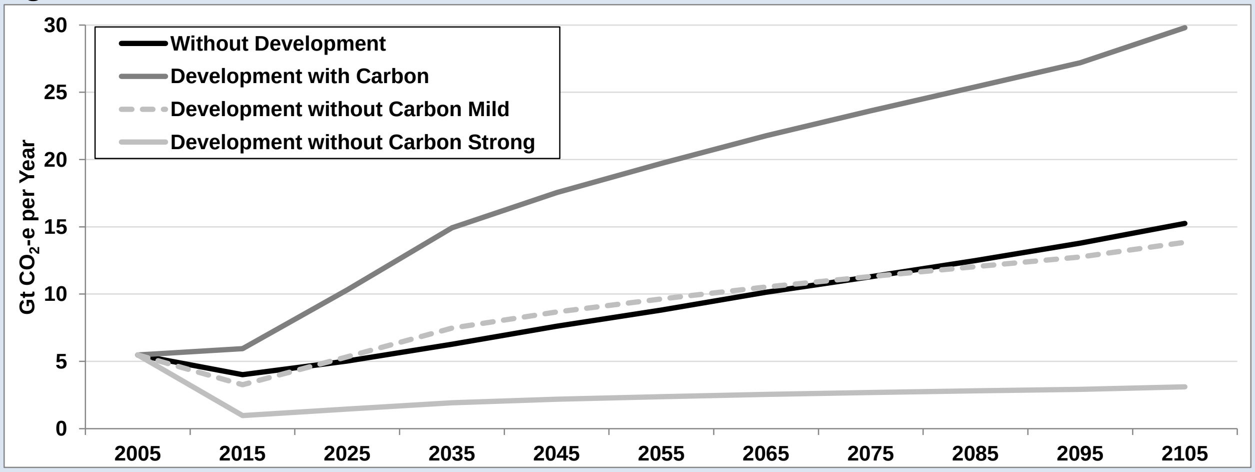
[22] By 2105, regional population is expect to grow to 681 million, but make up only 5.7 percent of world population because of faster growth in other regions. Population is expected to shrink by 0.1 to 0.3 percent per year in Barbados, Trinidad and Tobago, Dominica, Grenada, Jamaica, St. Vincent and the Grenadines, and Guyana. The highest rates of population growth are expected in Guatemala (72 percent), Bolivia (54 percent), Honduras (50 percent), Belize (49 percent), and Paraguay (48 percent).

Figure 6: Latin America and the Caribbean Annual CO_2-e Emissions, 2005-2105



When policy-induced reductions to emissions intensities are modeled, emissions fall despite converging world incomes. In the mild policy Development with Carbon scenario, 21st century cumulative regional emissions fall to 900 Gt CO_2-e; in the strong policy scenario, regional cumulative emissions are only 200 Gt – 7 percent of the global budget –and by 2105, annual regional emissions have fallen to 3.1 Gt.

A successful climate policy will require public actions to support adherence to the autonomous-intensity-reduction pattern:

- *Support for emissions intensity reductions in countries at risk of exhibiting rising emissions per dollar as incomes grow:*El Salvador, Grenada, and Trinidad and Tobago have all seentheir emissions intensities rise together with per capita income in the past few decades. Countries with this pattern of growth may need international support in developing low-carbon energy and industrial sectors to achieve autonomous, income-driven reduction in emissions intensity.
- *Support to countries with anomalously high emissions intensities:* Bolivia, Honduras, Guyana, and Brazil have emissions intensities that are far higher than would be expected given their income levels. Again, assistance in jump-starting low-carbon energy and industrial sectors in the next one to two decades may be necessary to bring these countries in line with the global pattern of income-driven reductions.
- *Innovation of low-cost low-carbon technology:* To increase the pace of emissions reduction and energy poverty eradication, middle and low-income countries around the world need financial support for local energy technological innovation as well as unfettered access to low-cost low-carbon technology developed beyond their borders. Latin America and the Caribbean are no exception in this regard.

