Emissions Pricing to Stabilize Global Climate

Valentina Bosetti, Sergey Paltsev, John Reilly and Carlo Carraro

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

Report No. 211
March 2012

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

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Emissions Pricing to Stabilize Global Climate

Valentina Bosetti[a], Sergey Paltsev[b], John Reilly[b], and Carlo Carraro[c]

Abstract

In the absence of significant greenhouse gas (GHG) mitigation, many analysts project that atmospheric concentrations of species identified for control in the Kyoto protocol could exceed 1000 ppm (carbon-dioxide-equivalent) by 2100 from the current levels of about 435 ppm. This could lead to global average temperature increases of between 2.5° and 6° C by the end of the century. There are risks of even greater warming given that underlying uncertainties in emissions projections and climate response are substantial. Stabilization of GHG concentrations that would have a reasonable chance of meeting temperature targets identified in international negotiations would require significant reductions in GHG emissions below "business-as-usual" levels, and indeed from present emissions levels. Nearly universal participation of countries is required, and the needed investments in efficiency and alternative energy sources would entail significant costs. Resolving how these additional costs might be shared among countries is critical to facilitating a wide participation of large-emitting countries in a climate stabilization policy. The 2°C target is very ambitious given current atmospheric concentrations and inertia in the energy and climate system. The Copenhagen pledges for 2020 still keep the 2°C target within a reach, but very aggressive actions would be needed immediately after that.

Contents

1. INTRODUCTION

This policy note discusses projected GHG emissions paths that are potentially consistent with alternative targets for ultimately stabilizing the global climate system at lowest economic cost and under alternative scenarios for country participation in pricing regimes. There is considerable uncertainty surrounding future emissions paths, given that different models make very different assumptions about future emissions growth (in the absence of policy), the cost and availability of emissions-reducing technologies, and so on. Nonetheless, projections from the

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This report was originally prepared for the *IMF Workshop on Fiscal Policy and Climate Mitigation*, September 16, 2011, Washington, DC.

models still provide decision makers with some broad sense of the appropriate scale of (near term and more distant) emissions prices that are consistent with alternative climate stabilization scenarios and how much these policies cost.

The next section discusses where we might be headed in the absence of mitigation policy, in terms of future GHG emissions trends, what these imply for the growth of atmospheric GHG concentrations and, ultimately, for the amount of likely warming over this century. We also discuss the benefits of different stabilization targets for atmospheric GHG accumulations in terms of potentially avoided warming. Section 3 discusses projected emissions pricing, and the costs of mitigation policies, to meet stabilization targets in the ideal (but unlikely) event of early and full global cooperation and with efficient pricing across all emissions sources and over time. Section 4 discusses the implications of delayed emissions reductions by all countries, or just developing countries. Recent emissions reduction pledges by country governments are briefly evaluated in light of the climate stabilization goals. Section 5 discusses the distributional burden of mitigation costs across countries and the potential complications for negotiation of long-term climate policy. A final section offers some thoughts on pragmatic policy steps in the near term.

2. WHERE ARE WE HEADED IN THE ABSENCE OF CLIMATE POLICY?

Climate change may pose substantial risks to natural and human systems (IPCC, 2007). In the absence of a policy that targets a reduction of greenhouse gas (GHG) emissions, projected "likely" temperature increases by the end of the century are in the range of 2.4° - 6.4°C above pre-industrial levels. The IPCC defines "likely" as a 66% chance or greater (IPCC, 2007).[1] A recent MIT study with updated climate and socioeconomic parameters provide even higher values: a 90% range of 3.8° - 7°C with a mean value of 5.2°C (Sokolov *et al*, 2009).

There are many efforts to project future emissions trends and the range of projections over the 21st century is wide. GDP and population growth are major determinants of emissions growth, while increases in energy efficiency (*e.g.*, cars with an ability to drive longer distances per unit of fuel, or buildings that require less energy to heat them) and increasing costs of fossil fuels had the opposing effect on emissions. Most likely, economic growth will remain a major factor in driving up emissions, whereas the role of population will slowly fade over time as most population projections forecast a stabilization of the world population in the second half of the

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[1] To date, temperatures are estimated to have risen by approximately 0.75°C relative to pre-industrial (year 1750) levels.

21st century. What differs most across forecasting models, hence causing the uncertainty affecting projections, are the assumptions concerning future GDP growth; the availability of fossil resources; the pace and direction of technical change, in turn affecting the cost of low-carbon technologies and the energy intensity of the economy; and behavioral shifts, affecting energy demand. Whether or not the world undertakes significant policy directed toward reducing GHG emissions is an additional uncertainty on top of various economic forces that will play out over the century.

In the absence of a climate stabilization policy, energy-related CO_2 emissions (the primary GHG) are projected to increase substantially during the 21st century. **Figure 1** shows the range of projections in a recent model comparison exercise organized by Energy Modeling Forum, EMF 22[2] (Clarke *et al*, 2009).[3] On average, fossil fuel CO_2 emissions grow from about 30 Gt (Gigatonne) CO_2 in 2000 to almost 100 Gt CO_2 by 2100.

The contribution of different regions to global emissions is more stable across models. OECD countries contribute 15-25% to total emissions in 2100. The USA continues as one of the main emitters among the OECD countries. However, its projected global emissions share decreases from the current 25% to 10% by the end of the century. A major role of BRIC (Brazil, Russia, India, and China) countries is foreseen, contributing by 2050 around 45-50% of total fossil CO_2 emissions. Consistently across models, at least 25% of the total emissions are attributed to China from 2020 onward. India, now accounting for 10% of global emissions, reaches on the order of 15% by mid-century. The rest of the developing world is projected to have an increasing role, moving from 17-25% of total emissions to 25-40%.

