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# An Elaborated Proposal for Global Climate Policy Architecture: Specific Formulas and Emission Targets for All Countries in All Decades

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# *An Elaborated Proposal for Global Climate Policy Architecture:*

## *Specific Formulas and Emission Targets for All Countries in All Decades*


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**THE HARVARD PROJECT ON INTERNATIONAL CLIMATE AGREEMENTS**

The goal of the Harvard Project on International Climate Agreements is to help identify key design elements of a scientifically sound, economically rational, and politically pragmatic post-2012 international policy architecture for global climate change. It draws upon leading thinkers from academia, private industry, government, and non-governmental organizations from around the world to construct a small set of promising policy frameworks and then disseminate and discuss the design elements and frameworks with decision-makers. The Project is co-directed by Robert N. Stavins, Albert Pratt Professor of Business and Government, John F. Kennedy School of Government, Harvard University, and Joseph E. Aldy, Fellow, Resources for the Future. For more information, see the Project's website: http://belfercenter.ksg.harvard.edu/climate

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## *Abstract*

This paper offers a detailed plan to set quantitative national limits on emissions of greenhouse gases, building on the foundation of the Kyoto Protocol. It attempts to fill in the most serious gaps: the absence of targets extending as far as 2100, the absence of participation by the United States and developing countries, and the absence of reason to think that countries will abide by commitments. The plan elaborates on the idea of a framework of formulas that can assign quantitative limits across countries, one budget period at a time. Unlike other proposals for century-long paths of emission targets that are based purely on science (concentration goals) or economics (cost-benefit optimization), this plan is based partly on politics. Three political constraints are particularly important. (1) Developing countries are not asked to bear any cost in the early years. (2) Thereafter, they are not asked to make any sacrifice that is different in kind or degree than was made by those countries that went before them, with due allowance for differences in incomes. (3) No country will accept an ex ante target that costs it more than 1% of GDP in present value, or more than 5% of GDP in any single budget period, or will abide by it ex post. An announced target path that implies a future violation of these constraints will not be credible, and thus will not provide the necessary signals to firms today. Thus paper tries out specific values for the parameters in the formulas (parameters that govern the extent of progressivity and equity, and the speed with which latecomers must eventually catch up). The resulting target paths for emissions are run through the WITCH model. The outcome is reasonable, in terms of both carbon abatement and economic cost, even though the targets obey the political constraints.

***An Elaborated Proposal for Global Climate Policy Architecture:***

***Specific Formulas and Emission Targets for All Countries in All Decades***

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*The author would like especially to thank Valentina Bosetti of FEEM who produced, by means of the WITCH model, all the simulations of the effects of my formula-based proposals, thereby bringing hitherto-abstract ideas to life. I would like also to thank Joe Aldy and Robert Stavins for encouraging me to persist in this line of research and for comments.*

This paper offers a framework of formulas that produce precise numerical targets for the emissions of carbon dioxide in all regions in all decades of this century. The formulas are based pragmatically on what is possible politically. The reason for the political approach is the belief that many of the usual science- and economics-based paths are not dynamically consistent; that is, it is not credible that successor governments will be able to abide by the commitments that today's leaders make.

The formulas are driven by six political axioms:

1. The US will not commit to quantitative targets if China and other major developing countries do not commit to quantitative targets at the same time, due to concerns about economic "competitiveness" and carbon leakage.

2. China and other developing countries will not make sacrifices different in character from those made by richer countries that have gone before them.

3. In the longer run, no country can be rewarded for having "ramped up" its emissions high above the levels of 1990.

4. No country will agree to participate if its expected cost during the course of the 21$^{st}$ century (in present discounted value) is more than Y, which is for now set at Y=1% of GDP.

5. No country will abide by targets that cost it more than X in any particular period, for now set at X=5% of GDP.

6. If one major country drops out, others will become discouraged and the system may unravel.

The proposed targets are formulated in the following framework. Between now and 2050, the EU follows the path laid out in the January 2008 EC Directive, the US follows the path in the Lieberman legislation, and Japan, Australia and Korea follow statements that their own leaders have recently made. China, India and other countries *agree immediately to quantitative targets*, which in the first decade*s merely copy their BAU paths*, thereby precluding leakage. They are not expected to cut emissions below their BAU until they cross certain thresholds. When that time comes, their emission targets are determined as the outcome of a formula that incorporates three elements: a Progressive Cut Factor, a Latecomer Catch-up Factor, and a Gradual Equalization Factor, which are designed to persuade them that they are only being asked to do what is fair in light of actions already taken by others. In the second half of the century, the formula determining the industrialized countries' paths need not be more complicated than the gradual equalization factor. The glue that holds the agreement together is that every country is given reason to feel that it is only doing its fair share.

We show the resultant paths for emissions targets, permit trading, the price of carbon, GDP costs, and environmental effects, by means of the WITCH model. Overall economic costs, discounted (at 5%), average 0.24% of GDP. No country suffers a loss of more than 1% of GDP overall, or more than 5% of GDP in any given period, by participating. Concentrations level off at 500 ppm in the latter part of the century. The proposed next steps will aim for a target of 450 ppm and make the model stochastic.

## *The Problem*

There are by now many proposals for a post-Kyoto climate change regime. There are many even if the set is restricted to those that accept the Kyoto approach of quantitative limits on greenhouse gas emissions at the national level accompanied by international trade in emission permits. The Kyoto targets applied only to the budget period 2008-2012, which is now upon us, and only to a minority of countries (in theory the industrialized countries). The big task is to extend the quantitative targets to the remainder of the century and to other countries – especially the United States, China, and other developing countries.

Virtually all the existing proposals are based either on the science of the environment (e.g., driven by a constraint to cap global concentrations at 450 ppm in 2100) or on the economics of cost-benefit analysis (weighing the economic costs of aggressive short-term cuts against the long-term environmental benefits).[1] This paper proposes a path of emission targets for all countries and for the remainder of the decade that is intended to be more practical in that it is based on politics, rather than on science or economics alone.[2]

The industrialized countries did in 1997 agree to quantitative targets at Kyoto for the first budget period, so in some sense we know that it can be done. But the obstacles are enormous. For starters, most of the signers will probably miss their 2008-2012 targets, and of course the United States never even ratified. At multilateral venues such as the UNFCCC

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[1] An example of the science-based approach is Wigley (2007). An example of the cost-benefit-base approach is Nordhaus (1994, 2006).

[2] Aldy, Barrett, and Stavins (2003) and Victor (2004) review a number of existing proposals. Among the many others offering their own thoughts on post-Kyoto plans, either more or less detailed, are Aldy, Orszag, Stiglitz (2001), Barrett (2006) , Nordhaus (2006), and Olmstead and Stavins (2006).

in Bali (2007) and the G8 in Hokkaido (July 2008), world leaders have (just barely) been able to agree on a broad goal for long-term global emission levels: cutting total emissions in half by 2050. But these meetings have not come close to agreeing on who will cut how much, not to mention setting targets at a near enough horizon that the same national leaders are likely still to be alive when the time comes, let alone still in office. For this reason, the aggregate targets cannot be viewed as anything more than aspirational.

Nobody has ever come up with an enforcement mechanism that simultaneously has sufficient teeth and is acceptable to the member countries. Given the importance countries place on national sovereignty it is unlikely that this will change.[3] Hopes must instead rest on weak enforcement mechanisms such as the power of moral suasion and international opprobrium. It is safe to say that in the event of a clash between such weak enforcement mechanisms and the prospects of large economic loss for a particular country, aversion to the latter would win out.

## 1. Necessary Aspects of a Workable Successor to Kyoto

I have suggested six desirable attributes[4] that any proposed successor to Kyoto should deliver:

- ***More comprehensive participation --*** specifically getting US, China, and other developing counties, to join the system of quantitative emission targets.

- ***Efficiency --*** incorporating market-flexibility mechanisms such as international trade of permits and providing advanced signals to allow the private sector to plan ahead, to the extent compatible with the credibility of the signals.

- ***Dynamic consistency --*** addressing the problem that announcements for steep cuts in 2050 are not credible. The lack of credibility stems from two sources. First, it is known that today's leaders cannot bind their successors. Second, the projected failures to meet the Kyoto targets, or even to peak, and the shortage of short-term national targets after 2012, makes the lack of seriousness painfully obvious.

- ***Equity --*** regarding developing countries. They point out that: it was the industrialized countries, not they, who created the problem of Global Climate Change (having contributed only about 20 percent of the carbon dioxide that has accumulated in the atmosphere from industrial activity over the past 150 years though admittedly this is changing rapidly); they should not be asked to limit their economic development to pay for the solution; they, in contrast to richer countries, do not have the ability to pay for emissions abatement; and they consider the raising of their people's current standard of living the number one priority (including reducing local air and water pollution). They might reasonably demand quantitative targets at equal amounts per capita, on equity

[3] The possibility of trade sanctions is probably the only serious proposal of penalties for non-participation. But they are not currently being considered at the multilateral level.

[4] Frankel (2007). Similar lists are provided by Bowles and Sandalow (2001), Stewart and Weiner (2003), and others.

grounds, even waiving any claims to reparations for the disproportionate environmental damages that fall on them.

- ***Compliance --*** recognizing that no country will join a treaty if it entails tremendous economic sacrifice. Similarly, no country, if it has already joined the treaty, will continue to stay in during any given period if it means huge economic sacrifice, relative to dropping out, in that period.

- ***Robustness under uncertainty --*** recognizing that the warning that countries will not comply if it requires huge economic sacrifice applies not just to ex ante calculations based on today's expected future growth rates, but also ex post, when future growth rates and other uncertain economic and technological variables become known.

Unlike the Kyoto Protocol, my proposal seeks to bring all countries in, realistically, and to look far into the future. But we can not pretend to see with as fine a degree of resolution at the century-long horizon as at a 5- or 10-year horizon. Fixing precise numerical targets a century ahead is impractical. Rather, we need a century-long sequence of negotiations, fitting within a common institutional framework that builds confidence as it goes along. The framework must have enough continuity so that success at early rounds builds members' confidence in each other's compliance and in the fairness, viability and credibility of the process. Yet the framework must be flexible enough that it can accommodate the unpredictable fluctuations in economic growth, technology, climate, and political sentiment that will inevitable occur. Only by striking the right balance between continuity and flexibility can we hope that the framework would last a century or more.

An example of such a framework in another policy area is the post-war General Agreement on Tariffs and Trade, which gave us 50 years of successful rounds negotiating trade liberalization, culminating in the founding of the World Trade Organization. Nobody at the beginning could have predicted the precise magnitude or sequence of the cuts in various trade barriers, or what sectors or countries would be included. But the early stages of negotiation worked, and so confidence in the process built, more and more countries joined the club, and progressively more ambitious rounds of liberalization were achieved.

Another analogy would be with the process of European economic integration, culminating in the European Economic and Monetary Union. Despite ambitions for more comprehensive integration, nobody at the time of the founding of the European Coal and Steel Community, or the subsequent European Economic Community, could have forecast the speed, scope, magnitude, or country membership that this path would eventually take. The aim should be to do the same with the FCCC.

### 1.1 Political constraints

This paper declares the following six claims regarding political feasibility to be axiomatic.

