CURRENT EMISSIONS REDUCTIONS PROPOSALS IN THE LEAD-UP TO COP-15 ARE LIKELY TO BE INSUFFICIENT TO STABILIZE ATMOSPHERIC CO_2 LEVELS: USING C-ROADS – A SIMPLE COMPUTER SIMULATION OF CLIMATE CHANGE – TO SUPPORT LONG-TERM CLIMATE POLICY DEVELOPMENT

Draft: For Comment and Review
10 March 2009

Elizabeth R. Sawin,[1] Andrew P. Jones,[1] Tom Fiddaman,[5] Lori S. Siegel,[1] Diana Wright[1] Travis Franck,[8] Andreas Barkman,[2] Tom Cummings,[4] Felicitas von Peter,[6] Jacqueline McGlade,[2] Robert W. Corell,[3] and John Sterman[7]

(1.) The Sustainability Institute, Hartland, Vermont (USA); (2.) The European Environment Agency, Copenhagen (Denmark); (3.) The H. John Heinz Center for Science, Economics and the Environment, Washington, D.C. (USA); (4.) Executive Learning Partnership, The Hague (The Netherlands); (5.) Ventana Systems, Inc. Harvard, Massachusetts (USA); (6.) The Forum for Active Philanthropy, Berlin (Germany and throughout Europe); (7.) System Dynamics Group at MIT, Cambridge, Massachusetts (USA); and (8.) MIT Joint Program on the Science and Policy of Global Change, Cambridge, Massachusetts (USA).

For correspondence: bethsawin@sustainer.org; apjones@sustainer.org

Summary

We report the creation and initial use of the Climate-Rapid Overview And Decision Support Simulator (C-ROADS) (1), a simple, fast, user-friendly simulation of climate change that conforms with accepted climate science while allowing decision makers to discover through interactive exploration the range of greenhouse gas emissions trajectories sufficient to achieve widely accepted goals for climate stabilization – such as stabilizing CO_2 levels at or below 350–450 parts per million (ppm) or limiting temperature increase to no more than 2° Centigrade over pre-industrial temperatures.

As an example of the utility of this computer simulation model for informing policy makers, other leaders, and the public about progress within the UNFCCC negotiations leading up to COP-15 (Copenhagen, Denmark, December 2009) we use C-ROADS to analyze the expected long-term impacts on the climate of proposals currently being put forth by national and regional governments. Our results show that these proposals – even if fully implemented – would be far from sufficient to meet the goals of stabilizing atmospheric CO_2 levels at or below 450 ppm (reaching ~ 730 ppm by 2100) or limiting warming to 2°C over pre-industrial temperatures (reaching ~4°C by 2100 (at the central estimate of climate sensitivity of the IPCC (2)).

Introduction

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) asserts the objective of achieving "stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system." (3)

In the period since the signing of Framework Convention, various scientists and policy makers have suggested goals and targets for avoiding the most dangerous consequences of human-caused climate change. The European Union has articulated a goal of limiting temperature increase to 2°C over pre-industrial temperatures (4). Atmospheric CO_2 levels of 450 ppm have been associated with a medium likelihood of limiting warming to no more than 2°C, while 550 ppm is unlikely to very unlikely to meet that temperature target (5). More recently, James Hansen and co-authors argued that slow climate processes augment climate sensitivity and that 350 ppm of atmospheric CO_2 represents a target humanity must meet if we wish "to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted." (6)

The achievement of these goals is increasingly understood to be essential for the future security of human communities, built infrastructure, and economic stability as well as for the integrity of ecosystems and the survival of a large number of non-human species. However, research has shown that, for the climate system, a number of factors make it extremely difficult for people to assess accurately whether or not a particular set

of measures will be sufficient to realize a given goal for atmospheric CO_2 level or temperature. Many people, including highly educated adults with substantial training in science, technology, engineering, or mathematics, misunderstand the fundamental dynamics of the accumulation of carbon dioxide and heat in the atmosphere (7, 8). Intuitive predictions of the response of the global climate system to emissions cuts underestimate both the degree of emissions reduction needed to stabilize atmospheric carbon dioxide levels and the lag time between changes in emissions and changes in global mean temperature (8). Such misunderstandings can prevent decision-makers from recognizing the long-term climate impacts likely to emerge from specific policy decisions and citizens from understanding the need for decisive action to reduce greenhouse gas emissions.

Furthermore, people charged with making decisions related to climate change – climate professionals, corporate and government leaders, and the general public – may understand the emissions reduction proposals of individual nations (such as those proposed under the UNFCCC process) but lack tools for assessing the likely collective impact of those individual proposals. The proposals are framed in heterogeneous terms (*e.g.,* as reductions in emissions relative to differing reference year emissions by differing target years, as reductions in emissions per unit of GDP, or in terms of per capita emissions targets.). Such heterogeneity makes it difficult to aggregate national proposals for future emissions reductions into a global emissions trajectory.

Thus, while enacting effective climate policy in the near term is an issue of great importance, decision makers – and the public who must ultimately be relied upon to support and enable sound climate policy – often lack the ability to assess whether proposed policy measures are sufficient to meet the long-term goals of avoiding the most dangerous consequences of climate change.

These challenges to effective decision-making in regard to climate change are typical of the challenges facing decision makers in other dynamically complex systems characterized by multiple feedbacks, time delays, and nonlinear cause-and-effect relationships. Decision making in such systems has been shown to be often suboptimal and biased (7, 9, 10).

Critical climate policy decisions will be made at the local, national, and global scales in the coming months and years. Key stakeholders need transparent tools grounded in the best available science to provide decision support for real-time exploration of different policy options and easily understandable information about the likely long-term impacts of such options (11). In other complex dynamic systems, computer simulations have been shown to help improve understanding and decision-making by providing users with quick turnaround feedback about the likely outcomes of policy choices (12, 13).