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[2] The EMF 22 International Scenarios engaged ten of the world's leading integrated assessment models (IAMs) to focus on the combined implications of different long terms stabilization targets, the possibility for transitory overshooting of those targets, and that of partial versus complete country participation. Four of the IAMs participated with two alternative versions for a total of 14 models.

[3] The range in Figure 1 does not represent the full uncertainty in the models projections, rather it shows a range of the median projections from each model.

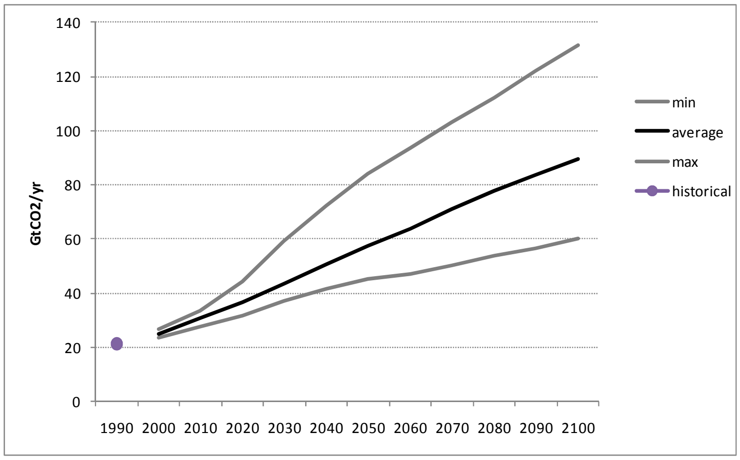

Figure 1. Energy-Related CO_2 emissions projections over 21st century. Source: Authors' calculations drawing from the EMF 22 dataset.

Anthropogenic CO_2 emissions are mostly energy-related, with a contribution from industrial processes (mostly cement production) and land use change. Over time, energy-related emissions are projected to grow faster than other emissions. While CO_2 is a major contributor towards global warming, other greenhouse gases (GHGs) also play a substantial role, especially methane (CH_4), nitrous oxide (N_2O), and a group of so-called F-gases (HFCs, PFCs, and SF_6)[4]. Currently, non-CO_2 gases contribute about 25% of total GHG emissions in warming equivalents over their atmospheric life span (IPCC, 2007). CO_2 emissions are projected to grow faster than non-CO_2 emissions over the 21st century. Among CO_2 emissions, land use emissions are also an important part of the story. The latest IPCC report estimates that destruction of tropical forests and peat lands contributed 18% of global anthropogenic GHG emissions in 2004. Emissions from deforestation come primarily from a subset of tropical countries, like Brazil, Indonesia, and some countries in Central and Western Africa. Reduced deforestation in these countries and reforestation of temperate regions could contribute to mitigation efforts.

Emissions projections, absent significant policy, show continued rapid increases in global concentrations of GHGs. The EMF-22 scenarios discussed above result in CO_2-equivalent concentrations of 800-1500 parts per million (ppm) by 2100 counting concentrations of the gases identified for control in the Kyoto protocol, up from 420 ppm in 2000. Other substances will also affect future climate. These include the CFCs, whose emissions are largely phased out under the

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[4] The major sources of F-gases are air conditioning, semiconductor production, electrical switchgear, aluminum and magnesium production.

Montreal Protocol, but that remain in the atmosphere as a powerful contribution to warming, and other short lived substances some of which are warming (*e.g.*, ozone and particulates) and some cooling (*e.g.*, sulfates). Prinn *et al* (2011) evaluated the climate impacts of all of these substances from a range of scenarios in the literature, including those developed by intergovernmental panels (represented by IPCC), national governments (selected scenarios from the U.S. government Climate Change Science Program, US CCSP), and industry (represented by Royal Dutch Shell Plc). In the no-climate-policy scenarios, the CO_2-equivalent concentrations of GHG reach up to 1780 ppm. The Prinn *et al* (2011) study finds global temperature increases of 4.5 to 7°C increase above present by 2100 in the absence of climate policy (**Figure 2**).

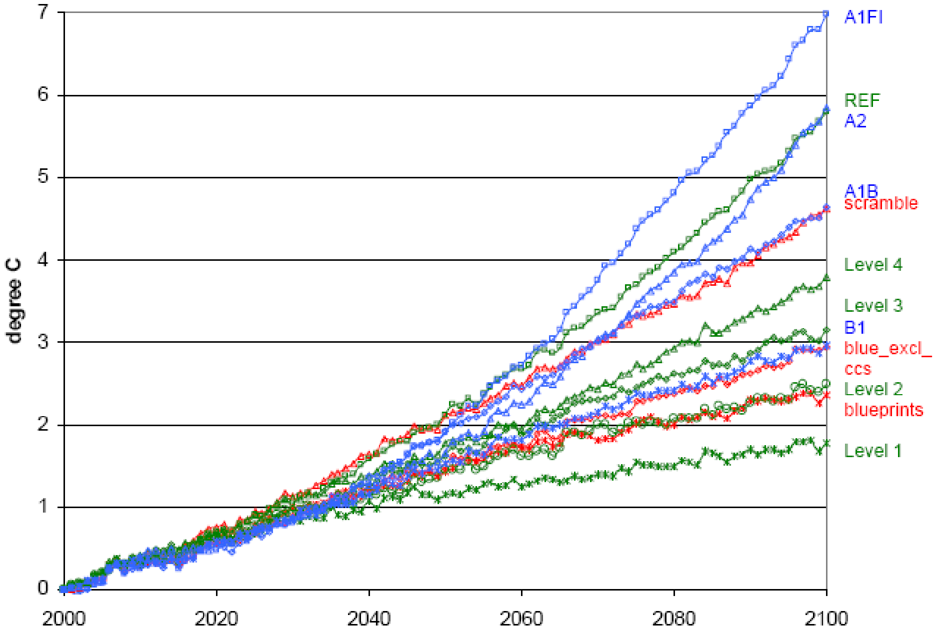

Figure 2. Increase in global mean temperature in degrees Centigrade (relative to 2000; CCSP scenarios in green, SRES in blue, Shell in red).
Source: Prinn *et al* (2011).

