Forthcoming, Simulation and Gaming

WORLD CLIMATE*:* A role-play simulation of global climate negotiations

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Global negotiations to reduce greenhouse gas (GHG) emissions have so far failed to produce an agreement. Even if negotiations succeeded, however, a binding treaty could not be ratified or implemented in many nations due to inadequate public support for emissions reductions. The scientific consensus on the reality and risks of anthropogenic climate change has never been stronger, yet public support for action in many nations remains weak. Policymakers, educators, the media, civic and business leaders and citizens need tools to understand the dynamics and geopolitical implications of climate change. The WORLD CLIMATE simulation provides an interactive role-play experience through which participants explore these issues using a scientifically sound climate policy simulation model. Participants playing the roles of major nations and regions negotiate proposals to reduce GHG emissions. Participants then receive immediate feedback on the implications of their proposals for atmospheric GHG concentrations, global mean surface temperature, sea level rise and other impacts through the C-ROADS (Climate Rapid Overview and Decision Support) policy simulation model used by negotiators and policymakers. The role-play enables participants to explore the dynamics of the climate and impacts of proposed policies using a model consistent with the best available peer-reviewed science. WORLD CLIMATE has been used successfully with students, teachers, business executives and political leaders around the world. Here we describe protocols for the role-play and the resources available to run it, including C-ROADS and all needed materials, all freely available at climateinteractive.org. We also present evaluations of the impact of WORLD CLIMATE with diverse groups.

KEYWORDS: Bathtub dynamics; carbon footprint; climate change; climate policy; C-ROADS; gaming; negotiation; problem solving; role-play; simulation; system dynamics

In 1992 the nations of the world created the United Nations Framework Convention on Climate Change (UNFCCC) to negotiate binding international agreements to address the risks of climate change. Almost 200 signatories—nearly every nation on earth—committed themselves to limiting greenhouse gas (GHG) emissions to prevent "dangerous anthropogenic interference in the climate system," [1] which is generally accepted to mean limiting the increase in mean global surface temperature to no more than 2°C above preindustrial levels [2]. Hopes were dashed at the Copenhagen climate conference in 2009 as face-to-face negotiations among dozens of heads of state broke down. No agreement was reached; rather each nation was encouraged to make voluntary pledges to reduce its emissions. To date, the pledges fall far short of what is needed (UNEP 2011, 2012, Rogelj *et al*. 2012), global GHG emissions have risen to record levels (Peters *et al*. 2013), and atmospheric CO_2 surpassed 400 ppm for the first time in the history of humans as a species (http://keelingcurve.ucsd.edu/).

Negotiations have failed even though scientific understanding of climate change and the risks it poses have never been stronger. In 2007 the Intergovernmental Panel on Climate Change (IPCC) concluded, in its Fourth Assessment Report (AR4), that "Warming of the climate system is unequivocal" and "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations" (IPCC 2007, AR4 *Summary for Policymakers* [SPM], 2, 5; emphasis in the original). The Fifth Assessment Report (AR5; 2013) is even stronger, stating "It is *extremely likely* [95-100% probability] that human influence has been the dominant cause of the observed warming since the mid-20th century" [3].

The Climate Change Communication Challenge

Policies to manage complex natural and technical systems should be based on the best available scientific knowledge. In the context of climate change such knowledge is provided by the IPCC and other scientific organizations. However, although necessary, scientific knowledge is not sufficient. In democracies, at least, the ratification of international agreements and passage of legislation to limit GHG emissions requires grass-roots political support. The failure of global negotiations can be traced to the huge gap between the strong scientific consensus on the risks of climate change and widespread confusion, complacency and denial among policymakers, the media and the public. For example, compared to the early 2000s, Americans are now "less worried about the threat of global warming, less convinced that its effects are already happening,

and more likely to believe that scientists themselves are uncertain about its occurrence" (Gallup 2010; see also Gallup 2012, Leiserowitz, Smith & Marlon 2010). Public opinion in other key emitter nations follows similar patterns (Gallup 2011, Leiserowitz & Smith 2010).