Motivated by those examples and by the critical and urgent challenge of crafting climate policy capable of avoiding dangerous anthropogenic interference with the Earth's climate, we have developed tested and employed a user-friendly computer simulation of climate change to support decision making in the run-up to COP-15 and beyond.

Model Structure and Validation

The Climate Rapid Overview and Decision Support (C-ROADS) simulator is a dynamic nonlinear simulation, tuned to the response of more disaggregated climate models.

There are a number of climate simulations that can be downloaded or run online, including FAIR (14), JCM (15), MAGICC (31), and others. Most are technically complex and suited to researchers well versed in the underlying science. C-ROADS is unique, not in its content, but in its focus on promoting learning and quick-turn-around decision support.

The simulation model is based on the biogeophysical and integrated assessment literature and includes representations of the carbon cycle, radiative forcing, global mean surface temperature, and sea level change.

Consistent with the principles articulated by Socolow and Lam (16) the simulation is grounded in the established literature yet remains simple enough to run quickly on a modest computer.

A schematic diagram of the structure of the C-ROADS simulator is show in Figure 1. Model users determine the path of net GHG emissions (CO_2 from fossil fuels and land use, CH_4, N_2O and CO_2 sequestration from afforestation), at the country or regional level, through 2100. The model calculates the path of atmospheric CO_2 and other GHG concentrations, global mean surface temperature, and sea level rise resulting from these emissions. Temperature feedbacks to the carbon cycle are not included in C-ROADS; as a result assessment of the likely climate impacts of given emissions scenarios using C-ROADS may underestimate potential increases in atmospheric CO_2 level or temperature increase that could arise from self-reinforcing warming dynamics.

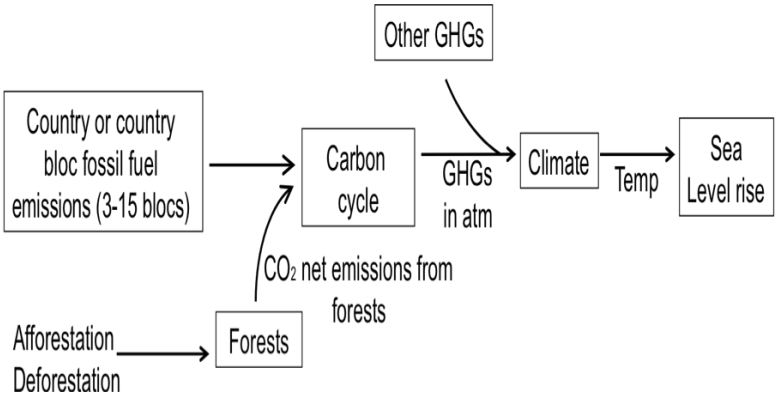

Figure 1. C-ROADS Structure. Fossil fuel carbon dioxide emissions scenarios for individual nations or groups or nations are aggregated into total fossil fuel CO_2 emissions which combine with additional uptake and/or release of CO_2 from land use decisions to form the input to the carbon cycle sector of the model. CO_2 concentrations and net radiative forcing from other greenhouse gases (CH_4 and N_2O) determine global temperature change.

The model displays historical data, including country-level CO_2 emissions from fossil fuels (17), CO_2 emissions from changes in land use (18), and GDP and population (19). "BAU" CO_2 emissions projections are tuned to replicate to the IPCC SRES A1FI and B1 scenarios (20). Emissions are allocated across regions according to the World Energy Outlook (21) projections. Population and GDP projections are based on the United Nations' World Population forecasts (22) and International Energy Agency (IEA) GDP forecasts (23).

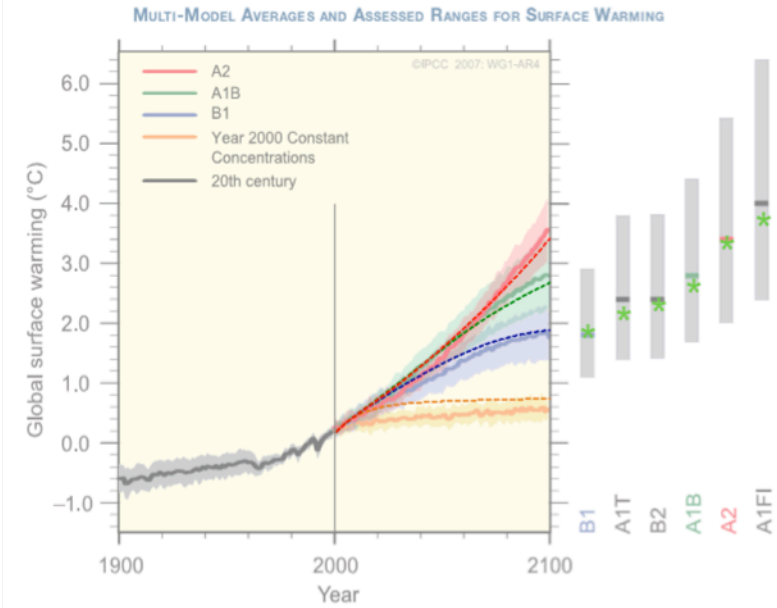

Figure 2. Comparison of C-ROADS surface temperature forecasts to the ensemble of models examined in AR4. Figure is adapted from the IPCC's Fourth Assessment Report Summary for Policy Makers. (30) Dashed lines show C-ROADS output for the corresponding emissions scenario. The grey bars at the right of the figure show the range of values produced by the ensemble of models for each emissions scenario. Green asterisks represent the C-ROADS value for temperature increase for each the specified emissions scenarios.