For a description of Latin America and the Caribbean's energy sector and detailed analysis of likely impacts of climate change on regional electricity production, see Escobar et al. (2011), *Energy-Water-Climate Planning for Development without Carbon in Latin America and the Caribbean*, released in conjunction with this report. For an economic analysis of climate change in the region, including analysis of the effects of economic development on energy use and greenhouse gas emissions, see ECLAC (2010).

6.Discussion and recommendations

Is there a path forward that balances climate and development (where development includes an end to energy poverty)? At present, most climate-economics models skirt this issue by implicitly treating the economic development of the poorest countries as if it were doomed to fail. This approach is overly simplistic and short-sighted: it either consigns the poor to remain poor for the next few generations at a minimum, or assures a failure of climate policy by failing to anticipate economic development.

Here are a few questions that the next generation of economic analyses should be asking and attempting to answer:

Can development derail climate policy? It is possible that, either on their own or with financial support from the international community, the poorest countries could follow India and China on a path to prosperity? Without targeted funding to support emissions intensity reduction while simultaneously alleviating energy poverty, this optimistic economic development scenario seems very likely to result in higher developing-country emissions. Meanwhile, if rich countries set weak mitigation targets for themselves, based on bad economic advice that assumes a pessimistic growth scenario for developing countries, the 21st century emissions budget is sure to be busted.In this manner, successful development (in combination with poor foresight) could indeed derail climate policy.

Can climate policy derail development? A global climate policy powerful enough to force developing countries to slow growth is a little hard to imagine, given the mood and track record of the international negotiations process. In theory, strongly enforced per country or per person emissions caps, enacted without supporting policy to aid reductions in emissions intensity, could slow or even stop economic growth in poor countries. In practice, this outcome is of most use as a counterfactual – a description of a world no one wants or expects. To make strong climate policy and strong economic development compatible will require significant investment in measures to support income-driven reductions to emission intensity.

A recent Center for Global Development working paper (Wheeler 2011) finds that developing countries accounted for 47 percent of the global increase in low-carbon energy generation from 1996 to 2002, and 68 percent of the increase from 2002 to 2008. The study concludes that developing countries are already full participants in emission mitigation, and bear a fair share of emission reduction expenditures, and goes on to issue this challenge to rich countries on behalf of poor countries: "We are willing to assume our fair share of the mitigation expenditure burden, as we have in the past. If you invest more aggressively in low-carbon energy, we will match you and maintain our fair share of the global expenditure burden. But you can scarcely expect us to pay a greater share of our incomes than you do, particularly since you have created more than your fair share of the problem"(p.8). This would serve as a good summation of the dynamic between the poor and the rich in climate policy negotiations, if only the "poor" were exemplified by China and India.

In 2010, China contributed the greatest share of global investment in renewable energy, followed by Germany and the United States. New investments in renewables in China and India represented a 28- and 29-percent increase over 2009, respectively(UNEP 2011). China and India's expected economic growth through 2020 is 8.3 percent per year, compared to 3.3-percent growth for non-OECD countries excluding China and India. The burdens and aspirations of China and India are not the burdens and aspirations of the rest of the developing world. In 2005, more than half (54 percent) of the low- and middle-income countries' populations did not live in China and India; in 2105, this share is expected to have grown to 71 percent.

For much of the rest of the developing world (and the poorest citizens of China and India), a fair interpretation of common but differentiated responsibilities is this: They have every right to continued economic growth, very little history of past emissions, and somewhere between very little and no responsibility to pay for future emissions mitigation. Taking such a pro-development stance seriously in climate-economics modeling requires the examination of the impacts of faster economic growth in developing countries. 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.