The gap between the science and public understanding means risk communication is now a major bottleneck to the implementation of policies consistent with climate science (Sterman 2011). However, effective risk communication around climate change is particularly difficult because the climate is an immensely complex dynamic system. Even well-educated people with strong backgrounds in Science, Technology, Engineering and Mathematics (STEM) do not understand the basic elements of complex dynamic systems, including feedback, stocks and flows, time delays and nonlinearities (Booth Sweeney and Sterman 2000, 2007; Sterman and Booth Sweeney 2007, Cronin, Gonzalez and Sterman 2009, Sterman 2010, 2011). Worse, in some nations, including the United States, climate change has become highly politicized. A concerted disinformation campaign seeks to undermine public understanding and acceptance of climate science (Oreskes & Conway 2010; Mann 2012). Hoffman (2011) argues further that climate change is becoming a polarizing issue where no compromise is possible, similar to abortion rights and gun control.

In such settings, the mere transmission of information in reports and presentations does not change attitudes and behaviors (Dean 2009, Fischhoff 2007, 2009, Olson 2009, Weber and Stern 2011). Successful risk communication begins with a thorough understanding of the mental models of the affected population (Morgan *et al*. 2001, Slovic 2000). Effective learning requires change in mental models that are often deeply entrenched. To do so, Sterman (2008, 2011) argues that scientists should develop a suite of "management flight simulators" and interactive learning environments for policymakers and the public as an integral component of the risk communication process. Such simulators enable people to learn key principles of system dynamics, principles that are applicable and useful in diverse settings, not only climate change (e.g., Morecroft and Sterman 1994, Sterman 2000). But why are simulators, and simulation games, needed? In some situations, they are not: experience and experiments enable people to learn, first hand, how a system operates. However, learning from experience is not possible for climate change. Climate science depends on simulation models because controlled experiments are not possible, the time scales involved are decades to millennia, and many climate impacts are irreversible. But why are simulations needed in the risk communication process? When experimentation is impossible, when the consequences of our decisions

unfold over decades and centuries, and when people hold strong prior beliefs, simulation becomes the main—perhaps the only—way we can discover *for ourselves* how complex systems work and what the impact of different policies might be.

Interactive, transparent simulations of the climate, rigorously grounded in the best available science, are now available, ranging from simple models to help people develop their understanding of stocks and flows (e.g., bit.ly/atmco2, bit.ly/stockflow, Moxnes and Saysel 2009) to games addressing various aspects of climate change (see, e.g., the special issue of Simulation and Gaming on climate change gaming; Reckien and Eisenack 2013) to more comprehensive models such as the C-ROADS and C-LEARN climate policy simulators (Sterman *et al*. 2012, 2013). To enable learning, the models give people control over assumptions and scenarios, encourage wide-ranging sensitivity analysis, and run nearly instantly. C-ROADS and C-LEARN are being used by a variety of policymakers and in interactive workshops for business leaders, educators and the public at large.

The WORLD CLIMATE Role-Play Negotiation

Here we describe WORLD CLIMATE, an interactive role-play simulation of the UNFCCC negotiations using the C-ROADS or C-LEARN models (Sterman *et al*. 2012, 2013). C-ROADS is a computer simulation of the global carbon cycle and climate developed under the Climate Interactive project. C-LEARN is a websim version of C-ROADS with a simplified interface. Both run on laptop computers in less than one second. WORLD CLIMATE works well using either model. For clarity, in the remainder of this article we focus on C-ROADS. Sterman *et al*. (2012) describe the model, assess its fit to historical data and compare it to state-of-the-art climate models. C-ROADS and C-LEARN are freely available, with full technical documentation, from climateinteractive.org. Many WORLD CLIMATE resources are also available in Mandarin Chinese, French, German and Spanish, as well as English.

WORLD CLIMATE is designed to help people grapple with a difficult real-world problem of great complexity, while fulfilling Mayer's (2009) criteria for effective games [4]. Useful in groups from six to sixty or more, participants play the role of negotiators for various nations or blocs of nations. Participants must consider their national interests as they negotiate a global agreement to mitigate climate change. As in traditional role-play simulations, participants receive briefings to help them understand the national interests and objectives of the nations they represent. They then negotiate with one another to agree on commitments for GHG emissions reductions from the present through 2100, long enough to capture projected population

growth, economic development and important climate impacts. Unlike traditional role-play negotiations, however, the participants' proposals are then entered into C-ROADS, providing them with immediate feedback on the likely consequences, including per capita emissions, the carbon intensity of the economy, GHG concentrations, global average surface temperature, ocean acidification and sea level rise, over the remainder of this century.

Typically, the emissions reductions participants propose fail to limit projected warming to the accepted target of 2°C above preindustrial levels. Participants then use the results to negotiate another set of proposals, with feedback from the model on the likely consequences.