The carbon cycle sector employs a box diffusion ocean and two-box biosphere, similar to but simpler than Goudriaan and Ketner (24) and Oeschger and Siegenthaler, *et al.* (25). It incorporates nonlinearities in ocean buffer chemistry and biosphere carbon uptake, but not temperature feedbacks.

Radiative forcing for CO_2, N_2O

and CH_4 employs equations from the TAR (26). The climate sector is based on Schneider and Thompson (27) as used in the DICE model (28). The model has been recalibrated with a thinner surface layer to better replicate observed and AR4- projected temperatures. The sea level rise sector is based on Rahmstorf (29).

Figure 2 shows a comparison of C-ROADS forecasts under a range of emissions scenarios relative to the ensemble of models in AR4 and presented in the summary for policy makers (30). While C-ROADS is not intended to be used to generate highly precise or spatially disaggregated predictions of future climate conditions, the results shown here demonstrate that C-ROADS behavior is consistent with accepted understandings of carbon cycle and climate system behavior.

A useful comparison can be performed against MAGICC, a model of intermediate complexity that in turn summarizes the output of more detailed carbon cycle and climate models (31). Generally, in comparison to MAGICC, C-ROADS slightly understates CO_2 concentrations for high-emissions scenarios (3 to 5% for A1FI), and overstates them for low-emissions scenarios (7% for the WRE 350 stabilization scenario). Similarly, C-ROADS displays slightly less temperature variation between high and low emissions scenarios, when compared with GCMs. It is impractical to fully replicate the response of complex models with the low order structure of C-ROADS – a design constraint in C-ROADS to promote transparency for users – but we anticipate that the inclusion of temperature feedbacks to the carbon cycle in future refinements of C-ROADS will result in more temperature variation between high and low emissions scenarios. In any case, the differences observed are much smaller than the intermodel variation in the C^4MIP, SRES, and AR4 model scenarios (32) and are small relative to overwhelmed by uncertainty about climate sensitivity and other factors.

The structure and behavior of C-ROADS are currently under review by an international panel of climate scientists and modelers whose assessment of the model's performance relative to its purpose is expected shortly.

Examination of Current Proposals within the UNFCCC process

The process leading up to the COP-15 meeting of the UNFCCC provides a good example of the type of challenge facing decision makers who are charged with addressing climate change. While COP-15 is focused on fulfilling the UNFCCC mandate of preventing dangerous anthropogenic interference with the climate, assessing the collective GHG emissions trajectories that could be expected from proposals under discussion at the national or regional level is difficult without tools that allow the aggregation of proposals framed in different terms and having different reference years and target years. Additionally, even if a collective future emissions trajectory is apparent to decision makers, the sufficiency of such an emissions trajectory to achieve a given goal – such as limiting temperature increase or stabilizing GHG concentrations at specific levels – is not intuitively apparent.

Because of these difficulties we have used C-ROADS to calcuate the global CO_2 emissions trajectory that would be expected as the collective result of proposals that are committed to or under discussion during the lead-up to COP-15. We (Sustainability Institute) have focused on proposals that are available in the public domain, using as our sources government reports or policy statements and news accounts of remarks made by political leaders.

Table 1 shows our interpretation of these emissions reduction proposals as well as any simplifying assumptions we made in order to translate these proposals into forms that could serve as input into C-ROADS' emissions sector. All countries not included in Table 1 are assumed to follow the C-ROADS "Business As Usual" trajectory which is calibrated to the IPCC A1FI emissions scenario (20).

Table 1 Interpretation of Current Emissions Reductions Proposals (by Sustainability Institute; as of March 1, 2009)

Country or Country Grouping	Our Interpretation of proposal	Notes	Source
Brazil	Eliminate deforestation by 2050 (12% of global total)	Brazil's national plan on climate change puts forth the objective of reducing deforestation by 40% between 2006 and 2009 and by a further 30% in each of the two following periods of four years (33). We made the simplifying assumption that this rate of reduction of deforestation would continue to 2050 (a sufficient period to eliminate deforestation at the stated rates). C-ROADS has a global parameter for CO_2 emissions from deforestation. We attributed 12% of this global value to Brazil, based on statistics (34) showing that Brazil currently contains 12% of the world's forested hectares.	Brazil National Plan on Climate Change November, 2007 and statements by Flavio Goldman, Deputy Secretary for International Relations, Sao Paulo, Brazil (33)
Canada	70% below 2006 by 2050	The stated policy is for emissions to fall to 60% to 70% below 2006 levels by 2050. We used the upper bound, i.e. 70%.	UNFCC Technical Report November, 2008 (35)
China	BAU	Documents such as China's 11th Five Year Plan put forth a goal of a 20% decrease in energy intensity for the period from 2005 to 2010. Given that 2010 is an extremely near term target and a modest improvement in emissions intensity is already included in "BAU", we made the simplifying assumption that, within the resolution of C-ROADS this trajectory is not distinguishable from 'BAU'	News accounts ([36]) and 11th Five Year Plan (37)
Europe	80% below 1990 levels by 2050	Includes: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom, Norway and Switzerland.	February 3rd and 4th, 2009 European Parliament (38)
India	BAU rate until 2035 and then constant emissions	India has proposed that per capita GHG emissions will not exceed the per capita GHG emissions of the industrialized countries. Under the proposals described in this table US and EU emissions per capita would fall to approximately 0.7 tons C/per person yr by 2050. Allowing India emissions to grow at the BAU rate until 2035 and then freezing results in approximately equivalent per capita emissions in India, the EU, and the US.	Prime Minister Manmohan Singh speech on release of Climate Change Action Plan, June 30, 2008, New Delhi (39)
Mexico	50% below 2002 levels by 2050		Statement by Mexico's Environment Secretary Juan Rafael Elvira, December 11, 2008, Poznan, Poland (40)
OECD Pacific	60% below 2000 by 2050	To fit the national groupings in the C-ROADS structure we made the simplifying approximation that New Zealand, Japan, and South Korea's future emissions	White Paper, Commonwealth of Australia,