1. The United States will not commit to quantitative targets if China and other major developing countries do not commit to quantitative targets at the same time, though this

2. China, India and other developing countries will not make sacrifices that they view as

    a. preventing them from industrializing,

    b. different in character from those made by richer countries who have gone before them,

    c. failing to recognize that richer countries should be prepared to make greater economic sacrifices to address the problem than poor countries (all the more so because their past emissions have created the problem), or

    d. failing to recognize that the rich countries have received an "unfair advantage" in being allowed to achieve current levels of emissions per capita far above those of the poor countries.

3. In the short run, emission cuts must be computed relative to current levels or BAU paths; otherwise the economic costs will be too great for the countries in question to accept. But in the longer run, no country can be rewarded for having "ramped up" its emissions far above the levels of 1990, the date agreed to at Rio and Kyoto. Fairness considerations aside, if post-1990 increases are permanently "grandfathered," then countries that have not yet agreed to cuts will have a strong incentive to ramp up emissions in the interval before they join.

4. No country will accept a path of targets that are expected to cost it more than Y per cent of GDP throughout 21st century (in present discounted value), for now set at Y=1.

5. No country will accept targets in any period that are expected to cost it more than X% of GDP or will in the future abide by such targets if it finds itself in such a position. In this paper, GDP losses are defined relative to what would happen if the country in question had never joined. An alternative would be to define GDP losses in a future period relative to what would happen if the country were to drop out in that period after decades of participation. For now, X% is set at 5% .

6. If one major country drops out, others will become discouraged and may also fail to meet their own targets, and the framework will unravel. If such unraveling in a future decade is foreseeable at the time that long-run commitments are made, then those commitments will not be credible from the start. If the commitments are not credible from the start, then firms, consumers, and researchers, will not base their current decisions to invest in plant and equipment, consumer durables or new technological possibilities on the carbon price that is implicit in the announced path. The reason for the political approach is the belief that many of the science- and economics-based paths are not dynamically consistent; that is, it is not credible that successor governments will be able to abide by the commitments that today's leaders make.

## 1.2 Squaring the Circle

Propositions 1 and 2 alone sound as though they add up to a hopeless Catch-22 problem. Nothing much can happen without the United States, the United States will not proceed unless China and other developing countries start at the same time, and China will not start until after the rich countries have gone first.

There is only one possible solution. At the same time that the US agrees to binding emission cuts in the manner of Kyoto, China and other developing countries agree to a path that immediately imposes on them binding emission targets, but the targets in the early years simply follow the BAU path. The idea of committing to only BAU targets in the early decades will provoke outrage from both environmentalists on one side and businesspeople on the other. But both sides might come to realize that this commitment is far more important than it sounds: it precludes the carbon leakage which absent such an agreement will undermine the environmental goal and it precludes the competitiveness losses which absent such an agreement will hurt carbon-intensive industries in the rich countries. And of course China would be crazy to agree to substantial actual cuts in the short term. Indeed China will also react with outrage at being asked to take on binding targets at the same time as the US. But it may come to realize it would actually gain from such an agreement, by acquiring the ability to sell emission permits (at top-quality market prices, as opposed to the lower prices they have received for projects under CDM or JI).

In the later decades, the proposed formulas do ask substantially more of the developing countries. But the formulas that drive the numerical target commitments obey notions of fairness, by asking for cuts that are no more than is analogous to the cuts made by others who have gone before them, with due allowance for their low levels of per capita income and emissions and for their baseline of rapid growth. I initially developed these ideas in Frankel (1999, 2005, 2007) and Aldy and Frankel (2004). I suggested that the formulas would depend on four or five variables: 1990 emissions, emissions in the year of the negotiation, population, income, and perhaps a few other special variables such as whether the country in question has coal or hydroelectric power (though the 1990 level of emissions conditional on per capita income can largely capture these special variables).

Here we narrow down the broad family of formulas to a more manageable set, and then put them into operation to produce specific numerical targets for all countries, for all five-year budget periods of the $21^{st}$ century. The formulas are made precise through the development of three factors: a short-term progressive factor, a late-comer catch-up factor, and a long-run equalization factor. The result is a set of actual numerical targets for all countries for the remainder of the century. These are then fed into the WITCH model, by Valentina Bosetti, to see the economic and environmental consequences. International trading plays an important role. The framework is flexible enough that one can tinker with a parameter here or there – for example if the economic cost borne by a particular country is deemed too high or the environmental progress deemed too low – without having to abandon the entire formulas framework.

## 2. Emission Targets for All Countries: The Rules to Guide the Formulas

All developing countries that have any ability to measure emissions would be asked to agree in 2010 to emission targets that do not exceed the business-as-usual (BAU) base path henceforth. The objective of getting them committed to these targets would be to forestall leakage and to limit the extent to which their firms can take business away from carbon-constrained competitors in the countries that have already agreed to targets below BAU under the Kyoto Protocol. (We expect that the developing countries would normally, if anything, receive payments for permits and thus emit less than the BAU base path.) Most of Africa would probably be exempted for some decades even from the BAU commitment, until it had better capacity to monitor emissions.

Countries are expected to agree to the next step, quantitative targets that entail specific cuts below BAU, when they cross certain thresholds. In the present simulations, we are generally guided by two thresholds: when their income exceeds $3000 per capita and/or their emissions per capita approach 1 ton or more. Given the inevitable lags in switching to a more carbon-conscious capital stock, this date of agreement naturally should predate by at least five years the budget period to which the target cuts apply. In the case of Kyoto the lead time was more than 10 years, from 1997 to 2010.

Emission targets are assigned in a way that is more sensitive to political realities than is typical of other proposed target paths which are constructed either to deliver a particular environmental goal or as the outcome of cost-benefit optimization. Call our approach "politics based," in order to distinguish it from the "science based" approaches that typically start from a specific constraint of concentration levels in 2100, and from the "economics based approaches" that typically start from full cost-benefit optimization.[5] Specifically, targets are based (i) on commitments that political leaders in various key countries have already proposed or adopted, or (ii) on formulas that tell the latecomer countries that the emission cuts they are asked to make are only their fair share, in that they correspond to the sacrifices that other countries before them have already made.

Finally comes the other important concession to practical realities: in the case of any simulation that in any period turns out to impose on any country an economic cost of more than X% of GDP (where X is initially taken to be 5%), it is assumed that this country drops out. Dropping out could be either explicit renunciation of the treaty or massive failure to meet the quantitative targets. For now, our assumption is that in any such scenario, other countries would follow by dropping out one by one, and the whole scheme would unravel.[6] The whole scheme would unravel much earlier if private actors rationally perceived that at some point in the future major players will face such high economic costs that compliance will break down. In this case the future carbon prices that are built into most models' paths

[5] It is uncomfortable to sail under a flag of political expediency rather than any of the more appealing flags: good science, good economics, cost-benefit optimization, or at least cost-minimization. But I think it is necessary, for reasons I have explained. (e.g., Frankel, 2007).

[6] A good topic for future extension of this research is to apply game theory, allowing some relatively less important countries to drop out without necessarily sinking the whole scheme. That is, if the economic damage to the remaining members arising from the defections, and the environmental damage, were not too great, the remaining countries might continue to participate rather than retaliate.

will lack credibility, private actors will not make investment decisions today based on them, and the effort will fail in the first period. Therefore, our approach to any scenario in which any major player suffers economic losses greater than X% would be to go back and adjust some of the parameters of the emission formulas, so that this is no longer the case.

We hope by these mechanisms to achieve political viability: non-negative economic gains in the early years for developing countries, thresholds to govern when cuts begin, average century costs of under 1% of GDP per annum, and protection for every country against loss in any period as large as 5% of GDP. Only by achieving political viability are announcements of future cuts credible. Only the credibility of announced future cuts will send firms the long-term price signals and incentives needed to guide investment decisions today.

### 2.1 Guidelines from Existing National Leaders' Announced Policies

Our model will produce specific numbers for every fifth year: 2012, 2017, 2022, etc. For 5-year budget periods, such as the Kyoto period 2088-2012, computations are based on the average of the starting year and ending year.

**The EU**: The emissions target for 2008-2012 was agreed at Kyoto: 8% below 1990 levels. In the second period, 2015-2020 -- for simplicity 2017 – the EU's target is the one that Brussels announced in January 2008: 20% below 1990 levels. On the one hand, as with the other targets publicly supported by politicians in Europe and elsewhere, skepticism is appropriate regarding the sincerity of their willingness to make the sacrifices necessary to achieve the targets. (It is not clear that even Europe will meet its Kyoto targets. Perhaps it can do so through by covering its shortfall with purchases of emission permits from other countries.) On the other hand, however, the commitment to this number was not conditional on other countries joining in. Indeed the EU has said it would cut 30% below 1990 if other countries joined in. So in this sense are being conservative in choosing the 20% target. For the third period, 2022-2027, and thereafter up to the 8$^{th}$ period, 2048-2052, the path progresses to 50% cuts below 1990 levels by equal increments: 25% below, 30%, 35%, 40%, 45%, and 50%.

**Japan, Canada, and New Zealand:** These three countries are assigned the Kyoto goal of 6% below 1990 levels. Of all ratifiers, Canada is probably the farthest from achieving its Kyoto goal.[7] But Japan dominates this country grouping in size. We assume that by 2010 the United States has taken genuine measures, which helps motivate these three to get more serious than they have been to date. In a small concession to realism, we assume that they do not hit the numerical target until 2012 (versus hitting it on average over the 2008-2012 budget period).[8]

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7 The current government's plan calls for reducing Canadian emissions in 2020 by 20 percent below 2006 levels (which translates to 2.7 percent below 1990 levels) and in 2050 by 60-70 percent. ("FACTBOX – Greenhouse gas curbs from Australia to India," Sept. 5, 2008, Reuters. www.alertnet.org/thenews/newsdesk/L5649578.htm.)

8 In 2007, Japanese Prime Minister Shinzo Abe supported an initiative to half global emissions by 2050. *FT* May 25. But ahead of the 2008 G8 Summit, Japan declined to match the EU's commitment to cut its emissions 20 per cent by 2020 [*FT*, April 24, 2008, p.3].

Japan's then-Prime Minister, Yasuo Fukuda, on June 9, 2008, announced a decision to cut Japanese emissions 60-80% by mid-century.[9] Similarly, in July, Australian Prime Minister Kevin Rudd announced plans to cut emissions to 60% below 2000 levels by 2050.[10] We interpret these targets as cuts of 10% every five years between 2010 and 2050. We compute them logarithmically. The cumulative cuts are 80% in logarithmic terms, or 51% in absolute terms (i.e., to .49 of the year-2010 emissions level).

**The United States:** A series of bills to cap greenhouse gas emissions were proposed in Congress in 2007 and early 2008. It is not improbable that some version of such legislation might pass by 2010.