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Technical appendix

Forecasting GDP growth

One of the most important forecasts of future economic growth is published by the IEA in its annual *World Energy Outlook* (*WEO*). Many models of energy, climate, and economy follow these IEA projections, among them the McKinsey & Co. marginal abatement pathways[23] and the IEA's own *Energy Technology Perspectives* and BLUE Map scenario.[24] *WEO 2010* projects that OECD countries' (used here as a proxy for developed countries) real economic output (that is, GDP after adjusting for inflation) in PPP terms will grow 1.8 percent per year from 2008 to 2020 and 1.9 percent per year from 2020 to 2035. In non-OECD countries, the projections are 5.6 percent from 2008 to 2020 and 3.8 percent from 2020 to 2035.The pace of projected growth in non-OECD countries, however, is dominated by two exceptional cases: China (8.8 percent and 3.9 percent in the two periods, respectively); and India (7.0 percent and 6.6 percent). Together, China and India make up 45 percent of the 2005 population in non-OECD countries, and 37 percent of world population. Economic growth in the remaining non-OECD countries is expected to take place at a slower pace, as shown in Table 1.[25]

Table 1: WEO 2010 projections for annual real GDP (PPP) growth

	2008-2020	2020-2035
OECD	1.8	1.9
Non-OECD	5.6	3.8
Eastern Europe/Eurasia	3.0	3.1
Russia	3.3	3.1
Other	2.6	3.1
Asia/Pacific	7.2	4.2
China	8.8	3.9
India	7.0	5.6
Other	3.7	3.4
Middle East/North Africa	4.5	3.8
Sub-Saharan Africa	4.7	2.8
Latin America/Caribbean	3.1	2.7
Brazil	3.1	3.1
Other	3.1	2.4

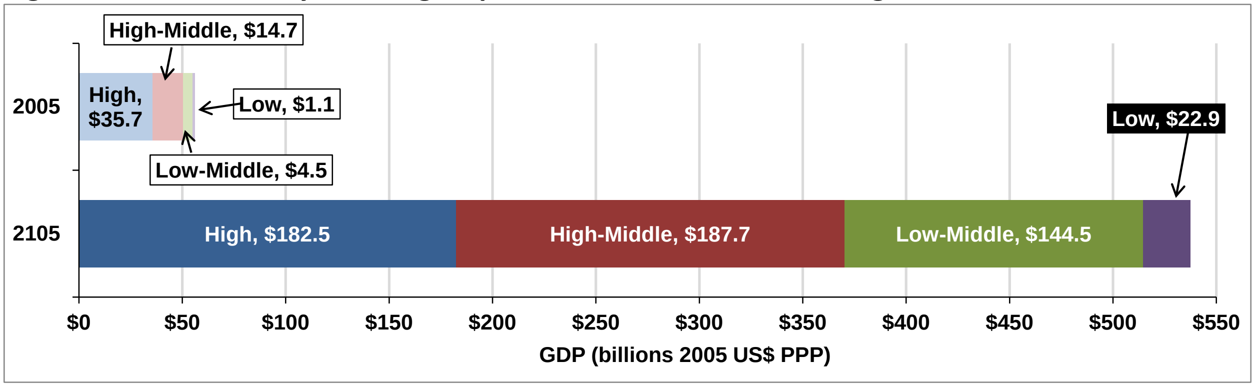
Source: IEA (2010a) and author's calculation based on IEA (2010a) data (see text for methodology).

Projecting these growth rates forward, with the assumption that real growth slows down as per capita incomes rise, results in global GDP (in today's PPP dollars) reaching $537 trillion in 2105, up from $56 trillion in 2005.[26] For simplicity the extended *WEO 2010* GDP growth projections are referred to as

[23] McKinsey (2009) follows the *World Energy Outlook 2007*(IEA 2007).
[24] IEA (2010c).
[25] Growth rates for Eastern Europe not including Russia, Asia not including China and India, and Latin America not including Brazil calculated as the residual of each region, based on *WEO 2010* real GDP (PPP) projections and World Bank 2008 real GDP (PPP 2005 US$), from the *World dataBank*, http://databank.worldbank.org/ddp/home.do?Step=3&id=4.
[26] In the model used for this report, projections are by decade from 2005 to 2105. Starting in 2045, countries with real per capita outputs (in PPP terms) greater than $35,000 are assigned a 1.5 percent long-term real GDP growth rate, and countries with per capita output between $20,000 and $35,000 are assigned a 2.0 percent rate. Countries

"standard" growth throughout this report. Figure 7 shows global GDP divided into groups of countries based on their 2005 GDP per capita: high, high-middle, low-middle, and low income.[27]Countries remain in their 2005 income groups regardless of projected future economic growth; for example, China, with a per capita GDP (PPP) of $4,088 in 2005, is in the high-middle-income group throughout the period modeled, even though its per capita income is expected to exceed the upper bound for the high-middle group ($12,275) by 2025.