		follow that of Australia's current proposal.	December, 2008 (41)
Russia and parts of Eastern Europe	1990 levels by 2012	To fit the national groupings in the C-ROADS structure we made the simplifying approximation that Albania, Romania, Bosnia & Herzegovinia, Croatia, Macedonia, Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan follow the same policy as Russia.	UNDP Development Report 2007/2008 (42)
South Africa	BAU until 2022; emissions constant until 2032, then 1% per year annual decline	Minister van Schalkwyk's statement was, "emissions peaking between 2020/25, then stabilising for a decade, before declining in absolute terms towards mid-century"(43). We choose a 1% decline as moderate rate of decrease.	Keynote address by Marthinus van Schalkwyk, South African Minister of Environmental Affairs and Tourism, Washington DC, 14 January 2009 (43)
US	80% below 1990 by 2050		President Obama campaign speech Aug 4 2008, Lansing MI (44, [45])

We used C-ROADS to ask whether this scale of reduction in global CO_2 emissions would be sufficient to achieve widely accepted climate goals such as stabilizing atmospheric CO_2 levels between 350 and 450 ppm or limiting mean global temperature increase to less than two degress Centigrade over pre-industrial levels.

Based on the interpretations of current proposals shown in Table 1, we used C-ROADS to calculate future CO_2 emissions from fossil use for those countries or groups of countries that have made publically available proposals for reductions of greenhouse gas emissions. The resulting CO_2 emissions trajectories are shown in Figure 3.

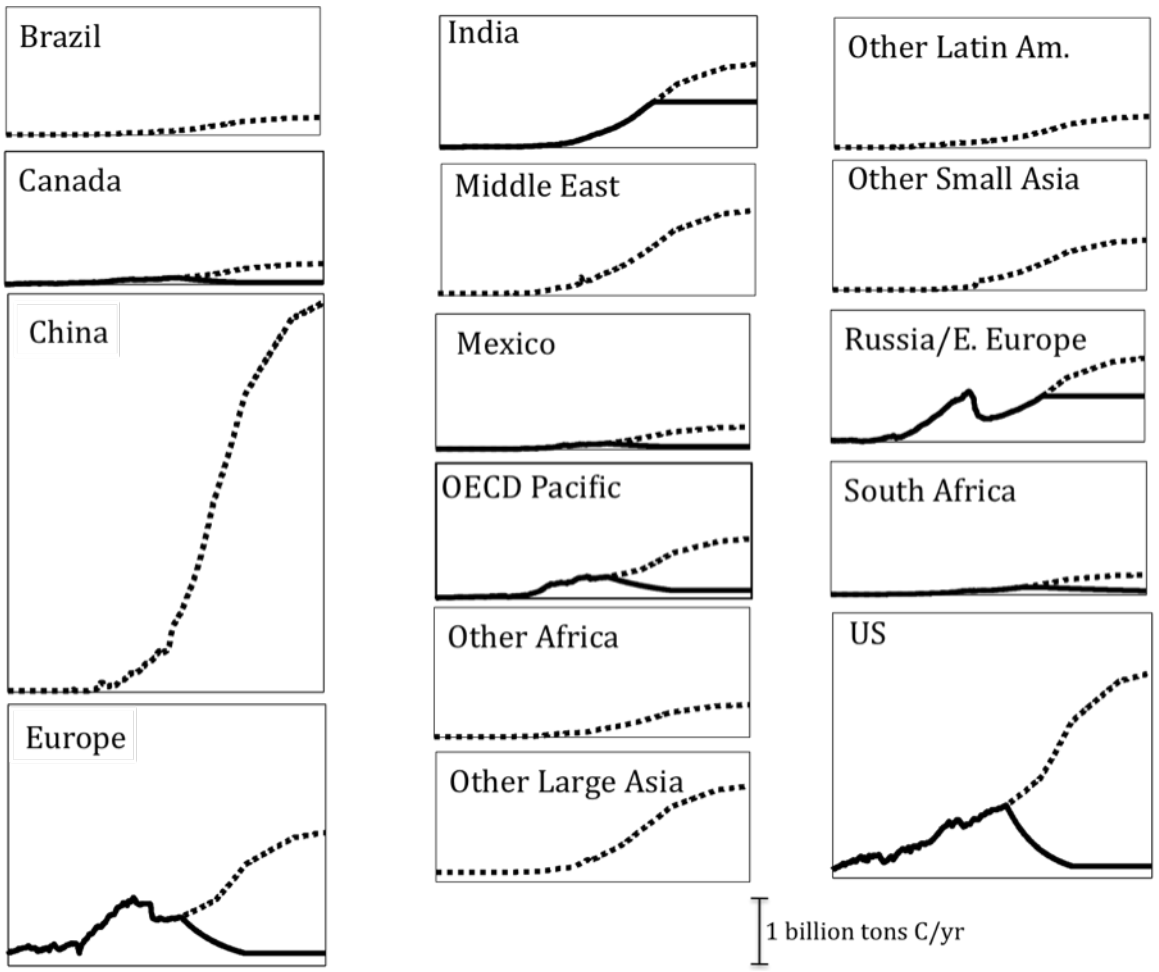

Figure 3. Emissions trajectories if current proposals for CO_2 emissions from fossil fuels were fully implemented over the time scales described in the proposals. All countries fall into one of the 15 blocs shown above, the default groupings of C-ROADS. Emissions are shown in billion tons C/year. Solid lines represent the projected emissions under the emissions reduction scenario described in Table 1. Dashed lines show the "BAU" emissions trajectory. For nations or blocs of nations without emissions reductions proposals listed in Table 1 only "BAU" emissions are shown. Only CO_2 emissions from fossil fuel use are shown.