The study included scenarios where decisions about global energy use were shaped by concerns about the environment. As IPCC SRES scenarios have story lines instead of explicit representation of the policies, their scenarios A1FI, A1B, and A2 can be interpreted as those where concerns of climate change have not significantly shaped energy policy. The same is true for the Shell's "Scramble" scenario. US CCSP has a specific no-climate-policy scenario, denoted by "REF" on Figure 2. The risks associated with these levels of temperature increase are not fully understood. However, existing scientific knowledge (IPCC, 2007) justifies at least slowing down the anthropogenic contribution to climate change.

The figure also includes the temperature results for some scenarios shaped by climate concerns. The set from the US CCSP developed emissions scenarios (Level 1-4) were formulated in terms of radiative forcing[5] that intended to avoid exceeding specific CO_2 concentration targets – 450, 550, 650, 750 ppm against a scenario without explicit policy (REF)[6]. The Shell's "Blueprints" and "Blueprints without carbon capture and storage (blue_excl CCS)" and the IPCC B1 scenarios do not include specific global concentration targets but they are scenarios where energy choices are shaped by climate change concerns. These scenarios where energy choices are shaped by climate concerns maintain global temperature increases to a range of just under 2°C to under 4°C above present through 2100.

3. CLIMATE STABILIZATION WITH A GLOBAL PARTICIPATION OF COUNTRIES

Stabilization of GHG concentrations at levels often discussed in international negotiations requires very substantial emissions cuts. **Figure 3** illustrates the difficulty of reaching some proposed targets, as some stringent targets are already exceeded or will be exceeded in the not-so-distant future. As can be seen, the world has already almost passed the often-discussed 450 CO_2e target for the Kyoto Protocol gases[7].

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[5] Radiative forcing is the difference between incoming and outgoing radiation energy; the metric for radiative forcing is watt per square meter.

[6] In some cases targets might be expressed in terms of concentration of CO_2 only (in ppm of CO_2), in others targets include all GHGs, hence are expressed in terms ppm of CO_2 equivalent, or CO_2e.

[7] It is important to distinguish between the concentrations of all GHGs and a subset of the Kyoto gases. In 2010, Kyoto gases concentration was about 440 ppm CO_2e, while for all GHGs concentration was around 465 ppm CO_2e.

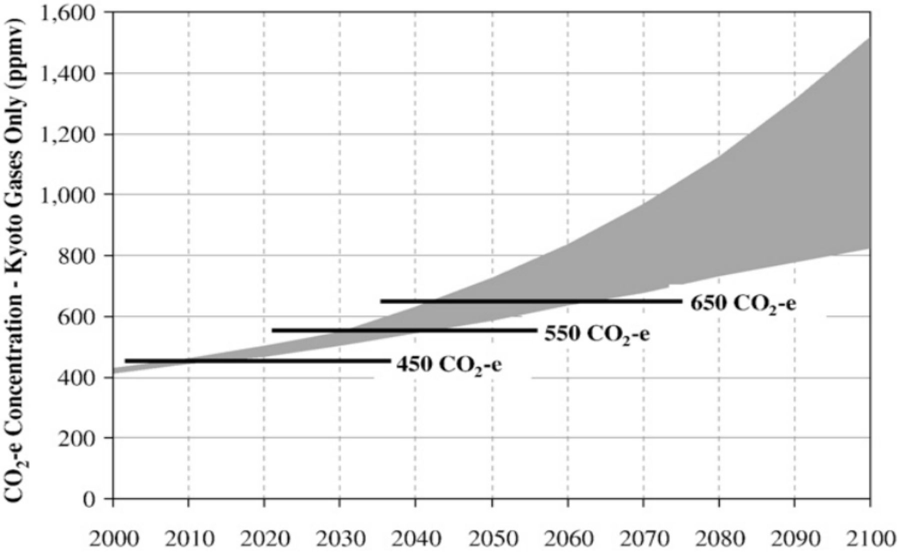

Figure 3. Relationship between different CO_2e concentration targets (Kyoto gases) and concentrations in the no-policy projections.
Source: EMF-22 (Clarke *et al*, 2009).

Yet, what are the economic costs of achieving substantial reductions? These depend on who participates and the efficiency of the policies used to achieve reductions. We start by reporting the costs and consequences of climate stabilization assuming a so called “first-best” world, with full international participation, a perfect international carbon market including all GHGs and foresight of future climate obligations. In reality, departures from all or many of these assumptions are likely to occur and would result in potentially higher economic penalties and inefficiencies of various kinds. Nonetheless such an ideal case is useful to understanding the basic dynamics of the system, and to have a benchmark for the discussion of more realistic cases.