The Bingaman-Specter bill would have reduce emissions to 2006 levels by 2020, and 1990 levels by 2030, but with a sort of safety-valve carbon price cap. The Lieberman-Warner bill was more aggressive.[11] True, it would have addressed only the electric power generation, heavy industry and transportation fuel sectors; but they constitute 75%-87% of the economy. The total cap would have begun by reducing emissions in 2012 below 2005 levels and would then have tightened gradually each year thereafter, reaching by the year 2050 emission targets that are equal to .3 of 2012 levels, i.e., 70% below.[12] If such a bill were not passed until 2010 or so, the goal of achieving 2005 levels by 2012 (let alone 4% below) would for all practical purposes be impossible. The sponsors would have to adjust 2012 to BAU levels, which are 39% above 1990 levels, or 33% logarithmically (i.e., 1990 was 28 % below 2012 BAU), so the 2050 target would be 42% below 1990 levels.[13] A slightly revised "manager's" version of the bill (Lieberman-Warner-Pelosi) earned strong congressional support in June 2008. It did not receive a large enough majority to become law, but the vote was widely considered an important step forward politically for the activist camp. It was presumed that a new bill in the next session would probably look similar and, with a new president, would have better chances of success.[14]

If taken at face value, with 2012 emissions returned to 2005 levels or lower, then the Lieberman-Warner targets would shave off another 13% from the target path, so that the

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[9] "Japan Pledges Big Cut in Emissions," *FT* June 10, 2008 p.6;

[10] A July 16, 2008, government "green paper," *Carbon Pollution Reduction Scheme*, reported details on implementation by domestic cap-and-trade. Rudd's initiative appears to have domestic political support. *The Economist*, July 26, 2008, p.52.

[11] S. 2191: America's Climate Security Act of 2007

[12] Section 1201, pages 30-32. [The percentage is measured non-logarithmically.]

[13] e.g.,http://theclimategroup.org/index.php/news_and_events/news_and_comment/carbon_trading_high_hopes_for_lieberman_warner/ [The number is 54 percent, measured logarithmically. This is the preferred way of defining percentage changes, because a 50% increase in emissions followed by a 50% decrease gets you back where you started from. Logs are too technical for non-specialist audiences. But measuring changes non-logarithmically has the undesirable property that a 50% increase (to 1.50) followed by a 50% decrease (to 0.75) does not get you back to your starting point (1.00).]

[14] This paper was written during the 2008 US presidential election campaign, in which both major presidential candidates supported measures along the lines of recent congressional bills that would limit emissions. John McCain advocated a 2050 target of 60 % reduction below 1990 levels, or 66 % below 2005 levels, close to Lieberman-Warner. *Washington Post*, May 13, 2008, p. A14; and *FT*, May 13, 2008, p.4. Barack Obama set a more aggressive target of 80 % reduction below 1990 levels – *FT* , Oct. 17, 2008.

2050 level would be 55% below 1990 levels.[15] There are four respects in which it might be naïve to accept these political aspirations at face value. First, it is not realistic to think that the United States could go from the steady emission growth rates of 1990-2007 (1.4% per year) to immediate rapid cuts, without *passing through an inter-mediate phase* of slowing, and then peaking or plateauing, before reversing. Second is the question of the other 20% of the economy; most likely it would not undergo proportionate cuts. Third is the point that many voters and politicians who support such legislation don't support the measures that would be needed to attain the targets (at lowest cost), namely raising the price of fossil fuels through such measures as a carbon tax or tradable permits. Fourth, this reduction is somewhat more aggressive than Europe's goal, measured relative to 1990 – and implies a much more aggressive rate of decrease than Europe's over the period 2012-2050. So far, American support for serious action has lagged far behind Europe's.

On the other hand, if China and other developing countries accept quantitative targets, as foreseen under this plan, this will boost domestic American support for tough action. In addition, one could argue that there is more "fat" in US emissions, so it should be easier to cut than Europe or Japan's. The terminal level of emissions in 2050 under the formula would still probably be substantially higher than Europe's, relative to population or GDP.

We assume that the emissions growth rate is cut in half during 2008-2012, to 0.7% per year or 3 ½ % cumulatively, reaching 31.5% above 1990 levels in 2012,[16] and turns flat at this level during 2012-2017. *Then* we implement the rest of the Lieberman-Warner formula: attaining in 2050 a level that is 67% below 1990 levels. Using our postponed base this is 98.5% below 2012 levels, logarithmically. Spread over 38 years, this is a cut of 2.6% per year or 13% every five years (which is a more aggressive rate of reduction than Lieberman-Warner).

Until recently it looked very unlikely that any "non Annex 1" countries would consider taking on serious cuts below a BAU growth path within the next decade. But in March 2008, the new president of South Korea, Myung-bak Lee, "tabled a plan to cap emissions at current levels over the first Kyoto period."[17] This is an extraordinarily ambitious target in light of Korea's economic growth rate; He also "vowed his country would slash emissions in half by 2050,"[18] like the industrialized countries – of which Korea is now one. emissions have risen 90 percent since 1990 and it is hard to imagine applying the brakes so sharply as to switch instantly from 5% annual growth in emissions to zero.[19] Perhaps President Lee thinks he can offset growth in South Korean emissions by paying North Korea to reforest. We choose to interpret the Korean plan to flatten emissions as

[15] That is 67% logarithmically. Or a cut of about 62% according to J.R. Pegg, *Environmental News Service*, October 2007.

[16] That is, 27 % logarithmically.

[17] "South Korea Plans to Cap Emissions," *International Herald Tribune*, March 21, 2008.

[18] "South Korea: Developing Countries Move Toward Targets," Lisa Friedman, *ClimateWire*, Oct. 3, 2008.

[19] This did not stop some environmental groups from criticizing the plan as not sufficiently ambitious. Such criticisms may give political leaders second thoughts about announcing any specific measures at all, as opposed to sticking with banal generalities.

covering a period stretched out over the next 14 years, so that in 2022 the level of emissions is the same as in 2007.[20]

Meanwhile. South Africa has evidently proposed that its emissions would peak by 2025 and decline by 2030.[21] We don't explicitly incorporate this target into our numerical exercise (because the WITCH model aggregates South Africa together with the rest of Sub-Saharan Africa, which is too poor to take on such commitments). But the South African statement makes more credible the idea that developing countries might at least agree to BAU targets very soon, and that a (richer) country like South Korea might seriously commit to peak by 2022.

Getting China to agree to binding commitments is the *sine qua non* of any successful post-Kyoto plan. Evidently China has announced plans to start cutting greenhouse emissions in 2030 (presumably that means relative to BAU, rather than in absolute terms).[22] Of course 2030 is much later than industrialized countries would like. The country is expected to cross the threshold of 1 ton of emissions per capita around 2014 and the threshold of $3000 in income per capita by 2022. (A five or ten-year lag would point to a first-cuts budget period around 2024-2027.) But persuading Beijing to move the 2030 date up by 5 years is not as critical as persuading it to accept some quantitative target in 2010, even if only BAU. The reason is that if China does not adopt some binding target in the near term, the US and most developing countries won't join, and then the entire enterprise will be undone.

The question then becomes how to determine the magnitude of China's cuts in its first budget period -- that is, the first in which it is asked to make cuts below BAU; how to determine Korea's cuts in its second budget period; and similarly for everyone else. (The other regions are Latin America -- which logically should act after Korea but before China in light of its stage of development -- Russia, and Africa.) Our general guiding principle is to ask countries only to do what is analogous to what has been done by others who have gone before them. To put this general principle into practice, we apply three factors.

### 2.2 Formula Guidelines Ask Developing Countries for "Fair" Targets Analogous to Those Who Have Gone Before

We call the first element in the formula the **Progressivity Factor**. It is based on the pattern of cuts across countries that was allocated at Kyoto, relative to BAU, as a function of income per capita. This pattern is illustrated in Figure 1, which comes from the data as they were reported at that time. Other things equal, richer countries are asked to make more

[20] One should note, first, that President Lee came to office setting a variety of ambitious goals beyond his power to bring about, especially for economic growth, and second that his popularity quickly plummeted to the extent that at the time of writing his ability to persuade his countrymen to take serious measures was in question.

[21] Lisa Friedman, *ClimateWire*, Oct. 3, 2008, op cit.. It should be noted that statements from Environmental or Foreign Ministries, if they have not been vetted by Finance or Economics Ministries, let alone issued by heads of government or approved by parliaments, do not carry a lot of weight. An example would be Argentina's announcement of a target in 1998.

[22] This was China's position in talks near Berlin with 5 big emerging nations (China, India, South Africa, Brazil and Mexico), ahead of the June 2007 G8 summit in Germany, according to Germany's environment minister [ *FT* 3/12/07].

severe cuts relative to BAU, the status quo from which they are departing in the first period. Specifically, each 1% difference in income per capita measured relative to EU income in 1997 adds to target cuts another 0.14% greater emissions abatement from BAU measured relative to the EU cuts agreed at Kyoto. Normally, at least in their first budget periods, countries' incomes will be below what the Europeans had in 1997, so that this factor dictates milder cuts relative to BAU than Europe's. In fact they are likely to be "growth paths:" actual increases relative to the preceding periods. The formula is: country cuts vs. BAU = EU's 2008 commitment + .14 * log (country income/cap / EU 2007 income/cap).

The second element in the formula we call the **Latecomer Catch-up Factor**. The latecomers are defined as those that have not ratified Kyoto or for whom Kyoto did not set quantitative targets. (Perhaps it should also include those like Canada who have ratified it but on current trends are not expected to meet the goal.) These countries should not be rewarded by permanently re-basing their targets to their higher levels. Aside from notions of fairness, such re-basing would give all latecomers an incentive to ramp up their emissions before signing on to cuts, or at a minimum would undercut any socially-conscious incentives they might otherwise feel to reduce emissions unilaterally in decades before they have joined the system. Thus the Latecomer Catch-up factor gradually closes the gap between the starting point of the latecomers and 1990 emission levels. It is parameterized according to the numbers implicit in the Lieberman proposal to bring the US to 70% below 1990 levels by 2050 and the Lee proposal to flatten Korea's emissions over a period beginning in 2008. In other words, countries are asked to move gradually in the direction of 1990 in the same way that the United States and Korea under the plan will have done before them.

The third element is the **Equalization Factor**. Even though developing countries have been given the benefit of starting to cut emissions later than rich countries, and making milder cuts, they still will complain that it is the rich countries who originally created an environmental problem for which the poor disproportionately bear the costs, rather than the other way around. Such complaints are not unreasonable. If we stopped with the first three factors, the richer countries would be left the permanent right to emit more greenhouse gases, in perpetuity, which seems unfair. In the short run, the unfairness of the gap in per capita targets is simply not going to alter the outcome. The poor countries will have to live with it. Calls for the rich countries to cut emissions per capita rapidly, in the direction of poor-country levels, ignore that the economic costs would be so astronomical that no rich country would ever agree to it. The same goes for calls for massive transfer payments from the rich to the poor (á la G-77). But when one is talking about a lead time of 50 to 100 years, the situation changes. With time to adjust, the economic costs are not as impossibly high, and it is reasonable to ask rich countries to bear their full share of the burden.

Accordingly, during each decade of the second half of the century, the formula will include an equity factor that moves emissions per capita in each country a small step in the direction of the global average of emissions per capita. This means downward in the case of the rich countries and upward in the case of the poor countries. Asymptotically the repeated application of this factor would eventually leave all countries with equal emissions per capita, although the national targets are not expected to converge fully by 2100.