Figure 7: World GDP by incomegroup in 2005 and 2105, standard growth



Source: Author's calculation based on World Bank data for 2005 (World dataBank, (http://databank.worldbank.org/ddp/home.do?Step=3&id=4) and IEA (2010a)growth rates (see text for methodology), limited to countries used in the dataset for this report.

These "standard" 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[28] and the Potsdam Institute for Climate Impact Research's (PIK) 2010 five-model comparison,[29] and in the middle of the range used in the IPCC's SRES emissions scenarios[30] (see Table 2). The models with the fastest GDP growth in the EMF comparison show a slightly quicker pace of growth in India and China than do the standard projections. In the PIK comparison, even the model with the most rapid economic growth reaches a global GDP of only $446 trillion (PPP) in 2100. In the IPCC scenario with the fastest GDP growth, SRES A1T, 2100 GDP reaches $820 trillion (PPP), but with only 3.1-percent average annual growth in non-OECD countries, compared to 2.9 percent in the standard projection – a slim margin.

The models that assume even slower growth than IEA may do so for several reasons. First, in business-as-usual scenarios that prohibit emissions mitigation policy, integrated assessment models using a welfare

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have continued GDP growth at the *WEO 2010* 2020-2035 rate until their per capita output exceeds $20,000. All monetary values in this report are given in 2005 US dollars.

[27] Countries were assigned to their income categories according to the divisions between income groups for the World Bank's income-level classifications (http://data.worldbank.org/about/country-classifications/country-and-lending-groups); this categorization differs from that reported by the World Bank, which is based on incomes for an earlier year.One revision was made to the World Bank classification system: The upper bound for incomes in the low-income group was raised from $1,005 to $2,000. Note that here, and throughout the original socio-economic projections presented in this report, 2005 world totals are slightly lower than in the original data. A small number of countries have been removed from the dataset due to missing underlying data for GDP, population, or emissions.

[28] Energy Modeling Forum(2009). EMF model inputs are reported in 2005 US$ MER terms. The ratio of 2005 global GDP (PPP, 2005 US$) to 2005 global GDP (MER, 2005 US$) is 1.24. Increasing 2105 GDP (MER) estimates by this amount very likely overestimates GDP (PPP) – the ratio of PPP to MER GDP would decrease with income convergence.

[29] Edenhofer et al. (2010).

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

optimization framework – including several models in the EMF comparison – may react dynamically to future damages by reducing economic growth in order to reduce emissions, thereby lowering damages and increasing social welfare. This dynamic is at work in the DICE (Nordhaus 2008) and CRED welfare optimization models, in which global GDP in 2105 is $342 and $288 trillion (PPP) respectively.[31] Second, some scenarios, such the SRES B2 and A2, explicitly use slow economic growth assumptions as part of a suite of scenarios designed to represent a range of possible futures.

Overall, most climate-economics models assume that economic growth in developing countries (excluding China and India) will proceed at a pace similar to or slower than that used in the standard, extended *WEO 2010* projections.

Table 2: Socio-economic growth in climate-economics models

Model	2100/2105 Real GDP (trillions 2005 US$ PPP)	2100/2105 Real GDP Average Annual Growth	2100/2105 Population (billions)	2100/2105 Real GDP per capita (2005 US$ PPP)	2100/2105 Real GDP per capita 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%

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.[32]

[31] DICE 2007; see Nordhaus (2008). CRED v.1.3; see Ackerman, Stanton and Bueno (2011a). Both models report inputs in 2005 US$ MER terms. The ratio of 2005 global GDP (PPP, 2005 US$) to 2005 global GDP (MER, 2005 US$) is 1.24. Increasing 2105 GDP (MER) estimates by this amount very likely overestimates GDP (PPP) – the ratio of PPP to MER GDP would decrease with income convergence.