It is important to distinguish between who is incurring the cost of mitigation from who is actually implementing mitigating activities. For example, mitigation can happen in developing countries, but it can be financed with some offset scheme financed by developed countries. Allocating internationally a given amount (typically determined by the stabilization target) of allowable emissions is going to affect the cost and who pays. This distributional issue would be extremely relevant both in the case of taxes and in that of permits. There are many ways to distribute the shares of emissions reduction among participating countries. One can propose reductions based on equal percent reduction, or GDP per capita, or population, or emissions intensity, or historical responsibility, or many other alternative ways. There is vast literature that analyzes these types of burden-sharing schemes. As any of the schemes benefit (or imposes the cost on) countries unevenly in different aspects of socio-economic indicators, there is no unique formula that would satisfy all participating countries. It is sometimes argued that in order to reach global economic efficiency (*i.e.*, reaching a target at a lowest global economic cost), emissions should be priced at same rate across different countries. This can be achieved by imposing the same GHG price across the countries through a system of carbon taxes, or by allowing a full trade in emissions permits among all countries and all sectors of the economy[8].

3.1 Emissions and Emissions Prices

Emission reductions and carbon prices results for the different models and under the different targets are reported in **Table 1**. In the EMF-22 exercise the global carbon price in 2020 that would be in line with a 650 ppm CO_2e[9] target ranges between $3 and $20 per metric ton of CO_2 (in year 2005 dollars). Carbon price increases to 10-52 2005$/t$CO_2$ when considering 550 ppm CO_2e target. Allowing for overshooting the target and then bringing back emissions to the 550 ppm target by the end of the century, would bring the price in 2020 down to 4-51 2005$/t$CO_2$. When considering the 450 ppm CO_2e target only two models find a solution for the target when no overshoot is allowed; for these two models, the price is above 100 2005$/tCO2. When overshooting is considered, half of the models are able to find a solution with the price of carbon ranges between 15-263 2005$/t$CO_2$.

Table 1. Change in CO_2 emissions and price of carbon in 2020. Source: Authors' elaboration of the EMF-22 dataset.

	Change in CO_2 Emissions in 2020 relative to 2000	**Change in CO_2 Emissions in 2050 relative to 2000**	**Price of Carbon in 2020 (2005 USD per ton C)***
450 ppm CO_2e (36% of models)	-67% to 31%	-13% to -92%	15-263 2005 USD ton C
550 ppm CO_2e	-4% to 50%	-67 % to 52%	4-52 2005 USD ton C
650 ppm CO_2e	30% to 57%	-16% to 108%	3-20 2005 USD ton C

**Ranges included the overshoot and not-to-exceed cases.*

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[8] Emissions trading may, for some countries, lead to a decrease in welfare (or total macroeconomic consumption) due to the terms-of-trade effect. For a discussion, see Babiker *et al* (2004). A discussion of a similar potential welfare worsening in presence of externalities (e.g., energy taxes) can be found in Paltsev *et al* (2007).

[9] As we are reviewing the "first best" world we are assuming that all GHGs are taxed. Hence, we use the CO_2 equivalency to aggregate all GHGs.

The reason why models are less capable of finding a feasible set of actions for more stringent targets resides in the fact that we are already very near to 450 ppm CO_2e. Staying below 450 ppm CO_2e would require an immediate and almost complete de-carbonization of the economy. This, under realistic assumptions, is likely to be technically unfeasible. Similarly, going back to the target after overshooting implies large deployment of negative emissions technologies. Not all models envision the deployment of technologies enabling us to remove CO_2 from the atmosphere (for example, biomass power generation coupled with CO_2 capture and storage). These technologies deployed at a massive scale would allow bringing down concentrations emission pathways later in the century[10].

As the "first best" assumption allows for the full trading in emissions permits, the 2020 carbon price will increase over time at a discount rate because of perfect substitutability of trading in emissions permits and other financial instruments. Different modeling groups assume different discount rates, usually in the range of 3-5%, so the carbon price would also increase over time at the same rate.

Looking at emission reductions needed to be in line with the different targets (first and second column in Table 1) it is important to notice that, for the near- and medium-term, there is not much difference in appropriate emission prices for 550 and 650 ppm—but very large emission reductions are required, even in the short run for the 450 ppm CO_2e scenario.

3.2 Policy Costs

The carbon price might be a misleading indicator for the economic cost of climate policy as it does not univocally translate in macroeconomic or welfare impacts. (For a detailed discussion, see, for example, Appendix B in Paltsev *et al*, 2009). Indeed economists usually measure the cost in terms of welfare loss (or loss in consumption measured as equivalent variation, that roughly can be interpreted as the macroeconomic combination of the cost of producing with more efficient technologies, or cleaner but more expensive fuels, the forgone benefits to households from cutting back on energy use, etc.). GDP loss is another popular measure for the cost of a

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[10] Currently, these negative carbon technologies are highly speculative. For a discussion concerning the potential role of bioenergy and carbon capture and storage technologies on the costs of stringent policy see Tavoni and Tol (2010). For a discussion about potential technological and economic obstacles for air capture technologies see Ranjan (2010).

policy, as many of the models used for climate policy analysis do not report welfare[11]. Most of the studies focus on emissions mitigation costs as climate benefits and potential ancillary non-climate benefits of GHG mitigation are much more uncertain.

EMF-22 reports the net present value of GDP costs (discounted at 5%) in the range of $2-24 trillion (year 2005 US dollars) for 650 ppm CO_2e stabilization, in the range of $16-45 trillion 2005$ for 550 ppm CO_2e stabilization, and $55-125 trillion 2005$ for 450 ppm CO_2e stabilization (losses as shares of the world GDP in net present value are discussed in the next section).