To project a future global CO_2 emissions trajectory under a scenario where all the emissions reductions policies in Table 1 were fully implemented we used the C-ROADS simulator to aggregate the national emissions trajectories pictured in Figure 3 (the "Current Proposals" scenario). In calculating this global emissions trajectory we assumed that all countries not listed in Table 1 follow a "BAU" CO_2 emissions scenario consistent with the IPCC SRES scenario A1FI (20). In the "BAU" scenario, land use CO_2 emissions were assumed to remain constant at 2005 levels through the century. In all scenarios, the two other primary

greenhouse gasses, CH_4 and N_2O were assumed to increase through the century at the same rate as was assumed in MAGICC's SRES scenario A1FI.

Figure 4(a) shows the expected global CO_2 emissions trajectory from fossil fuel use for the "Current Proposals" scenario. "BAU" emissions and emissions under two more ambitious GHG emissions reductions proposals (discussed in more detail below) are included for reference.

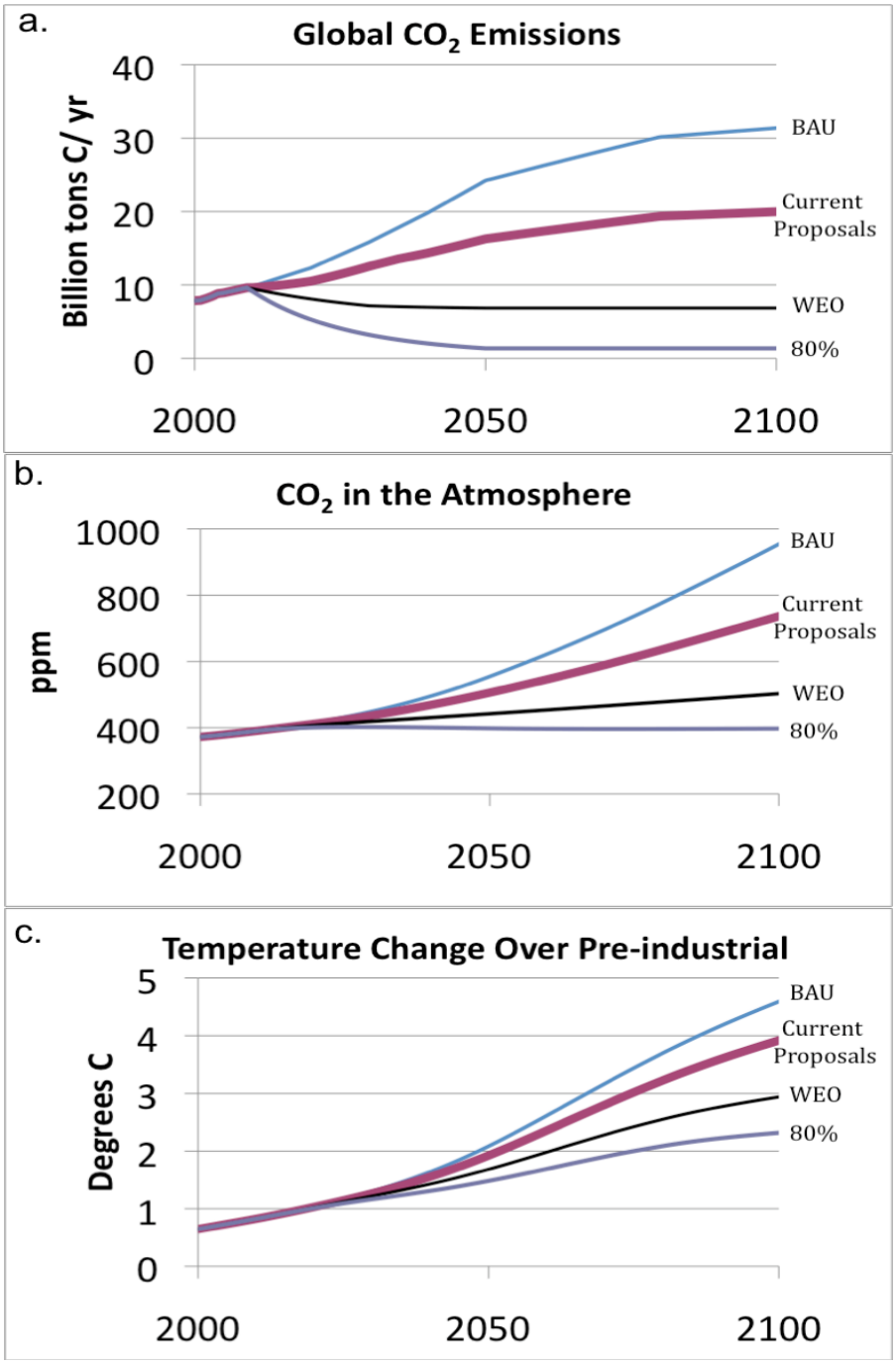

Figure 4. Global emissions, CO_2 concentration, and temperature increase for a range of scenarios; Business As Usual (BAU) is calibrated to the IPCC's SRES A1FI; "Current Proposals" include the emissions reductions proposals outlined in Table 1; "WEO" is the "450 Policy Scenario" in the World Energy Outlook 2008 report plus an 89% reduction in land use emissions from 2009 levels by 2050; and "80%" is a global 80% reduction of fossil fuel emission of 1990 levels by 2050 plus an 89% reduction in land use emissions from 2009 levels by 2050.