## 2.3 The Numerical Emission Target: Paths that Follow from the Formulas

Table 1, at the end of the paper, reports the emissions targets produced by the formulas for each of 11 geographical regions, for every period between now and the end of the century. We express the emission targets in several terms:

- in absolute tons (which is what ultimately matters for determining the economic and environmental effects)
- in per capita terms (which is necessary for considering any issues of cross-country distribution of burden)
- relative to the BAU path (Business as Usual), which is important for evaluating the sacrifice asked of a new joiner in the early decades, and
- relative to 1990 levels, which is the phrasing of Kyoto, and in our framework remains relevant in the form of the Latecomer Catch-up term.

The 11 regions are:

| | |
|---|---|
| EUROPE = Old Europe + | New Europe |
| US = The United States | KOSAU = Korea + South Africa + Australia (3 coal-users) |
| CAJAZ = Canada, Japan + New Zealand | TE = Russia and other Transition Economies |
| MENA = Middle East + North Africa | SSA = Sub-Saharan Africa |
| SASIA= India and the rest of South Asia | CHINA = PRC |
| EASIA = Smaller countries of East Asia | LACA = Latin America + the Caribbean |

The United States, even more than other rich countries, is currently conspicuous by its high level of emissions per capita. But the target path peaks after 2010, and begins to decline. All the rich regions peak by 2015, and then start to decline. Figure 3 reports aggregate OECD targets. It also shows actual emissions, which decline more gradually than the targets through 2045 because over 1 Gt of carbon permits are purchased on the world market (out of roughly 4). Of the non-rich countries, the Transition Economies, MENA, China and Latin America all peak in 2040 . Sub-Saharan Africa and the smaller East Asian economies all remain at very low levels throughout the century. Figure 4 shows that among non-OECD countries overall, both the targeted caps and actual emissions peak in 2040, with the latter substantially below the former. In other words the poor countries sell emission permits to the rest.

Total world emissions peak in 2045, at just over 10 Gt, and then decline rather rapidly, falling below 5 Gt in 2090 (Figure 5). Thanks to the post-2050 equalization formula, emissions per capita converge nicely in the long run, below one ton per capita toward the end of the century, as Figure 2 shows.

## 3. Economic and Environmental Consequences of the Proposed Targets, According to the WITCH model

To estimate the economic and environmental implications of these targets is a complex task. There are many fine models out there, but not all are able or eager to put my whims into action.[23] I was fortunate to link up with the WITCH model of FEEM (Fondazione Eni Enrico Mattei, in Milan), as applied by Valentina Bosetti.

WITCH (www.feem-web.it/witch) is an energy-economy-climate model developed by the climate change modeling group at FEEM. The model has been used extensively in the past three years for analysis of the economics of climate change policies. WITCH is a hybrid top-down economic model with energy sector disaggregation. It features technological change via both experience and innovation processes. Countries are grouped in 12 regions that cover the world and that strategically interact following a game theoretic set-up. The WITCH model and detailed structure are described in Bosetti et al (2006) and Bosetti, Massetti and Tavoni (2007).

Modelers' original baselines have been disrupted by such developments as the stronger-than-expected growth in Chinese energy demand and completely unexpected spike in oil prices in the course of the current decade. WITCH has been updated with more recent data and revised estimates for future projection of the main drivers (population, GDP, fuel prices, energy technologies data). The base calibration year has been set at 2005, for which data on socio-economic, energy and environmental variables are now available. (Bosetti, Carraro, Sgobbi, and Tavoni, 2008.)

### 3.1 Economic effects

While economists trained in cost-benefit analysis tend to focus on economic costs expressed as a percentage of GDP, the politically attuned tend to focus more on the predicted impact on the price of carbon, and thereby on the prices of gasoline, home heating oil, and electric power.[24]

In the WITCH simulations of the effects of our plan, the world price of carbon dioxide reaches $30 a ton in 2020, as Figure 6 shows. It is then flat for a few decades, as a consequence of the assumption that major developing countries do not take on major cuts in emissions before 2040. (The price even dips a bit in 2035, an undesirable feature.) But it climbs rapidly thereafter, as the formula targets begin to bite for developing countries.

[23] A few of many examples of models applied to specific proposed emission paths to derive the economic and environmental effects are Edmonds, Pitcher, Barns, Baron, and Wise (1992), Edmonds, Kim, McCracken, Sands, and Wise (1997), Hammett (1999), Manne, Mendelsohn, and Richels (1995), Manne and Richels (1997), McKibbin and Wilcoxen (2006), and Nordhaus (1994, 2008). Weyant (2001) explains and compares models.

[24] Frankel (1998). This attitude may seem irrational to an economist; after all, price effects could in some cases be purely redistributional. But the public is probably correct in its instinct that predicted price effects are more reliable indicators of the degree of economic dislocation than GDP losses, which are subject to larger modeling uncertainty. Furthermore distributional effects are key for politics.

By 2050 it has surpassed $100 per ton of CO2, Only toward the end of the century does it level off, at almost $700 per ton of CO2.

Figure 7 illustrates by regions the economic costs of the path, expressed as a fraction of GDP. Most regions sustain economic losses that are small in the first half of the century – under 1% of GDP -- but that rise toward the end of the century. Given a positive rate of time discount, this is a good outcome. No region in any period goes over our self-imposed threshold of 5% of GDP. The present discounted values of the costs by country are reported in Table 2. No country is asked to pay costs that are expected exceed 1% of GDP over the century. (All economic effects are gross of environmental benefits. No attempt is made to estimate those benefits or net them out.)

In this scenario, the highest decade costs are borne by China, just toward the end of the century, reaching 4.1% of GDP in 2100. (On the other hand the PDV of China's cost is less than those of the United States and several other regions.) The maximum GDP loss for the United States is 1.9%, and for the EU 1.4%, both occurring around 2080. These estimated economic costs of participation are overestimated, however, and increasingly so in the later decades, if the alternative to staying in the treaty one more decade is dropping out, after 7 or 8 decades of participation. The reason is that the country will have already substantially altered its capital stock and economic structure in a carbon-friendly direction. The economic costs reported in the simulations and graphs treat the alternative as never having joined the treaty in the first place.

Three regions – sub-Saharan Africa, the smaller countries of East Asia, and (to a smaller extent) the Indian sub-continent – actually register substantial gains toward the end of the century, the benefits of being able to sell permits to richer countries. (Perhaps some tinkering with these countries' targets in the latter half of the century is called for.) Aggregating across regions worldwide, and discounting to present value with a discount rate of 5%, total economic costs come to 0.24% of annual Gross World Product.

### 3.2 Environmental effects

The outcome in terms of cumulative emissions of greenhouse gases is close to those of models that build in environmental effects or scientist-based constraints, even though no such inputs were used here . Concentrations stabilize at 500 ppm CO2 in the last quarter of the century.

Correspondingly, temperature is projected to hit 3 degrees Celsius above pre-industrial levels at the end of the century, as oppose to almost 4 degrees under the Business as Usual trajectory. The relationship between concentrations and temperature is however highly uncertain and depends on the assumptions made about climate sensitivity. For this reason both figures are reported. (Most scientists and environmentalists prefer objectives that are substantially more ambitious)

## 4. Conclusion

The results reported here are only the beginning. Several particular extensions are high priority for future research.

**4.1 Directions for Future Research**

First, we could tinker slightly with the parameters. We could aim to tighten up slightly on emissions targets toward the end of the century from the transition economies and the smaller countries of East Asia, so that they do not benefit so much. We could calibrate the adjustment to hit exactly a 2100 concentration target of 500 ppm, thus facilitating comparisons with others' research. Or we could loosen up on the emission targets for China and the United States, to reduce their economic costs. A high priority is to facilitate comparisons by tightening some parameters to see what it would take to hit a 2100 concentration level of 450 ppm or 2 degrees centigrade, which are the goals of the climate change community. In the other direction, we could calibrate the adjustment so as to hit a 2100 target of 550 ppm, again facilitating comparisons.

Second, we could design an algorithm to search over values of some of the key parameters in such a way as to attain the same environmental goal – say 500 ppm – with minimum economic cost. To continue resting on the political foundation: the objective could be to minimize the GDP loss for any country in any period, so as to minimize the incentive for any country to drop out. Or we could declare that we have already specified enough political constraints (e.g., no period loss above 5% of GDP), and proceed to do a cost-benefit optimization exercise subject to those constraints.

Third, we could compare our proposed set of emissions paths to those being used in exercises by other Integrated Assessment Modelers. Presumably we could identify countries and periods in the others' paths where we believe the agreement is unlikely to hold up because the targets were not designed to cap economic costs for each country.

Fourth, we could eventually design a user-friendly "game" that anybody could play, choosing different emissions targets for various countries over time, and discovering how easy it is either to wreck the economy or to wreck the environment. It would be a learning tool, hypothetically for policy-makers themselves. Someone who believes that the GHG abatement in the targets presented in this paper is insufficiently ambitious, or someone who believes that the burden falling on his or her own country is too high would be invited to try out alternatives for themselves. Perhaps a character from an adversely impacted country would pop up on the screen and explain to the user how many millions of his compatriots have been plunged into dire poverty by the user's policy choices.

Fifth, we could implement constraints on international trading, along the lines that the Europeans have sometimes discussed. Such constraints can arise either from a worldview in which it is considered not ethical to pay others to take one's medicine, or a more cynical worldview where it is considered that international transfers will only line the pockets of corrupt leaders The constraints could take the form of restrictions that a country cannot satisfy more than Y% of its emissions by international permit purchases. Or they could take the form of restrictions that only countries with a score in international governance ratings over a particular threshold can sell permits, or only those who promise to use the funds for green projects, or only those that have a track record of demonstrably meeting their commitments under the treaty.

The sixth possible extension is the most important step intellectually: to introduce uncertainty, especially in the form of stochastic growth processes. The variance of the GDP forecasts at various horizons would be drawn from historical data. We would adduce the consequences of our rule that if any country finds in any period that ex post it loses more than 5% of GDP by staying in, even though this had not been the expectation ex ante, that country will drop out. At a first pass, we could keep the assumption that if one country pulls out, the entire system falls apart. The goal would then be to design a version of the formulas framework that minimized the probability of collapse.

A more sophisticated approach would be to allow the possibility that the system could withstand the loss of one or two members. We would try to account for the effect of dropouts on remaining members, with some sort of application of game theory. Ideally we would also try to account for the effect of possible future breakdown on expectations of firms deciding long-term investments from the start. Of course we could try other values of X besides 5%. One hypothesis to be explored is that, once one allows for political constraints, X determines the stringency of the emissions path even more than does the discount rate in cost-benefit analysis.[25]

The ultimate objective in making the model stochastic is to seek modifications of the policy framework that are robust, that protect against inadvertent stringency to individual countries, on the one hand, or inadvertent "hot air" on the other hand.. Three possible modifications are promising. First, we could allow some degree of re-basing based on unexpected evolution in population and income. (Not in emissions themselves, for to do so would be to introduce moral hazard.) Second, when each decade's target is set, it is indexed to GDP within that budget period. Perhaps the constant of proportionality in the indexation formula would equal 1, in which case it becomes an efficiency target, expressed in carbon emissions per GDP. This approach would be much less vulnerable to within-decade uncertainty.[26] The third possible policy feature to achieve greater robustness is the economists' favorite: an escape clause or safety valve, perhaps with a floor on the price of carbon in addition to the usual ceiling.