US CCSP (Clarke *et al*, 2007) does also report the cost of climate policy as a percentage reduction in the global GDP, but rather than net present values, reports the loss in different periods of time. The most stringent stabilization level in this study is roughly equal to 550 ppm CO_2e (450 ppm when only CO_2 contributions are considered). The loss of the world GDP in comparison to a scenario with no climate policy is in the range of 1-4% in 2040 and 1-16% in 2100.

Emissions pricing will induce emissions reductions in the sectors where these reductions are cheapest. Models have different views about the timing of emissions reduction, but most of the projections agree that the power generation sector will be the first area where less-carbon-emitting (*e.g.*, natural gas) or almost-zero-carbon-emitting technologies (*e.g.*, nuclear, hydro, renewables) are introduced because of various economic substitutes that already exist in this sector[12]. Less-emitting technologies in transportation (*e.g.*, gasoline/electric hybrid vehicles, more fuel efficient conventional vehicles) and energy-saving technologies in buildings and industry are also promising, but currently look more expensive. Substantial reductions in GHG emissions in agriculture and cement production are also costly, but to achieve climate stabilization, emissions from all sectors of the economy need to be reduced drastically. For more stringent climate stabilization targets, the reductions are needed to begin in the near future, and if the models are correct, some very ambitious targets (*i.e.*, 450 ppm CO_2e) might be already out of reach. Previous economic analyses have estimated that there may be significant and relatively inexpensive and cost effective opportunities for protecting and enhancing global forest carbon

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[11] As GDP measures not only consumption, but also government spending, investment and net trade, it is a less satisfactory indicator of cost of a policy. For additional discussion, see Appendix B in Paltsev *et al* (2009).

[12] Jacoby *et al* (2012) provide an assessment of the role of natural gas in a potential U.S. climate policy considering recent shale gas development.

stocks. Linking REDD (Reducing Emissions from Deforestation and forest Degradation) could be extremely beneficial as it is a low cost carbon abatement opportunity, although several implementation issues would need to be overcome. Deforestation mitigation could lower the total costs of climate stabilization policies by around 10-25% depending on the policy scenario, and could enable additional reductions of about 20 ppm CO_2e with no added costs compared to an energy-sector only policy (Bosetti *et al*, 2011). However, most of rainforest countries have not yet developed the implementation capacity for monitoring and enforcing country scale projects and this might diminish the role of REDD in the next decade.

Deferring the bulk of mitigation action to later periods can make sense if we are optimistic about the availability, cost and speed of deployment of low-emissions technologies. A further degree of freedom is represented by negative emissions technologies. However, relying on a technological future which might not evolve as expected comes at a risk of missing the target completely.

4. INCOMPLETE PARTICIPATION AND DELAYED ACTION

Carbon prices as well as mitigation costs depend critically on assumptions about (1) innovation and the availability of low-carbon alternatives to conventional fossil fuels, (2) flexibility of substitution within the energy-economic system, (3) the credibility of future policies that triggers long term investments and (4) the immediate action of all countries or of major emitters. In this section we investigate the latter crucial assumption and how it might influence results presented so far.

For a given stabilization target, delayed global action implies a higher post peak reduction rate. Short term inaction would then result in a required pace of de-carbonization so rapid that replacement of capital would need to be abrupt and very costly. Only under the optimistic assumption of large-scale CO_2 removal, the tradeoff between costs and timing of action can be less severe. If the world continues according to business-as-usual until 2030, stabilization at 550 ppm CO_2e will no longer be possible, according to most models. The target might still be feasible if ambitious mitigation policies at global scale are postponed until 2020, but this delay could substantially scale up global mitigation cost. Climate policy aiming at 450 ppm CO_2e target leaves even less leeway for a delay of cooperative mitigation action (Edenhofer *et al*, 2009).

Rather than complete global inaction, more likely we will face asymmetry of actions across world regions. Significant mitigation actions are planned to take place in some developed countries within the next decade (*e.g.,* the EU has committed to the 20% reduction below 1990 levels target by 2020). However, it is unlikely that emerging economies will make substantial emissions reductions in the coming decade. This asymmetric participation will most likely increase the global costs of those stabilization scenarios that remain feasible; some of the more stringent targets may not be feasible.

Inaction in developing countries clashes with the fact that the bulk of emissions in the next decades will be coming from non-OECD countries. If CO_2 emissions are not regulated in some major emitting countries, two inefficiencies arise: (1) static inefficiency, as mitigation does not take place where mitigation costs are lowest, and (2) dynamic inefficiency, as unregulated countries are those where most of the new investments will take place. Investing instead in fossil technologies, fast growing countries eventually lock-in in these long-lived technologies (*e.g.,* a new coal plant may be in use for 50 years) and later conversion to low-carbon technologies becomes more costly, or simply impossible if early scrapping is deemed unfeasible. Finally, non-participating countries might react to lower fossil fuel prices, deriving from the contraction in the demand, and increase their emissions, thus partially offsetting the environmental benefit of early movers. One solution frequently pointed out by economists is the use of incentive systems (as for example an evolution of the Clean Development Mechanism) to induce reductions in developing countries while limiting leakage. (See Bosetti and Frankel, 2009, for a detailed discussion of political feasibility of alternative targets.)

For a more detailed discussion, we report again results from the latest Energy Modeling Forum exercise (EMF-22, Clarke *et al*, 2009) that looked extensively into the issue of asymmetry of participation to a climate agreement and how this would affect the feasibility of stabilization scenarios as well as the costs. **Figure 4** reports the results in terms of percentage of loss in the world GDP (in net present value) for different models, different targets, different emission pathways (including and excluding overshooting), and for different levels of participation (full and delayed).