Under "BAU" emissions reach approximately 30 billion tons C/yr by 2100; under "Current Proposals" emissions reach approximately 20 billion tons C/yr by 2100.

Figure 4(b) shows the evolution of atmospheric CO_2 levels over time under the "Current Proposals Scenario." CO_2 emissions from fossil fuels (Figure 4a) as well as emissions from deforestation (adjusted to reflect Brazil's proposal (Table1)) were used by the simulator to calculate atmospheric CO_2 levels.

Figure 4b strongly suggests that the current emissions reductions proposals outlined in Table 1 will not be sufficient to achieve the goal of stabilizing CO_2 levels between 350 and 450 ppm by the end of this century. Instead, in this scenario CO_2 emissions are so high that atmospheric CO_2 levels continue to rise throughout the century and reach approximately 730 ppm by 2100. While this is an improvement over the 900 ppm future of the BAU scenario it falls far short of the goal of stabilizing CO_2 levels.

Figure 4c shows that current proposals are insufficient to allow humanity to achieve the goal of limiting temperature

increase to less than 2°C over pre-industrial levels. Instead the model shows a temperature rise of somewhat more than 3°C even if all proposals were fully implemented.

While the current suite of proposals coming from national goverments are insufficient to stabilize CO_2 levels near 400 ppm or limit temperature increase to less than 2°C, other proposals are able to achieve these goals.

Figure 4 also includes C-ROADS projections of the impacts on atmospheric CO_2 level and temperature increase under the WEO proposal (which allows CO_2 levels to stabilize around 500 ppm) and under a scenario of a global reduction in emissions of 80% by 2050 that results in approximately 400 ppm CO_2 at 2100.

The "WEO" scenario shown in Figure 4 employs the fossil fuel emissions trajectory of the "450 Policy Scenario" in the World Energy Outlook 2008 report (46) and an 90% reduction in land use emissions by 2050, relative to 2009 levels. It assumes a leveling of global CO_2 emissions at 29% below 2009 levels by 2040 through extensive involvement in a global cap-and-trade policy and resulting extensive deployment of hydropower, biomass, wind, and other renewable energy, plus carbon-capture-and-storage for coal. OECD countries would reduce fossil fuel emissions by almost 40% in 2030, compared with 2006 levels, while other major economies would limit emissions growth to 20%.

The "80%" scenario is an 80% reduction of global fossil fuel emissions by 2050, relative to 1990 levels, plus a 90% reduction in land use emissions by 2050, relative to 2009 levels.

Discussion

Because it is difficult for decision makers to (a) aggregate diverse emissions reductions proposals into an single global emissions projection and (b) mentally simulate from that emissions projection the resulting atmospheric CO_2 level or temperature increase, it is very difficult, even for the most informed and well-intentioned decision makers, to know whether the policies they are considering adopting are sufficient to achieve goals for stabilizing CO_2 levels and limiting global temperature increase to within a safe range.

Simple computer simulation models have the potential to provide decision makers with a general understanding of whether current policy options are sufficient to achieve desired goals.

Sound, science-based, climate policy will require that decision makers and those who advise them have access to a wide range of tools capable of making clear the long-term impacts of policy options under consideration. Simple models can play an important role in helping decision makers discover whether or not policies under consideration are capable of achieving results of the general magnitude desired.

Our analysis strongly suggests that, in order to achieve widely discussed long-term climate goals, leaders and policy makers will need to agree to implement greenhouse gas emissions reductions that are significantly stronger than those currently being discussed in the context of the UNFCCC, at least those proposals that are available within the public domain.

Our conclusions are sobering, especially given the small amount of time remaining to adjust negotiating positions in the run-up to the COP-15 conference, as our results suggest that current proposals, if fully implemented would lead to CO_2 levels in 2100 that close only about half of the gap between "BAU" and targets such as stabilization of CO_2 levels at between 350-450 ppm.

This conclusion indicates that, for COP-15 to produce an agreement capable of avoiding the most dangerous consequences of climate change, major shifts in negotiating position will be required.

The seriousness of this conclusion makes it important to consider the level of confidence decision-makers should have in our conclusions. Could the world's nations actually be more closely on track to achieve the goal of preventing dangerous anthropogenic interference with the climate system than our analysis suggests? Might there be assumptions inherent in the C-ROADS structure or in our process for gathering estimates of

current national emissions reductions proposals that could result in systematic biases that lead to higher global emissions or climate impacts than might be expected based on accepted climate science?

For our results to be exaggerating the gap between widely accepted goals and the likely outcomes of "Current Proposals" one of two things must be true: our analysis must be shown to (1) overestimate the likely global CO_2 emissions trajectory if all current proposals were to be implemented or to (2) overestimate the impact of that emissions trajectory on atmospheric CO_2 concentration and temperature increase. We consider each of these possibilities below.

It is possible that we are over-estimating the global emissions trajectory that can be expected in the 'Current Proposals' scenario because we are not aware of proposals in one or more countries that actually have strong support but which are not yet in the public domain. It is certainly possible that there exist national level proposals which have not been included in this analysis and which would result in a lower expected CO_2 emissions trajectory than we have calculated here. This possibility could best be addressed if a systematic process – perhaps with the UNFCCC process – were in place to make use of formal tools to characterize current proposals and analyze their possible effects.