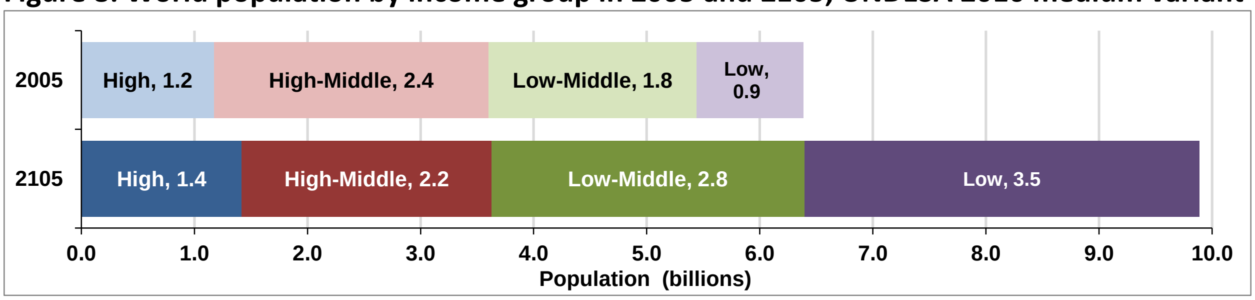
[32] In the EMF 12-model comparison (Energy Modeling Forum 2009), the FUND model's population projections for India are implausibly small and appear to have been recorded erroneously. This apparent error is excluded from the range presented above.

Forecasting population growth

The IEA's *WEO* publications and the PIK model comparison rely on the medium variant of the UN-DESA long-range projections of population growth by country; until their most recent installment in 2010, these projections had been changed only gradually over time.[33] In the EMF model comparison and SRES scenarios, population growth varies by model,with levels reaching from 8.7 to 10.6 billion in 2100 in the former – still very close to the UNDESA medium variant projections – and 7.0 to 15.1 billion in the latter (see Table 2). The SRES scenarios are designed to represent a broad spectrum of possible socio-economic futures and therefore include projections of slow, medium, and rapid population growth.[34]

In the UN-DESA's latest,2010 revision of*World Population Prospects*, the medium variant projects a global population in 2100 that is only slightly larger than that of the 2008 revision, but there have been important changes in the expected distribution of population increases across countries.[35] In the new projections, high and low-income countries have slightly faster population growth than previously expected, high-middle-income countries experience slower growth – including a 200 million person decrease in China's 2100 population – and low-middle-income countries experience much faster growth (see Figure 8). UN-DESA's revised 2010 median variant population projections are used throughout this report, except where explicitly stated.

Figure 8: World population by income group in 2005 and 2105, UNDESA 2010 medium variant



Source: World Population Prospects, 2010 Revision (UN-DESA 2011), limited to countries used in dataset for this report.

Forecasting GDP per capita growth

GDP per capita for the Without Carbon scenario is calculated as the ratio of standard real GDP (PPP) and national population for each country and year. The EMF and PIK model comparisons both project lower global average GDP per capita (see Table 2). 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 include a larger range of per capita income projections by design; the WEO-based projections shown in Figure 1 above roughly match the high end of the IPCC per capita income projections for OECD countries, but only approach the middle of the IPCC's projections for non-OECD countries.

Forecasting greenhouse gas emissions

In this report, greenhouse gas emissions are modeledas the product of real national GDP (PPP) and national emissions intensity (CO_2-e emissions per dollar of GDP). Base-year 2005 emissions are total greenhouse gas – including non-CO_2 gases – from CAIT (WRI 2010). Base-year emissions intensity is calculated as the ratio of 2005 emissions and 2005 GDP for each country in the dataset.

[33]UN-DESA (2011).

[34] SRES storylines: http://sedac.ciesin.columbia.edu/ddc/sres/.

[35] For a detailed explanation of the UN-DESA's new methodology, see UN-DESA (2011).

Emissions for future years are calculated using the "autonomous-intensity-reduction pattern" as follows:

$$Intensity_t = e^a Income_t^b$$

where t is the year, 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. 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.[36]

[36] EMF, PIK, and SRES emissions are reported in CO_2 (excluding non-CO_2 gases). We convert these values 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 2011a).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.