The key result, consistent across models, is that the 450 ppm CO_2e stabilization scenarios are basically unfeasible if only the OECD coalition immediately undertake mitigation action while BRICs and the rest of the world remain on their business-as-usual path until 2030 and 2050, respectively. Half of the models cannot find a feasible set of investment actions for the 550 ppm CO$_2$e scenario as well, when participation of developing countries is delayed. Overshooting becomes critical for the feasibility of this intermediate target and the price of carbon that OECD countries face in 2020 increases on average, by a factor of three. There is a wide range of disagreement across models, depending on assumptions about flexibility of substitution across technologies and, once more, on the assumptions concerning the availability of negative emissions technologies (green versus blue markers in Figure 4 distinguish models with and without bioenergy with carbon capture and storage (BECS) technologies).

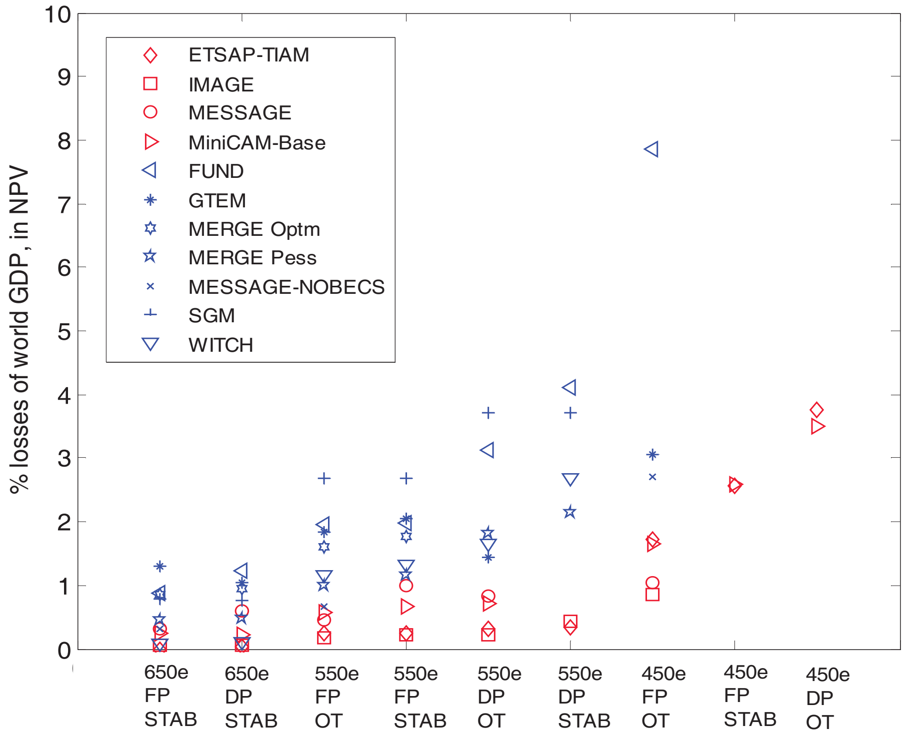

Figure 4. Policy costs for the EMF22 data set by model run. Green colors indicate models with BECS and blue models without BECS. FP=full, immediate participation of Developing Countries, DP=delayed participation of Developing Countries. STAB=target not to exceed, OS=target can be overshot. Source: Tavoni and Tol, 2010.

More generally, the set of technologies that will be available and the speed at which they will be deployed significantly affect not only the costs of any climate policy, but also the time we can wait without entering an irreversible path. The stricter the climate objective or the later the mitigation effort starts, the more we will need to resort to technologies which have potential implications that we have not yet fully understood. This obviously requires a careful and realistic estimation of the costs and potentials of these technologies, the research development and demonstration requirements to make them available with a reasonable level of certainty, and the potential barriers and external costs that might be linked to their deployment on a large-scale.

How do projections we have discussed so far compare with the current state of climate negotiations? Instead of an ideal global system, countries agreed on submitting their “pledges” during the meetings in Copenhagen in 2009 and Cancun in 2010, where most of developed countries submitted their emissions reductions targets relative to emissions in 1990, 2000, or 2005[13]. Brazil, Mexico, Indonesia, South Africa and South Korea proposed the reductions relative to their business-as-usual emissions[14], and China and India submitted carbon intensity reduction targets (*i.e.,* CO_2 emissions per unit of GDP). Some of the pledges have conditions attached, such as the provision of finance and technology or ambitious actions from other countries; some pledges were provided as ranges. This leads to a degree of freedom in their implementation and a range of potential outcomes rather than a single estimate.[15]

The implications of these pledges for 2020 global emissions will hence depend on what pledges are implemented and what rules will be applied. Many scientific groups have estimated global emissions in 2020 based on the Copenhagen Accord pledges. The 2010 Emission Gap Report (den Elzen *et al*, 2010) collects these estimates and shows that, on one hand, emissions in 2020 could be as low as 49 $GtCO_2e$ (range: 47-51 $GtCO_2e$) when countries implement their conditional pledges in their more stringent declination. On the other hand, they could be as high as 53 $GtCO_2e$ (range: 52-57 $GtCO_2e$) when countries implement unconditional pledges in their more lenient declination.