### 4.2 A Politically Credible Framework

Our results suggest that the feasible set of emission target paths is far more constrained than modelers treat it as. The lofty debates over the optimal discount rate or fair allocation rules might be fairly irrelevant **:** for many discount rates or cross-country allocations, the agreement would at some point during the century collapse altogether, because it imposes unacceptably high costs on some countries, relative to defecting -- which would raise the costs on those who remain in, thereby snow-balling. A century-long path

[25] Notwithstanding that relative small disagreements over the discount rate can mean the difference in cost-benefit analyses between "do nothing" and "do everything." Arrow, Stiglitz, et al (2995), Cline (1992), Dasgupta (2001), Newell, Richard, and Pizer (2001), and Stern (2007).
[26] Lutter (2000).

that entailed a collapse of the agreement in a few decades would not be believed today, and thus would evoke fend actual steps toward emissions-reduction today.

The traditional Integrated Assessment result is that an economically optimal path entails relatively small increases in the price of carbon in the first half of the century and much steeper ones later. It is interesting that a similar result emerges here purely from political considerations, with no direct input from cost/benefit calculation.[27] The broad similarity of the results for the aggregate path does not mean that the difference in approaches does not matter. The framework here specifies the allocations of emission targets across countries in such a way that every country is given reason to feel that it is only doing its fair share. Without such a framework for allocation, announcements of distant future goals are not credible and so will not have the desired effects. Furthermore, the framework – a decade-by-decade sequence of emission targets each determined as an outcome of a few principles and formulas – is flexible enough that it can accommodate (by small parameter changes) major changes in circumstances during the course of the century.

[27] Integrated Assessment Models (IAMs) tend to give the result that the optimal path entails shallow cuts in earlier years, deeper cuts coming only later, because (for example) scrapping coal-fired power plants today is costly, while credibly announcing stringent goals 50 years from now would be cheaper, by giving time to plan ahead. Benefit-cost maximization, though obviously right in theory, is not the most useful logic in practice, because of uncertainty by modelers over the discount rate and uncertainty by agents over the credibility of such announcements.

EUROPE = Old Europe + New Europe
CAJAZ = Canada, Japan + New Zealand
MENA = Middle East + North Africa
SASIA= India and the rest of South Asia
EASIA = Smaller countries of East Asia
KOSAU = Korea, South Africa + Australia (all coal-users)
TE = Russia and other Transition Economies
SSA = Sub-Saharan Africa
CHINA = PRC
LACA = Latin America + the Caribbean

## Table 1: Emission Targets for each of 11 regions, according to the formulas

| Target Absolute (tons C, thousand millions) | | USA | EUROPE | KOSAU | CAJAZ | TE |
|---|---|---|---|---|---|---|
| 2005 | 1 | unlimited | unlimited | unlimited | unlimited | Unlimited |
| 2010 | 2 | 1.87591 | 1.11405 | 0.39768 | 0.57841 | 0.83501 |
| 2015 | 3 | 1.94157 | 1.03870 | 0.42442 | 0.55573 | 0.67594 |
| 2020 | 4 | 1.30761 | 0.96336 | 0.44852 | 0.37796 | 0.66297 |
| 2025 | 5 | 1.20331 | 0.86043 | 0.39051 | 0.33085 | 0.65000 |
| 2030 | 6 | 1.16946 | 0.76932 | 0.34938 | 0.28811 | 0.62161 |
| 2035 | 7 | 0.99089 | 0.67646 | 0.30825 | 0.24575 | 0.59321 |
| 2040 | 8 | 0.87106 | 0.58305 | 0.29015 | 0.20451 | 0.52161 |
| 2045 | 9 | 0.70636 | 0.49000 | 0.27206 | 0.16478 | 0.45000 |
| 2050 | 10 | 0.61066 | 0.39713 | 0.23973 | 0.12656 | 0.43857 |
| 2055 | 11 | 0.46374 | 0.31752 | 0.20776 | 0.09037 | 0.42715 |
| 2060 | 12 | 0.33833 | 0.25053 | 0.17718 | 0.06115 | 0.39760 |
| 2065 | 13 | 0.23476 | 0.19564 | 0.14718 | 0.03834 | 0.36806 |
| 2070 | 14 | 0.15059 | 0.15149 | 0.11754 | 0.02093 | 0.34270 |
| 2075 | 15 | 0.07546 | 0.11360 | 0.10205 | 0.00651 | 0.31734 |
| 2080 | 16 | 0.01309 | 0.08293 | 0.08415 | 0.00651 | 0.29465 |
| 2085 | 17 | 0.01309 | 0.05875 | 0.06874 | 0.00651 | 0.27196 |
| 2090 | 18 | 0.01309 | 0.04350 | 0.05546 | 0.00651 | 0.27196 |
| 2095 | 19 | 0.01309 | 0.03218 | 0.04413 | 0.00651 | 0.27196 |
| 2100 | 20 | 0.01309 | 0.02389 | 0.03443 | 0.00651 | 0.27196 |

| Target per capita EMI/cap (ton C) | USA | EUROPE | KOSAU | CAJAZ | TE |
|---|---|---|---|---|---|
| 2005 | | | | | |
| 2010 | 5.959875 | 2.19314 | 3.33309 | 3.488708 | 2.361965 |
| 2015 | 5.9000597 | 2.034108 | 3.485317 | 3.342658 | 1.90879 |
| 2020 | 3.8165856 | 1.88247 | 3.619444 | 2.28108 | 1.874489 |
| 2025 | 3.3896319 | 1.682114 | 3.106391 | 2.013828 | 1.846711 |
| 2030 | 3.1930277 | 1.508378 | 2.752488 | 1.775699 | 1.780967 |
| 2035 | 2.6314473 | 1.333237 | 2.418626 | 1.538616 | 1.717625 |
| 2040 | 2.2570115 | 1.15741 | 2.278319 | 1.304175 | 1.529284 |
| 2045 | 1.7905777 | 0.981416 | 2.14553 | 1.072331 | 1.3394 |
| 2050 | 1.5172552 | 0.803789 | 1.903243 | 0.841058 | 1.329423 |
| 2055 | 1.1323618 | 0.649746 | 1.660727 | 0.612362 | 1.316717 |
| 2060 | 0.8140531 | 0.518629 | 1.426595 | 0.421951 | 1.245583 |
| 2065 | 0.5580811 | 0.409995 | 1.194543 | 0.269141 | 1.17121 |
| 2070 | 0.3546375 | 0.321607 | 0.962386 | 0.14932 | 1.107318 |
| 2075 | 0.1765108 | 0.244518 | 0.843796 | 0.047163 | 1.040919 |
| 2080 | 0.0305026 | 0.181107 | 0.703458 | 0.047871 | 0.980961 |
| 2085 | 0.0304601 | 0.130269 | 0.581589 | 0.04856 | 0.918848 |

| | | | | | |
|---|---|---|---|---|---|
| 2090 | 0.0304991 | 0.097993 | 0.475492 | 0.049227 | 0.932359 |
| 2095 | 0.0306198 | 0.073718 | 0.383792 | 0.049867 | 0.945926 |
| 2100 | 0.0308232 | 0.055677 | 0.30408 | 0.050471 | 0.959493 |

| Target relative to 1990 | USA | EUROPE | KOSAU | CAJAZ | TE |
|---|---|---|---|---|---|
| 2005 | | | | | |
| 2010 | 1.2991066 | 0.923116 | 1.711276 | 1.296883 | 0.881742 |
| 2015 | 1.3445754 | 0.860684 | 1.826342 | 1.246032 | 0.713767 |
| 2020 | 0.9055473 | 0.798252 | 1.930048 | 0.847438 | 0.700073 |
| 2025 | 0.8333149 | 0.712968 | 1.680436 | 0.74182 | 0.686378 |
| 2030 | 0.8098726 | 0.637466 | 1.503449 | 0.645987 | 0.656395 |
| 2035 | 0.6862129 | 0.560523 | 1.326462 | 0.551005 | 0.626411 |
| 2040 | 0.6032238 | 0.483127 | 1.248578 | 0.458534 | 0.550798 |
| 2045 | 0.4891721 | 0.40602 | 1.170694 | 0.369467 | 0.475185 |
| 2050 | 0.4228958 | 0.32907 | 1.031587 | 0.283763 | 0.463119 |
| 2055 | 0.3211528 | 0.263103 | 0.894019 | 0.202629 | 0.451053 |
| 2060 | 0.2343013 | 0.207594 | 0.762419 | 0.137111 | 0.419856 |
| 2065 | 0.1625767 | 0.162112 | 0.633352 | 0.085973 | 0.388658 |
| 2070 | 0.1042862 | 0.125523 | 0.505787 | 0.046929 | 0.36188 |
| 2075 | 0.052256 | 0.094134 | 0.43913 | 0.014594 | 0.335102 |
| 2080 | 0.0090671 | 0.068719 | 0.362122 | 0.014594 | 0.311141 |
| 2085 | 0.0090671 | 0.048681 | 0.295797 | 0.014594 | 0.28718 |
| 2090 | 0.0090671 | 0.036041 | 0.238662 | 0.014594 | 0.28718 |
| 2095 | 0.0090671 | 0.026667 | 0.189895 | 0.014594 | 0.28718 |
| 2100 | 0.0090671 | 0.019799 | 0.148161 | 0.014594 | 0.28718 |

| Target relative to BAU | USA | EUROPE | KOSAU | CAJAZ | TE |
|---|---|---|---|---|---|
| 2005 | | | | | |
| 2010 | 1 | 0.863229 | 1 | 1 | 1 |
| 2015 | 0.9371763 | 0.752269 | 1 | 0.905732 | 0.748124 |
| 2020 | 0.581248 | 0.661356 | 1 | 0.590706 | 0.69065 |
| 2025 | 0.4989641 | 0.565722 | 0.830614 | 0.502363 | 0.646592 |
| 2030 | 0.4568277 | 0.488448 | 0.714646 | 0.429266 | 0.597003 |
| 2035 | 0.3673451 | 0.417528 | 0.61113 | 0.362023 | 0.554113 |
| 2040 | 0.3082628 | 0.351703 | 0.561303 | 0.299568 | 0.47647 |
| 2045 | 0.2397447 | 0.290089 | 0.516263 | 0.240963 | 0.403957 |
| 2050 | 0.1994863 | 0.231543 | 0.44799 | 0.185165 | 0.388689 |
| 2055 | 0.1463711 | 0.182703 | 0.383122 | 0.132276 | 0.374136 |
| 2060 | 0.1028562 | 0.142069 | 0.320549 | 0.089421 | 0.341369 |
| 2065 | 0.0690426 | 0.109557 | 0.262093 | 0.056024 | 0.310468 |
| 2070 | 0.0430316 | 0.083936 | 0.20668 | 0.030565 | 0.284775 |
| 2075 | 0.0210417 | 0.062401 | 0.177751 | 0.009503 | 0.260545 |
| 2080 | 0.0035778 | 0.045236 | 0.145628 | 0.009505 | 0.239754 |
| 2085 | 0.0035201 | 0.031871 | 0.11849 | 0.009509 | 0.219978 |
| 2090 | 0.0034824 | 0.023542 | 0.095581 | 0.009533 | 0.219501 |
| 2095 | 0.0034894 | 0.017585 | 0.07682 | 0.009658 | 0.220698 |
| 2100 | 0.0035068 | 0.013187 | 0.060614 | 0.009778 | 0.222352 |