It is also possible that elements found in the 'real world' but not within the model structure might put limits on future emissions, resulting in less impact on CO_2 concentration and temperature increase than our analysis suggests. Particularly given the very large anticipated future emissions of China (Figure 3) it could be argued that the GDP growth upon which China's future emissions are predicated can not continue through the century without encountering other physical or social limits which would constrain CO_2 emissions. C-ROADS structure contains no such constraints, making this a valid question. We have used C-ROADS to test scenarios in which the growth in China's emissions is severely constrained. Even if China's emissions were frozen at current levels our model indicates an overshoot of both a 450 ppm goal and a 2°C temperature increase. Experiments such as these suggest that the finding that current proposals are not likely to meet 2°C is robust.

We also believe it is unlikely that C-ROADS is overestimating the impacts of the CO_2 emissions trajectory on atmospheric CO_2 level and temperature increase. It is possible that temperature goals could still be met if climate sensitivity is low. However, subjective probability distributions for equilibrium climate sensitivity suggest that this is unlikely. Uncertainty about the carbon cycle is not as great, so it is unlikely that C-ROADS substantially overstates the atmospheric trajectory given CO_2 emissions. More importantly, C-ROADS lacks many of the positive feedback loops that may exist in the climate system (*e.g.,* feedbacks between temperature and carbon in soil and biomass, and feedback between temperature increase and other greenhouse gasses such as methane in hydrates and permafrost). The absence of such feedback processes in the C-ROADS structure implies that temperature increases in the 'real' system could be larger than in our simulation runs.

While we believe it unlikely that current proposals are sufficient to achieve climate goals we hope that other groups, using other models, will also analyze the situation and share their findings in ways that provide decision makers with timely and accurate information. A diversity of approaches and models applied to this question would enhance global understanding of the size of the gap between current policy options and what will be required to meet the goal of stabilizing CO_2 levels in a range that prevents the most dangerous consequences of climate change.

Finally, although our analysis suggests that the sum of current, publicly available emissions reductions proposals are likely to be insufficient to achieve widely accepted goals such as stabilizing atmospheric CO_2 levels between 350 and 450 ppm, our results also show that the achievement of such goals is within reach, given sufficient emissions reductions undertaken quickly enough.

In our simulation runs (Figure 4), global reduction in emissions of CO_2 from fossil fuel to 80% of 1990 levels by 2050, combined with a 90% decrease in CO_2 emissions from deforestation, result in CO_2 levels in

the range of 400 ppm and a temperature increase over pre-industrial temperatures in the range of 2°C by the simulated year 2100. These results are consistent with the lowest emissions scenarios in AR4 (47) and subsequent scenarios (48). In addition, when we simulate the fossil emissions reduction scenario of the WEO ("450 Policy Scenario") in combination with a 90% reduction in CO_2 emissions from deforestation, the resulting atmospheric CO_2 levels and temperature increase through 2100 is much closer to widely accepted climate goals than is seen with the current proposals for greenhouse gas emissions reduction that we have analyzed.

These results indicate that the achievement of widely accepted goals for the avoidance of dangerous climate change is not precluded by the inherent dynamics of the climate system, though it may require rates of change that challenge the limits of conventional economic assumptions.

In the run up to COP-15, it is critical that decision makers and the general public understand that while (a) limiting temperature increase to 2°C or less is not likely to be achieved by the current range of greenhouse gas emissions reductions proposals being discussed in public domain, (b) a set of proposals that together add up to a global reduction of around 80% of 1990 emissions by 2050 combined with concerted reductions in deforestation could achieve this essential goal.

References

1 See http://www.climateinteractive.org
2 Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Synthesis Report. Section 2.3. P 16.
3 Framework Convention on Climate Change, United Nations, 1992
4 EU Council Conclusions - Climate Change (17 October 2005: Luxembourg)
5 IPCC WGII AR4 Ch 19 Figure 19.1.
6 J. Hansen, M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo , D. L. Royer, and J. C. Zachos. Target atmospheric CO2: Where should humanity aim. Open Atmos. Sci. J. (2008), vol. 2, pp. 217-231
7 Brehmer, B. 1989. Feedback Delays and Control in Complex Dynamic Systems, in Miling, P. and E. Zahn (eds.), *Computer Based Management of Complex Systems.* Berlin: Springer Verlag, 189-196.
8 Sterman, J. (2008) Risk Communication on Climate: Mental Models and Mass Balance. *Science*, 322, 532
9 Kleinmuntz, D. and J. Thomas.1987. The Value of Action and Inference in Dynamic Decision-Making. *Organization Behavior and Human Decision Processes* 39(3), 341-364
10 Sterman, J.S. 1989. Misperceptions of Feedback in Dynamic Decision Making. *Organizational Behavior and Human Decision Processes*, 43(3), 301-335.
11 Corell, R.W., Lee, K., and P.C. Stern. Strategies and Methods for Climate-related Decision Support. In press.
12 Morecroft, J.D.W. and J.D. Sterman, Eds. 1994. *Modeling for Learning Organizations*. Portland, OR: Productivity Press.
13 Sterman, J. S. Business Dynamics. 2000. Irwin McGraw Hill: Boston, MA.
14 FAIR 2.0 - A decision-support tool to assess the environmental and economic consequences of future climate regimes. Netherlands Environmental Assessment Agency, http://www.mnp.nl/en/themasites/fair/index.html
15 Matthews, Ben. The Java Climate Model. http://www.chooseclimate.org/jcm/index.html
16 Socolow, R.H. and S.H. Lam. 2007. Good Enough Tools for Global Warming Policy Making Phil. Trans. R. Soc. A (2007) 365, 897–934.
17 Marland, G., T.A. Boden, and R.J. Andres. 2008. Global, Regional, and National Fossil Fuel CO2 Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory, U.S. Department of Energy.
18 Houghton, R. A. 2006. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. The Woods Hole Research Center. Carbon Dioxide Information Analysis Center (CDIAC), http://cdiac.ornl.gov/ftp/trends/landuse/houghton/Global_land-use_flux-1850_2005.xls.
19 Maddison, A., 2008. Historical Statistics for the World Economy: 1-2006 AD. Conference Board and Groningen Growth and Development Centre, Total Economy Database, http://www.ggdc.net/maddison.
20 Nakicenovic, N. and R. Swart, Eds. 2000. *Special Report on Emissions Scenarios*. Cambridge University Press: Cambridge, United Kingdom.
21 International Energy Agency (IEA). 2007. World Energy Outlook (WEO).
22 United Nations. 2004. World Population to 2300.