Emission pathways consistent with a “likely” chance of meeting the 2°C limit generally peak before 2020, have emission levels in 2020 around 44 $GtCO_2e$ (range: 39-44 $GtCO_2e$), have steep emission reductions afterwards and/or reach negative emissions in the longer term. Hence, the ranges implied by Copenhagen pledges do not necessarily rule out the 2°C target, as the two ranges are not severely distant from one another. However, as previously discussed, the larger the overshoot will be, the faster the de-carbonization in the second half of the century will be needed, with all the implications that we have discussed above.

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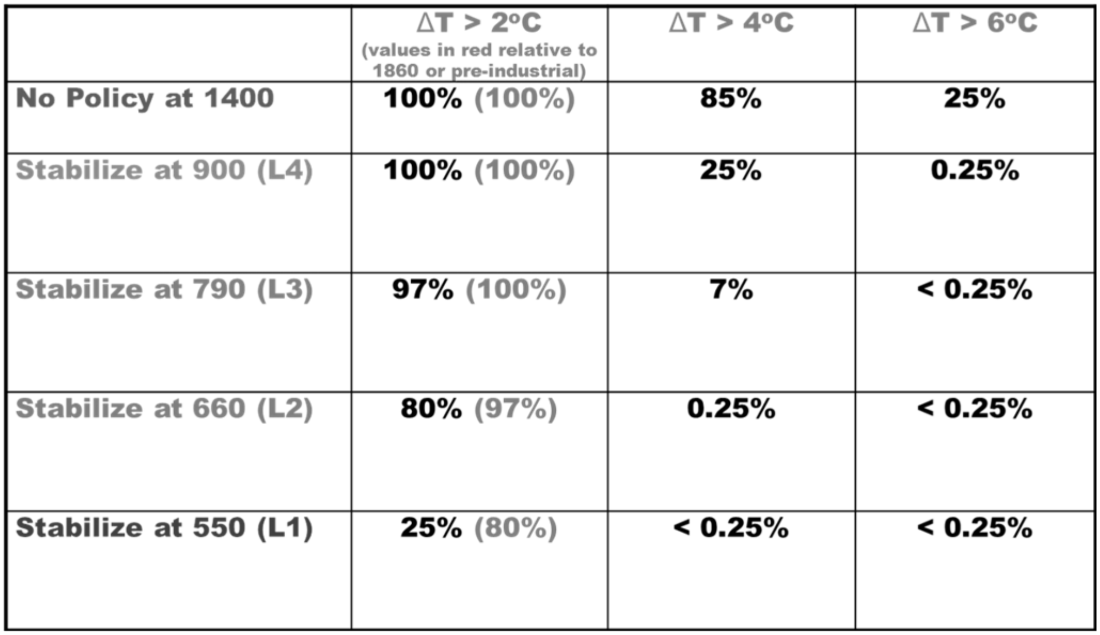
[13] Typical targets for developed regions like the U.S., EU, Canada, Japan are in the range of 20 % GHG reduction relative to 2000 levels.

[14] Targets expressed with respect to baseline emissions are particularly tricky as they can be interpreted in very different ways depending on the baseline projection adopted.

[15] The reader is referred to the UNEP website for an overview of all pledges http://www.unep.org/climatepledges/

The consideration that the 2° C target could be out of reach should not be a reason for inaction. Even limited actions towards reducing GHG concentrations result in a substantial reduction in risk of exceeding a certain temperature threshold. **Table 2** (adapted from Webster *et al*, 2009) illustrates the benefits of at least some mitigation actions in comparison to the no-action scenario. For example, stabilization at 800 ppm reduces the probability of exceeding 4°C in 2100 to 7% from 85% in the no-policy scenario. Therefore, even a limited action directed at GHG reductions by a subset of regions will appreciably reduce the probability of more extreme levels of temperature increase.

Table 2. Cumulative probability of global average surface warming from 2000 to 2100 (400 MIT IGSM forecasts per case). Source: Adapted from Webster *et al* (2009).



	$\Delta T > 2^{o}C$ (values in red relative to 1860 or pre-industrial)	$\Delta T > 4^{o}C$	$\Delta T > 6^{o}C$
No Policy at 1400	**100%** (100%)	**85%**	**25%**
Stabilize at 900 (L4)	**100%** (100%)	**25%**	**0.25%**
Stabilize at 790 (L3)	**97%** (100%)	**7%**	**< 0.25%**
Stabilize at 660 (L2)	**80%** (97%)	**0.25%**	**< 0.25%**
Stabilize at 550 (L1)	**25%** (80%)	**< 0.25%**	**< 0.25%**

5. WHO BEARS THE COSTS OF ABATEMENT?

As discussed in the previous section, the current state of climate negotiations does not give high hopes for universal participation. When regions or economic sectors are excluded, the costs of meeting the global target are higher in participating countries for any given emission target. When policy instruments deviate from an idealized economy-wide GHG tax or pricing, the costs of meeting a target also increase substantially. (For a discussion when GHG pricing or cap-and-trade system is replaced with renewable energy requirements, see, for example, Morris *et al*, 2010.) Absent near universal participation, stringent climate stabilization goals are quite costly or not achievable, because economic activity and emissions would shift to nations that do not sign the agreement[16]. Even with all nations taking on commitments, the policies would require a complex system of financial transfers to simultaneously satisfy widely-discussed burden-sharing goals. Ultimately, differences in the costs of abatement between countries will depend on their energy, industrial and agricultural systems (that would determine marginal costs of abatement in the sectors), emissions allocations, policy instruments, and financial transfers.