Table 1, continued

| Target Absolute (tons C, thousand millions) | | MENA | SSA | SASIA | CHINA | EASIA | LACA |
|---|---|---|---|---|---|---|---|
| 2005 | 1 | unlimited | unlimited | unlimited | unlimited | unlimited | unlimited |
| 2010 | 2 | 0.51177 | unlimited | 0.41288 | 1.83009 | 0.39464 | 0.49779 |
| 2015 | 3 | 0.58766 | unlimited | 0.51088 | 2.08354 | 0.48358 | 0.58216 |
| 2020 | 4 | 0.65678 | unlimited | 0.63579 | 2.41191 | 0.57966 | 0.67417 |
| 2025 | 5 | 0.72000 | 0.11618 | 0.78210 | 2.78142 | 0.67840 | 0.77043 |
| 2030 | 6 | 0.84033 | 0.13962 | 0.94549 | 3.16425 | 0.77640 | 0.86843 |
| 2035 | 7 | 0.72017 | 0.16584 | 1.12277 | 3.53883 | 0.87116 | 1.04104 |
| 2040 | 8 | 0.60000 | 0.19496 | 1.31222 | 4.56351 | 0.96049 | 0.85091 |
| 2045 | 9 | 0.52080 | 0.22704 | 1.50976 | 3.78176 | 1.04308 | 0.66078 |
| 2050 | 10 | 0.44160 | 0.26210 | 1.48059 | 3.00000 | 1.11788 | 0.63716 |
| 2055 | 11 | 0.36789 | 0.29990 | 1.41692 | 2.66327 | 1.18609 | 0.57931 |
| 2060 | 12 | 0.29418 | 0.34262 | 1.35326 | 2.32654 | 1.25792 | 0.51555 |
| 2065 | 13 | 0.35892 | 0.38810 | 0.99442 | 2.05546 | 1.32273 | 0.42716 |
| 2070 | 14 | 0.42367 | 0.43582 | 1.21498 | 1.76701 | 1.37956 | 0.37107 |
| 2075 | 15 | 0.40177 | 0.48507 | 1.11969 | 1.57271 | 1.42759 | 0.28336 |
| 2080 | 16 | 0.37986 | 0.53502 | 0.94502 | 1.37841 | 1.46632 | 0.25200 |
| 2085 | 17 | 0.36158 | 0.58478 | 0.87403 | 1.12881 | 1.49555 | 0.20166 |
| 2090 | 18 | 0.34330 | 0.63185 | 0.73042 | 0.77349 | 1.51245 | 0.15573 |
| 2095 | 19 | 0.31049 | 0.66792 | 0.73042 | 0.61098 | 1.50458 | 0.11473 |
| 2100 | 20 | 0.27768 | 0.70057 | 0.73042 | 0.47083 | 1.48923 | 0.07814 |

| Target per capita EMI/cap (ton C) | MENA | SSA | SASIA | CHINA | EASIA | LACA |
|---|---|---|---|---|---|---|
| 2005 | | | | | | |
| 2010 | 1.4484148 | | 0.251596 | 1.346227 | 0.573311 | 0.888837 |
| 2015 | 1.5331238 | | 0.289807 | 1.491598 | 0.6644 | 0.983446 |
| 2020 | 1.5928577 | | 0.338348 | 1.686859 | 0.758998 | 1.085022 |
| 2025 | 1.6407048 | 0.098813 | 0.393843 | 1.912125 | 0.852115 | 1.18936 |
| 2030 | 1.8152101 | 0.107916 | 0.454456 | 2.156224 | 0.94156 | 1.294737 |
| 2035 | 1.4847729 | 0.117361 | 0.518982 | 2.411387 | 1.026594 | 1.509506 |
| 2040 | 1.1879659 | 0.127262 | 0.586223 | 3.130537 | 1.107186 | 1.207674 |
| 2045 | 0.9963073 | 0.13773 | 0.655432 | 2.624554 | 1.183369 | 0.923623 |
| 2050 | 0.821831 | 0.148871 | 0.628427 | 2.115135 | 1.255288 | 0.882286 |
| 2055 | 0.6701501 | 0.160769 | 0.590547 | 1.907912 | 1.322423 | 0.796892 |
| 2060 | 0.527093 | 0.174752 | 0.556277 | 1.693712 | 1.396477 | 0.70652 |
| 2065 | 0.6356864 | 0.189876 | 0.40497 | 1.520838 | 1.466296 | 0.584893 |
| 2070 | 0.7454041 | 0.206209 | 0.492397 | 1.328978 | 1.531506 | 0.509142 |
| 2075 | 0.7057241 | 0.223795 | 0.453645 | 1.202517 | 1.591763 | 0.390753 |
| 2080 | 0.669531 | 0.242684 | 0.384518 | 1.071629 | 1.646945 | 0.350289 |
| 2085 | 0.6427211 | 0.262948 | 0.358808 | 0.892426 | 1.697112 | 0.283416 |
| 2090 | 0.6185244 | 0.28397 | 0.303934 | 0.621937 | 1.739143 | 0.221927 |
| 2095 | 0.5698987 | 0.302496 | 0.3095 | 0.499718 | 1.75832 | 0.166291 |
| 2100 | 0.5218552 | 0.322343 | 0.316632 | 0.391758 | 1.773993 | 0.115518 |

| Target relative to 1990 | MENA | SSA | SASIA | CHINA | EASIA | LACA |
|---|---|---|---|---|---|---|
| 2005 | | | | | | |
| 2010 | 1.6402885 | 14080.14 | 2.04396 | 2.202274 | 3.132063 | 1.681723 |
| 2015 | 1.8835256 | 14080.14 | 2.529109 | 2.507268 | 3.837937 | 1.966757 |
| 2020 | 2.1050641 | 14080.14 | 3.147475 | 2.902419 | 4.600476 | 2.277601 |
| 2025 | 2.3076923 | 3.271662 | 3.871782 | 3.347076 | 5.384127 | 2.602804 |
| 2030 | 2.693379 | 3.931739 | 4.680644 | 3.807762 | 6.161905 | 2.933885 |
| 2035 | 2.308228 | 4.670102 | 5.558267 | 4.25852 | 6.913968 | 3.517039 |
| 2040 | 1.9230769 | 5.49013 | 6.496139 | 5.491593 | 7.622937 | 2.874703 |
| 2045 | 1.6692282 | 6.393512 | 7.474059 | 4.550851 | 8.278413 | 2.232366 |
| 2050 | 1.4153795 | 7.380812 | 7.329673 | 3.610108 | 8.872063 | 2.15258 |
| 2055 | 1.1791289 | 8.44527 | 7.014479 | 3.2049 | 9.413413 | 1.957126 |
| 2060 | 0.9428782 | 9.648278 | 6.699285 | 2.799692 | 9.983492 | 1.741707 |
| 2065 | 1.1503995 | 10.92901 | 4.922888 | 2.47348 | 10.49786 | 1.443116 |
| 2070 | 1.3579208 | 12.27282 | 6.014734 | 2.126367 | 10.94889 | 1.25362 |
| 2075 | 1.2877149 | 13.65971 | 5.543029 | 1.892551 | 11.33008 | 0.957299 |
| 2080 | 1.2175089 | 15.06632 | 4.678302 | 1.658734 | 11.63746 | 0.851336 |
| 2085 | 1.1589079 | 16.46757 | 4.326877 | 1.35838 | 11.86944 | 0.681298 |
| 2090 | 1.1003069 | 17.79308 | 3.615963 | 0.930792 | 12.00357 | 0.526101 |
| 2095 | 0.9951592 | 18.80882 | 3.615963 | 0.73524 | 11.94111 | 0.387605 |
| 2100 | 0.8900115 | 19.72825 | 3.615963 | 0.566579 | 11.81929 | 0.263973 |

| Target relative to BAU | MENA | SSA | SASIA | CHINA | EASIA | LACA |
|---|---|---|---|---|---|---|
| 2005 | | | | | | |
| 2010 | 1 | | 1 | 1 | 1 | 1 |
| 2015 | 1 | | 1 | 1 | 1 | 1 |
| 2020 | 1 | | 1 | 1 | 1 | 1 |
| 2025 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2030 | 1.077932 | 1 | 1 | 1 | 1 | 1 |
| 2035 | 0.859388 | 1 | 1 | 1 | 1 | 1.077373 |
| 2040 | 0.6690679 | 1 | 1 | 1.172209 | 1 | 0.800324 |
| 2045 | 0.5444729 | 1 | 1 | 0.896204 | 1 | 0.570415 |
| 2050 | 0.4342851 | 1 | 0.865637 | 0.664752 | 1 | 0.509214 |
| 2055 | 0.3412661 | 1 | 0.741186 | 0.557116 | 1 | 0.430966 |
| 2060 | 0.2566215 | 1 | 0.631303 | 0.457682 | 1 | 0.357623 |
| 2065 | 0.295144 | 1 | 0.419284 | 0.383525 | 1 | 0.277703 |
| 2070 | 0.3293209 | 1 | 0.469036 | 0.315189 | 1 | 0.227257 |
| 2075 | 0.2961617 | 1 | 0.400734 | 0.270118 | 1 | 0.164346 |
| 2080 | 0.2665236 | 1 | 0.317317 | 0.229453 | 1 | 0.139155 |
| 2085 | 0.2424396 | 1 | 0.278467 | 0.183188 | 1 | 0.1066 |
| 2090 | 0.2213897 | 1 | 0.223463 | 0.123143 | 1 | 0.079384 |
| 2095 | 0.1957135 | 1 | 0.218306 | 0.096421 | 1 | 0.057336 |
| 2100 | 0.1717606 | 1 | 0.215132 | 0.073937 | 1 | 0.038452 |

* * *

## Table 2: Implied Economic Cost of Emission Targets for each of 11 regions

(PDV at discount rate = 5%. Expressed as per cent of GDP)

| USA | OLDEURO | NEWEURO | KOSAU | CAJAZ | TE | MENA | SSA | SASIA | CHINA |
|---|---|---|---|---|---|---|---|---|---|
| 0.55% | 0.18% | 0.77% | 0.22% | 0.31% | 0.98% | 0.62% | -1.33% | -0.35% | 0.50% |

**Figure 1: The Emissions Cuts That Were Agreed at Kyoto Were Progressive with Respect to Income, when Expressed Relative to BAU**