The debrief addresses a wide range of concerns, including the biogeochemical dynamics of the climate, underlying principles of system dynamics, geopolitical, economic and cultural barriers to global agreements, managing hope and fear amidst an uncertain future and the technological and behavioral changes that can help reduce GHG emissions and limit the damage from climate change.

We have run WORLD CLIMATE for business leaders, policymakers, oil industry executives, the US Forest Service, students at MIT and other universities, high school students, religious congregants and many others. WORLD CLIMATE helps people learn the policy-relevant science of climate change, viscerally experience the international politics and explore realistic solutions to the challenges of building a low-carbon economy.

WORLD CLIMATE is not a platform for advocacy. Participants are free to propose any policies they choose, including no action, and to explore alternative assumptions about the response of the climate to GHG emissions. The simulation shows participants the likely consequences of *their* choices, using a model that captures the best available scientific knowledge, but does not prescribe what should be done.

We next describe the WORLD CLIMATE game and debriefing. Like any complex role-play, effective delivery requires practice, but many have learned to run the simulation successfully from the free materials. We close with assessment of the game from formative evaluations that provide insight into how the experience affects participants' understanding and attitudes.

Overview, Roles and Setup

Table 1lists the materials needed for the simulation. The time required can range from a minimum of about 45 minutes for an abbreviated session to as long as a day. We recommend three to four hours. We have also successfully run the simulation across multiple days in university settings where class sessions are

50 or 80 minutes. A single facilitator can run WORLD CLIMATE, although additional facilitators help in large groups. Participants need not prepare prior to the session. If the opportunity for preparation exists, assign a short reading such as the most recent IPCC Assessment Report *Summary for Policymakers*.

Materials

Briefing Memos for each delegation (1 per participant)
Nametags/credentials for delegates (1 per participant)
Placards with delegation name for tables (1 per delegation)
Proposal Record Sheets (several per delegation)
1 table for each delegation with sufficient chairs for each participant
Food/drinks for delegates representing developed nations
Computer with C-ROADS installed or internet connection to access C-LEARN model
Projector for computer output
Blackboard/Whiteboard/Flip Chart to record proposals, notes
Large sheet or tarpaulin to demonstrate impact of sea level rise
Candle, matches, large cup of water and/or fire extinguisher

Optional: Background readings (e.g., IPCC *Summary for Policymakers*)

Sequence of play

1. Welcome and introductions
2. Participants assigned to roles, take seats & read briefing memos
3. Secretary General calls the Conference of the Parties to order and addresses the delegates
4. Negotiation Round 1
    a. Negotiations among parties
    b. Two-minute plenary address by representative of each delegation outlining their proposal
    c. Proposals entered into C-ROADS or C-LEARN model
    d. Results shown and discussed
    e. Sea level rise illustrated with sheet and website
    f. Bathtub dynamics discussed,
    g. Burning Candle demonstration
5. Negotiation Round 2 (steps a-d)
6. Negotiation Round 3 (steps a-d)
7. Secretary General brings negotiation to close
8. Debriefing
    a. Participant reactions, comments, feelings; shifts (if any) in negotiating positions across rounds noted and discussed.
    b. Implementation: can emissions be cut? Costs and barriers to implementation of participant proposals
    c. How can we catalyze change (participants' theories of change)
    d. Wrap-up: Personal aspirations and commitments to action
9. Thank yous; participant evaluations and feedback

Table 1. WORLD CLIMATE materials and sequence of play. Briefing memos and slides are freely available at climateinteractive.org.

Participants are divided into negotiating teams representing different nations and regions. Six nations/blocs work effectively; these are the United States, European Union, other developed nations, China, India, and other developing nations. The C-ROADS model supports the six-party mode (and also offers a 15 nation/bloc mode). The online C-LEARN model supports the three-party mode [5]. In all cases every nation on Earth is represented by one of the delegations.

The simulation is best conducted in a flat room with tables for each delegation that can be moved as needed (Figure 1). Placards denote the table assigned to each delegation.