Two interacting equity concerns would have to be dealt with in seeking the global emissions goal. First, incentives and compensation for developing country participation will be required, consistent with the principle of common but differentiated responsibilities. Second, since mitigation costs and compensation payments by developed countries will be substantial, they also will need to find an acceptable burden-sharing arrangement among themselves. Simple emissions reduction rules are incapable of dealing with the highly varying circumstances of different countries.

Successful climate negotiations will need to be grounded in a full understanding of the substantial amounts at stake. For example, for 50% global emissions reductions by 2050 relative to 2000, Jacoby *et al* (2009) show that if developing countries (including China and India) are fully compensated for the costs of mitigation in the period to 2050, then the average welfare cost to developed countries is around 2% of GDP in 2020 (relative to reference level), rising to 10% in 2050. The implied financial transfers are large—over $400 billion per year in 2020 and rising to around $3 trillion in 2050. The United States' share of these transfers is $200 billion in 2020, and over a trillion dollars in 2050[17].

With less than full compensation the welfare burden on developing countries would rise, but the international financial transfers would remain at unprecedented scale. It is an extreme assumption that developing countries will demand complete compensation. If, as is likely, they are willing to bear some costs, then the welfare burden on the developed countries will be reduced. Also, the burden is lowered somewhat if compensation only covers direct mitigation

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[16] Most studies report carbon leakage from the Kyoto Protocol targets being in the range of 5-15%. For a discussion of estimates of carbon leakage, see IPCC (2007) section 11.7.2.1 at: http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch11s11-7-2-1.html

[17] Given large budget deficits at present, these transfers seem even more unrealistic. Even one of the Copenhagen Accord goals of $100 billion per year by 2020 for climate financing from "a wide variety of sources" seems quite questionable at this point, which illustrates a degree of difficulty to reach a global agreement when developing countries are expecting to get help with GHG emissions mitigation.

costs and not other losses associated with the policy, as might come through terms-of-trade effects. In the process the required financial transfers are reduced as well, but they remain large[18].

In general, the cost of mitigation is higher in energy-exporting countries, while energy-importers have some counter-effects in terms-of-trade due to lower fossil fuel prices that allow them to reduce the cost of participation. The welfare costs can be both substantial and wildly different across regions depending on the allocation methods and policy instruments chosen[19]. What makes matters worse is that climate change related damages vary wildly as well but in a very different way, adding up to the complexity of the problem. For success in dealing with the climate threat, any negotiation of long-term goals and paths to achievement need to be grounded in a full understanding of the substantial amounts at stake.

6. CONCLUSION

Without significant emissions mitigation action, the likely atmospheric temperature increase is projected to range between 2.5° and 6°C by the end of the century. The risks associated with temperature increases above 2°C are not fully understood. Existing scientific knowledge justifies at least slowing down the anthropogenic contribution to climate change.

In 2000, global GHG emissions were about 40 gigatonnes (Gt); a successful implementation of the Copenhagen Accord is expected to result in about 50 Gt in 2020. To be on a 2°C target path by 2050, most models project the global emissions in the range of 15-20 Gt. Some models envision a development of (still unproven) negative carbon technologies that would allow the postponement of some mitigation action. Postponing the mitigation actions, especially in emerging countries where large portions of energy capital are being installed for the first time, can be very costly. Extra costs associated with the delayed actions increases non-linearly with the stringency of the target, and some more stringent targets become infeasible if action is postponed.

To reduce the cost while achieving an equitable sharing of them, decisions about where emissions reductions are taken and how they are paid for should be separated. Emission mitigation should take place where it is most efficient. Innovation, both on energy efficiency and

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[18] In this case the annual financial transfers to developing countries are lower by $77 billion in 2020 and by $108 billion in 2050 (Jacoby *et al*, 2009).

[19] Higher the deviation from the “first-best” instruments (such as universal carbon taxes), the larger the costs.

alternative energy sources, is needed. Carbon pricing (*e.g.,* carbon taxes or a price established through a cap and trade system) would provide a signal to trigger both innovation and adoption of technologies needed for a low carbon economy.

Advocates of rapid climate stabilization might be dismayed by some of the harsh technical, economic, and practical realities discussed above. Keeping mean projected warming above pre-industrial levels to 2.0°C, or stabilizing atmospheric GHGs at 450 ppm (about current levels), would require rapid widespread international adoption of emissions control policies, and the development, and global deployment, of negative emission technologies later in the century to reverse atmospheric accumulations, after a period of overshooting the long-term concentration target. Even the 550 ppm target (mean projected warming of 2.9°C), is extremely challenging, not least because required emissions prices escalate rapidly with further significant delay in controlling global GHGs, and the annual transfers to provide some compensation for developing countries are large and contentious to design. On the other hand, near-term emissions prices that are consistent with the 650 ppm target are more moderate, and delayed action on emissions reductions is less serious for this case, though obviously this target entails greater risks of dangerous warming.

The huge uncertainties—surrounding both the extent of climate change associated with a given atmospheric concentration target, and our ability to develop technologies that would enable a rapid stabilization of the climate if the earth warms up rapidly—point to the importance of putting a policy architecture in place in the near term, and delaying decisions about how rapidly emissions should be scaled back in the distant future until some of the uncertainties have been resolved.

Acknowledgments
We thank Ian Parry (International Monetary Fund) for his valuable comments. The Integrated Global System Model (IGSM) and its economic component, the MIT Emissions Predictions and Policy Analysis (EPPA) model, used in the analysis is supported by a consortium of government, industry, and foundation sponsors of the MIT Joint Program on the Science and Policy of Global Change. (For a complete list of sponsors, see: http://globalchange.mit.edu).

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