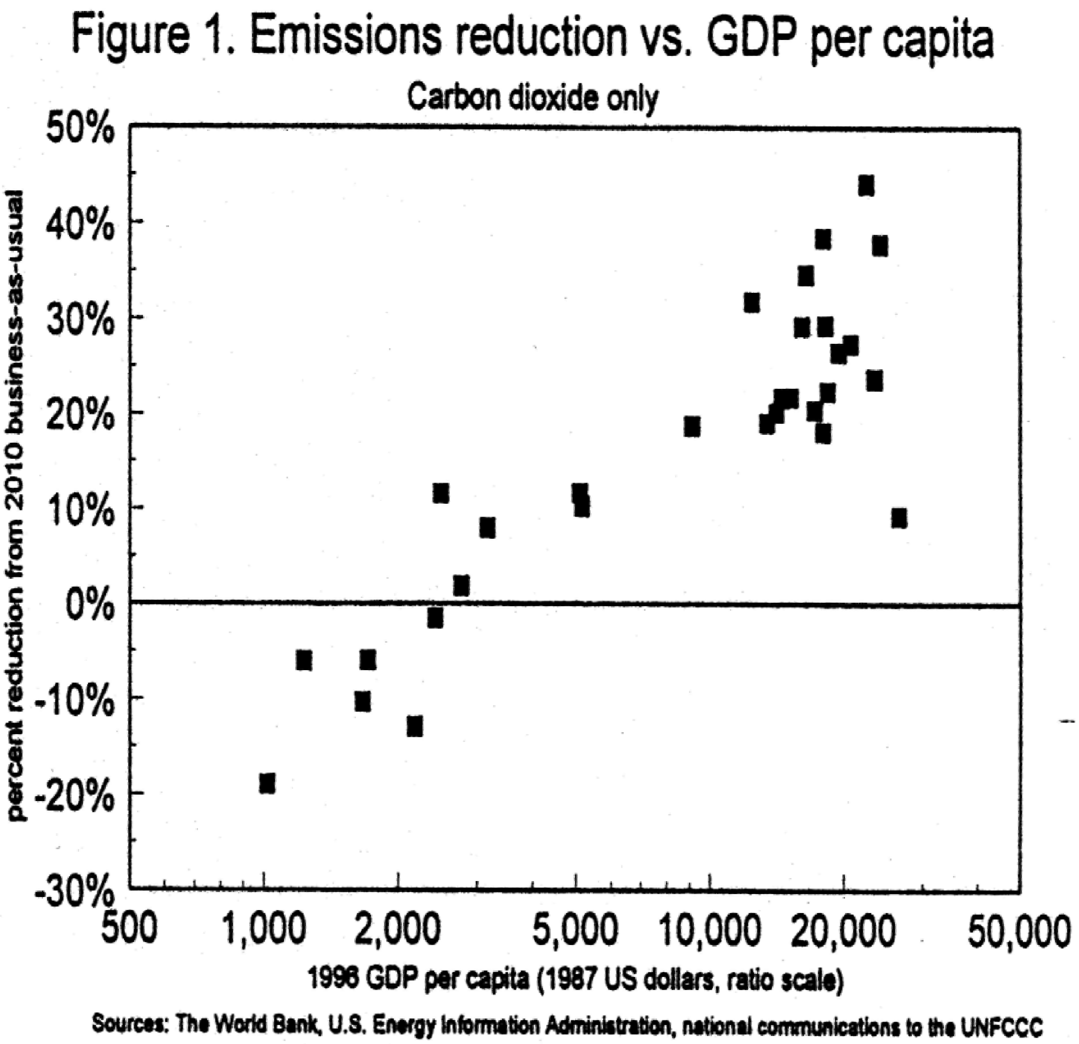


**Figure 2: Targets for emission per capita, by region**

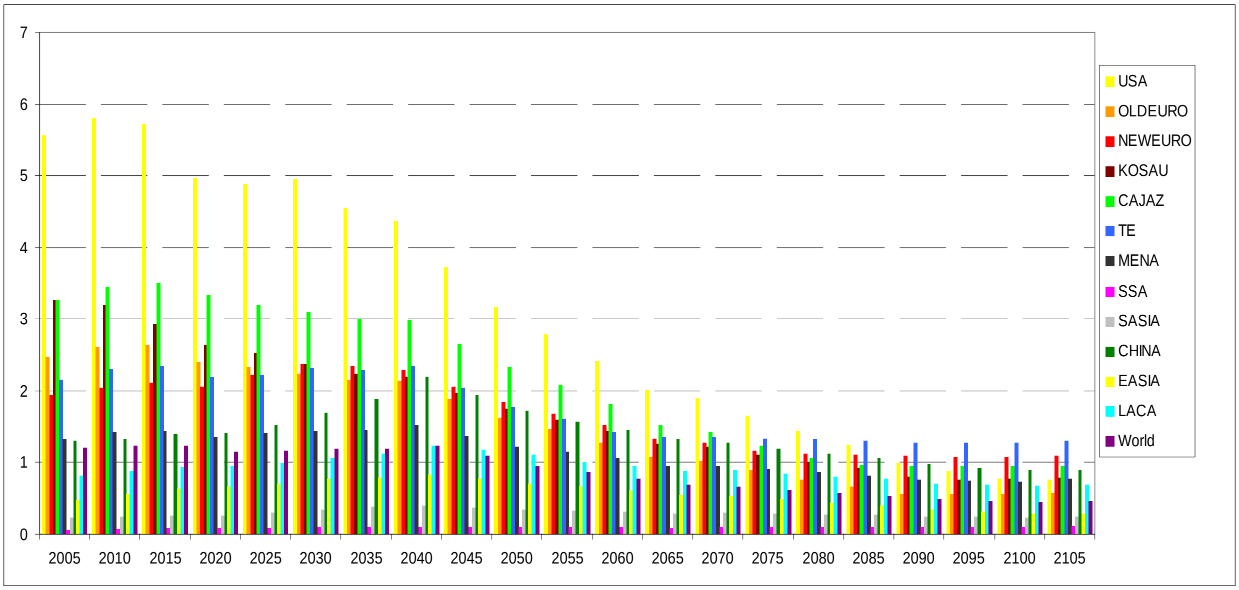



**Figure 3: Emissions path for industrialized countries in the aggregate (Predicted actual emissions exceed caps by amount of permit purchases)**

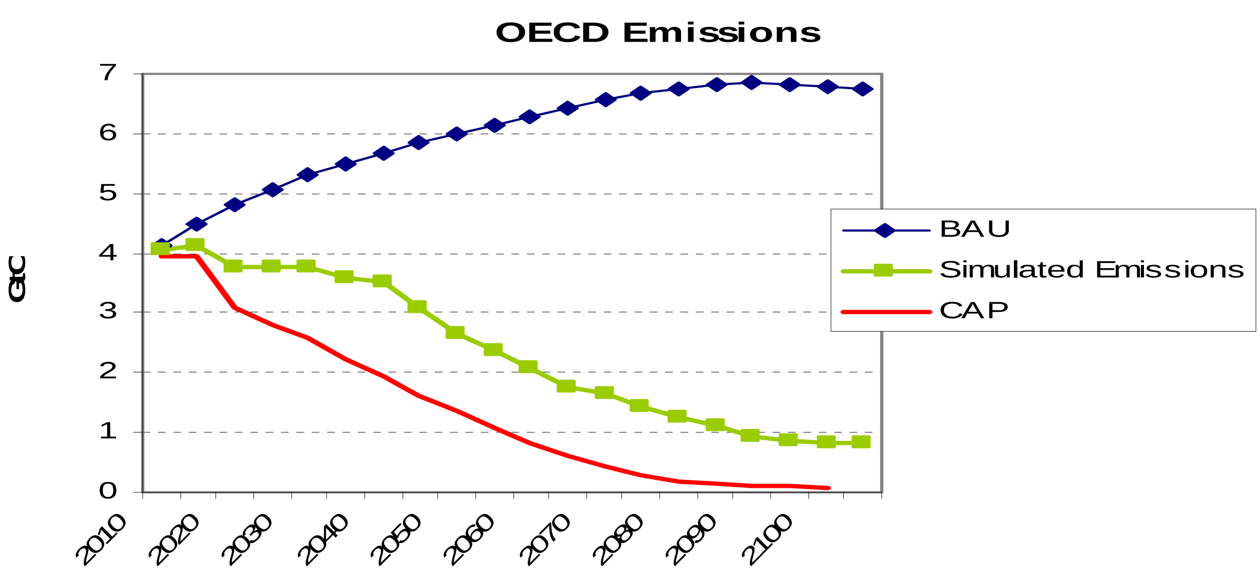


**Figure 4: Emission paths for poor countries in the aggregate**
**(Predicted actual emissions fall below caps by amount of permit sales)**