23 International Energy Agency (IEA). 2008. World Energy Outlook (WEO).
24 Goudriaan, J. and P. Ketner. 1984. A Simulation Study for the Global Carbon Cycle, including Man's Impact on the Biosphere. Climatic Change 6: 167-192.
25 Oeschger, H., U. Siegenthaler, et al. 1975. A Box Diffusion Model to Study the Carbon Dioxide Exchange in Nature. Tellus XXVII(2): 167-192.
26 Houghton, J.T., Y. Ding et. al. Climate Change 2001: Working Group 1: The Scientific Basis. Intergovernmental Panel on Climate Change (IPCC). 2001. Cambridge University Press.
27 Schneider, S.H., and S.L. Thompson. 1981. Atmospheric CO2 and Climate: Importance of the Transient Response. Journal of Geophysical Research 86: 3135-3147
28 Nordhaus, W. D. 1994. Managing the Global Commons. Cambridge, MA: MIT Press
29 Rahmstorf, S. 2007. Sea-Level Rise A Semi-Empirical Approach to Projecting Future Sea Level Rise. Science. 315:368-370.
30 IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom
31 Wigley, T.M.L (2008) MAGICC/SCENGEN 5.3: User Manual (Version 2). http://www.cgd.ucar.edu/cas/wigley/magicc/
32 Friedlingstein, P., Cox, P., Betts, R., Bopp, L., von Bloh, W., Brovkin, V., Cadule, P., Doney, S., Eby, M., Fung, I., Bala, G., John, J., Jones, C., Joos, F., Kato, T., Kawamiya, M., Knorr, W., Lindsay, K., Matthews, H.D., Raddatz, T., Rayner, P., Reick, Roeckner, E., Schnitzler, K.-G., Schnur, R., Strassmann, K., Weaver, A.J., Yoshikawa, C. and Zenget, N., 2006: Climate-carbon cycle feedback analysis: results from the C4MIP model intercomparison. *J. Clim*. **19**, 3337–3353.
33 (Brazil) National Plan on Climate Change — Nov 2007
http://www.mma.gov.br/estruturas/imprensa/_arquivos/96_11122008040728.pdf
34 Source: http://faostat.fao.org/site/377/default.aspx#ancor FAO Statistics Division 20
35 UNFCCC, Synthesis of information relevant to the determination of the mitigation potential and to the identification of possible ranges of emission reduction objectives of Annex I Parties: an update, Technical paper (FCCC/TP/2008/10), November 7, 2008, page 8.
http://unfccc.int/resource/docs/2008/tp/10.pdf
36 Great potential for China and U.S. to jointly tackle climate change," www.chinaview.cn 2009-02-20 16:08:20
http://news.xinhuanet.com/english/2009-02/20/content_10856717.htm
37 Great potential for China and U.S. to jointly tackle climate change," www.chinaview.cn 2009-02-20 16:08:20
http://news.xinhuanet.com/english/2009-02/20/content_10856717.htm
38 http://www.bellona.org/articles/articles_2009/EP_Emission_reduction
39 http://www.pmindia.nic.in/lspeech.asp?id=690
40 Mexico pledges 50 percent cut in greenhouse gases," by Vanessa Gera, Associated Press, December 11, 2008
41 "Carbon Pollution Reduction Scheme: Australia's Low Pollution Future," White Paper (Executive Summary) by Commonwealth of Australia, 15 December 2008.Executive summary available at
http://www.climatechange.gov.au/whitepaper/summary/index.html; Full paper at
http://www.climatechange.gov.au/whitepaper/report/index.html
42 UNDP Human Development Report 2007/2008, "Fighting climate change: Human solidarity in a divided world." Human Development Report Office , OCCASIONAL PAPER . Climate Change. Russia Country Paper, by Renat Perelet, Serguey Pegov and Mikhail Yulkin 2007/12
http://hdr.undp.org/en/reports/global/hdr2007-2008/papers/Perelet_Renat_Pegov_Yulkin.pdf
43 http://www.info.gov.za/speeches/2009/09011415451001.htm
44 Prepared text available at: http://www.nytimes.com/2008/08/04/us/politics/04text-obama.html
45 "Barack Obama and Joe Biden: New Energy for America"
http://www.barackobama.com/pdf/factsheet_energy_speech_080308.pdf
46 International Energy Agency. World Energy Outlook 2008. Part C: The Role of Energy in Climate Policy. Table 18.4. Energy-related CO2 emissions by sector and fuel in the 550 and 450 Policy Scenarios (Gt) (pp. 444-447).
47 B. Fisher, N. Nakicenovic et al., 2007. Table 3.5 in Climate Change 2007: Mitigation. Contribution of WGIII to the Fourth Assessment Report of the IPCC. Cambridge: Cambridge University Press
48 Van Vuuren et al. 2007, "Temperature increase of 21st century mitigation scenarios" PNAS v105 no4 pp 15258-15262.