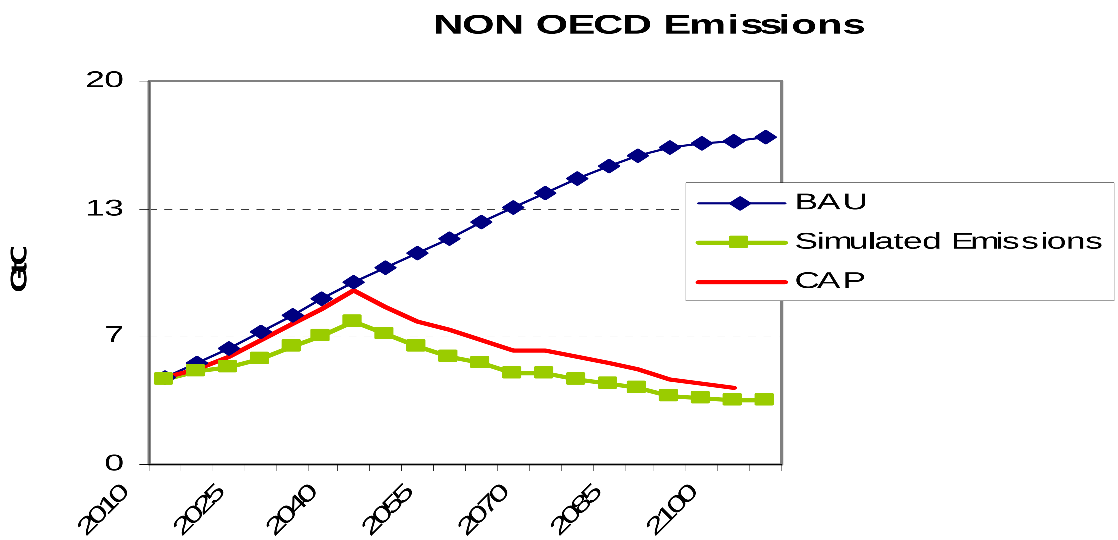



**Figure 5: Emissions path for the world, in the aggregate**

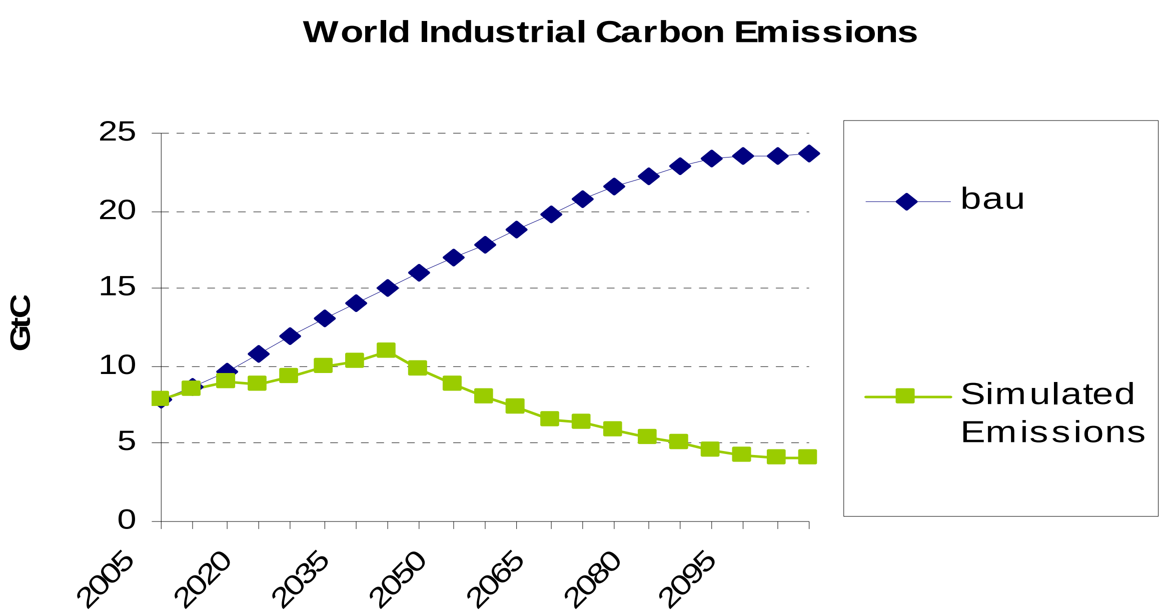


**Figure 6: Price of Carbon Dioxide Rises Slowly Over 50 Years, then Rapidly**

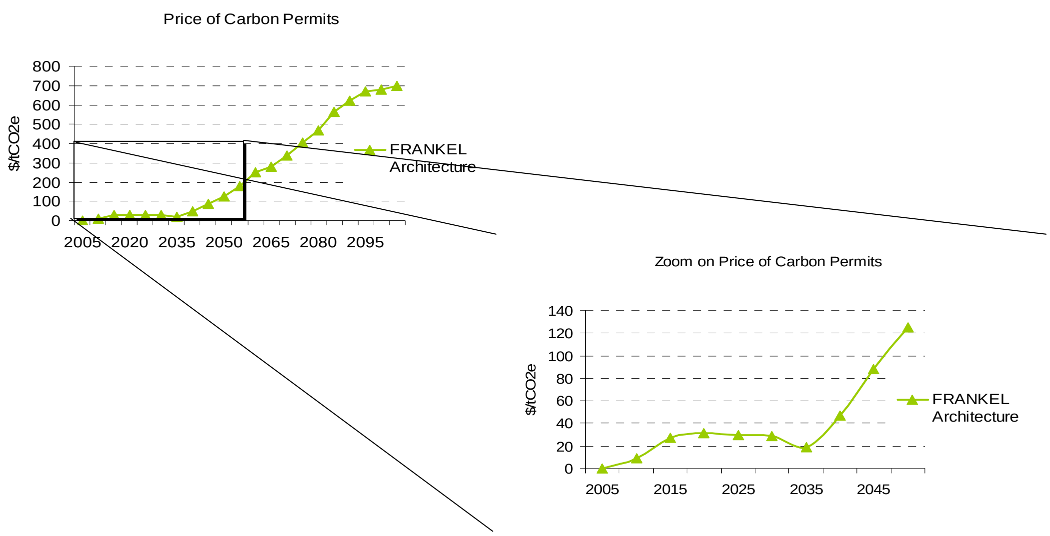



**Figure 7 : Distribution of economic costs across regions**

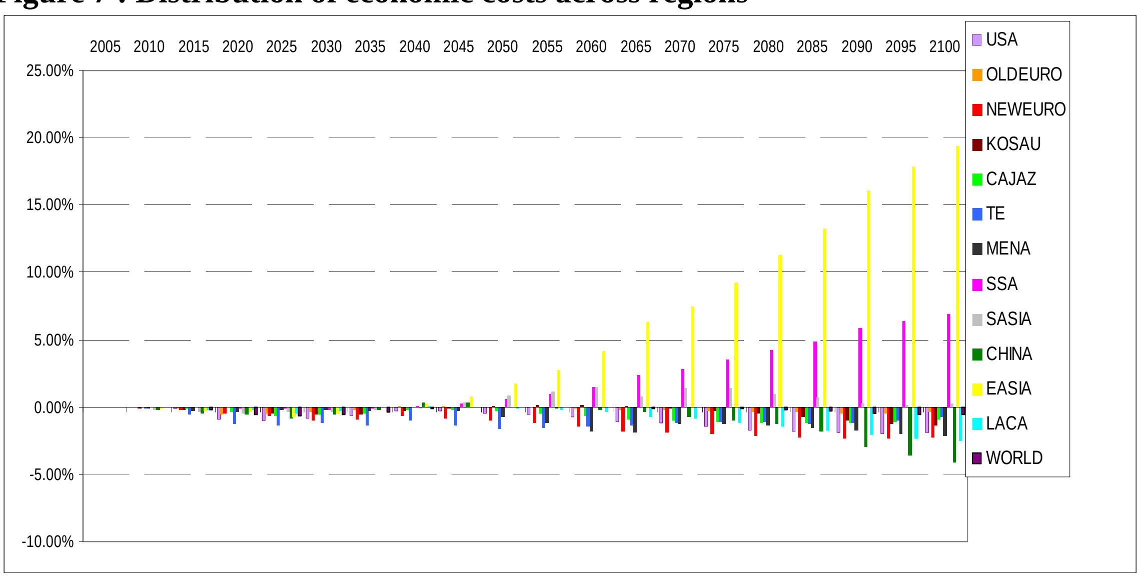


**Figure 8: Aggregate Gross World Product Loss by Budget period, 2015-2100**

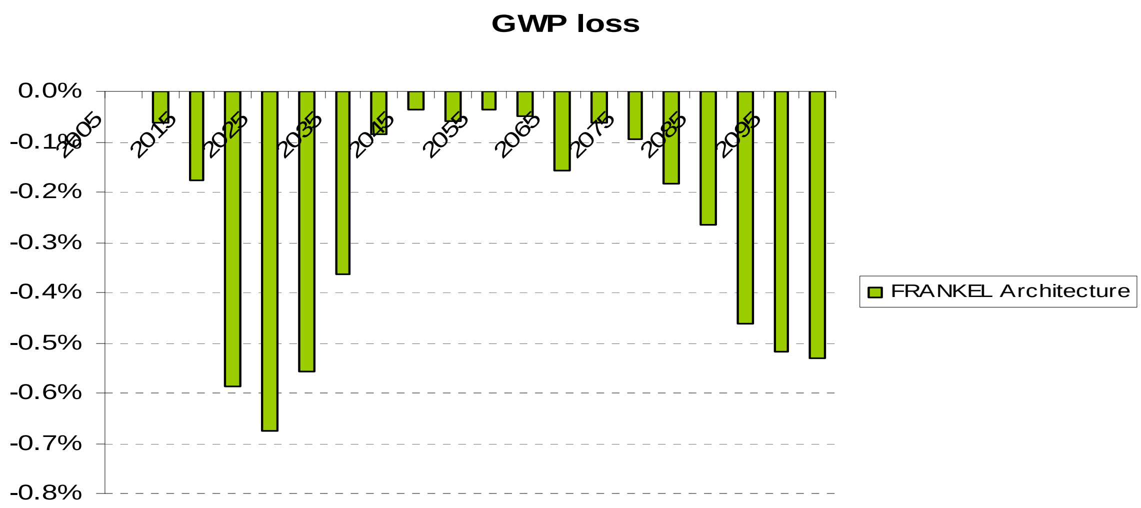



**Figure 9: Concentrations come close to the 2100 concentrations goal of 500ppm**

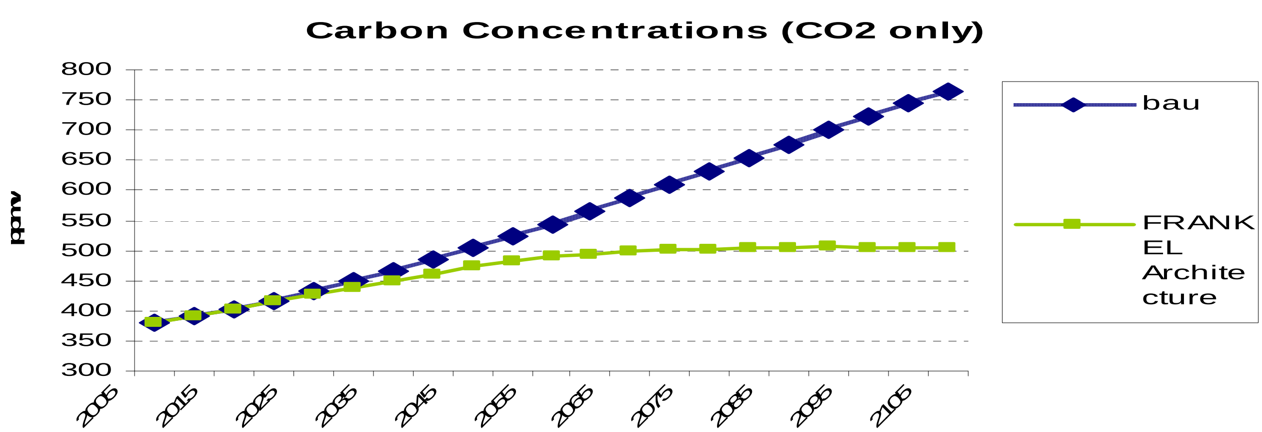
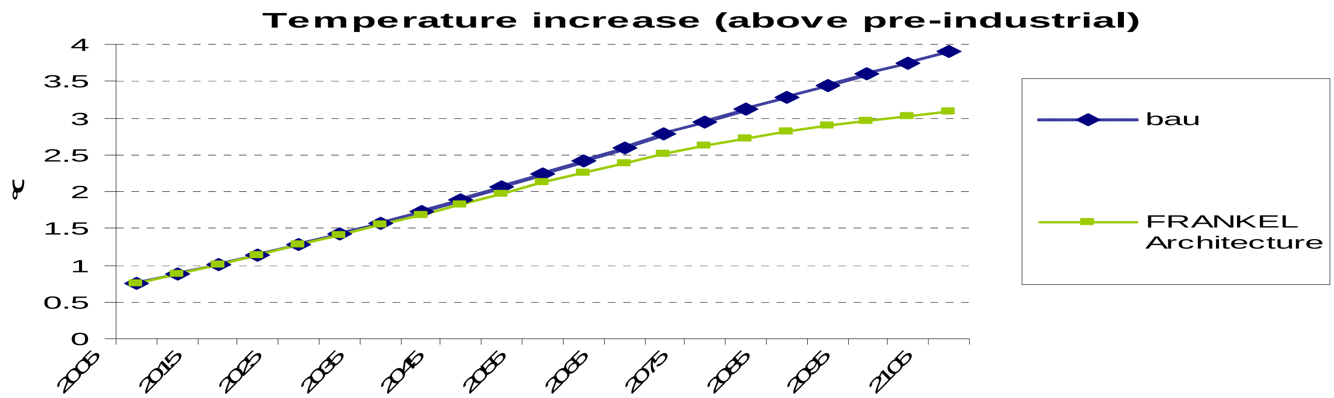


**Figure 10**



Temperature increase (above pre-industrial)
℃
4
3.5
3
2.5
2
1.5
1
0.5
0
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
2105
bau
FRANKEL Architecture

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