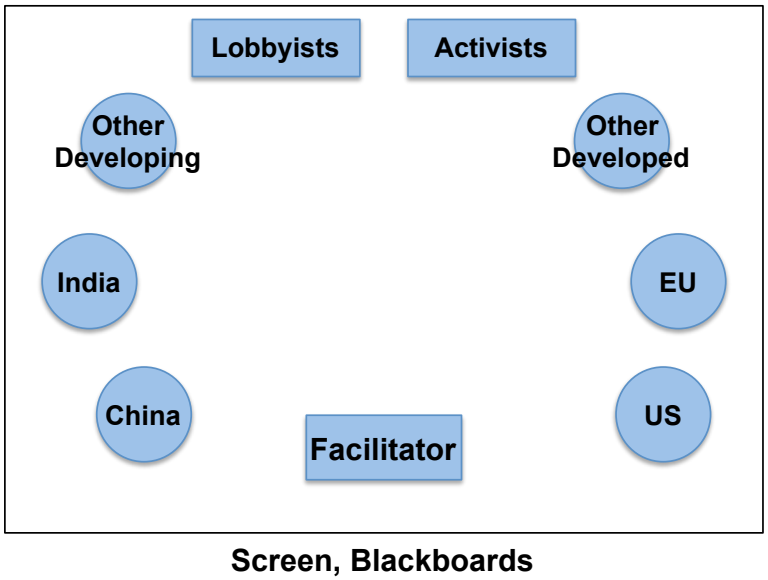


Figure 1. Typical room layout, for six-party mode with optional fossil fuel industry lobbyists and environmental activists. The large open space in the middle will be where the delegates representing the Other Developing Nations will be seated on the floor, and where delegates can meet to negotiate. The tables for the developed nations (US, EU, Other Developed) should have food and drink, while those of the developing nations (China, India, Other Developing) should be bare.

Part of the value of the exercise lies in coming to understand the perspectives of other nations. We recommend pre-assigning people to balance each delegation by nation of origin, gender, etc. If pre-assignment is not possible, assign participants randomly, or ask them to identify the delegation that includes their own country, or for which they feel affinity, and then swap them so that participants play roles that differ from the country they favor. Give participants badges with their names and delegation, similar to the credentials UNFCCC delegates wear.

To accommodate larger groups we have created other roles, including lobbyists for the fossil fuel industry and activists representing environmental NGOs or indigenous populations. Briefing memos for these groups are available online. These actors can be encouraged to lobby, stage demonstrations, lead walkouts and employ other tactics used in the actual negotiations, e.g., www.youtube.com/watch?v=Xg88rf-5t4A. The workshop can also be run with groups playing the role of advocates for other species and future generations – including, where appropriate, the actual children of participants. For large groups it is useful to designate an ombudsperson who works to broker deals among delegations.

Briefing the Negotiators

To help participants understand the economic and political constraints they face, each delegation receives a confidential Briefing Memorandum outlining the negotiating position of the nation(s) they represent. Each memo describes the negotiating position for their delegation and data on GHG emissions they can use to argue their case. Table 2 excerpts text from the memos for the US and Chinese delegations. The US memo stresses that China is now the world's largest GHG emitter, although the Chinese memo emphasizes that the vast majority of GHG emissions to date were generated by the developed nations.

To reinforce the national interests of the delegates, we set the tables for the delegations representing the developed nations (the US, EU and Other Developed Nation delegations in the six-party version) with tablecloths, food and drinks, the more lavish the better, although a simple box of pastry can suffice. The tables for the other delegations are bare.

To further reinforce the power differential among nations the facilitator should ask all the delegates from the least developed nations to sit on the floor, with exceptions only for physical hardship. Requiring participants representing the poorest nations to sit on the floor while those representing the rich nations enjoy seats, food and drink vividly demonstrates the differences in economic and political power among nations.

After the delegates receive their briefing memos, the facilitator, playing the role of the UN Secretary General (currently Ban Ki Moon) or Secretary of the UNFCCC (currently Christiana Figueres), formally calls the meeting to order. The Secretary General's introduction and charge to the negotiators not only presents participants with up-to-date information on GHG emissions and climate risks, but impresses upon the participants that although they are playing a game, the risks are real, the issues difficult and the responsibility on them, as negotiators, is serious, as Ban Ki Moon stated at COP17:

CONFIDENTIAL
Briefing for Upcoming Climate Negotiation

TO: Negotiators for the ***United States*** at UN conference on Climate Change
SUBJECT: Our negotiating goals

You head the United States delegation at the upcoming negotiations on climate change.

The best available science shows the risks of climate change are real and serious. The United States seeks to negotiate a global agreement to reduce greenhouse gas (GHG) emissions that achieves the best outcome for our economy and vital national interests, as well as for the world. A majority of the public in our country believes climate change is real, and that human activity contributes significantly to it. Most support agreements to address the climate change issue. However, most oppose higher taxes on energy or other actions that will raise the cost of living. Climate change ranks near the bottom of most people's priorities including jobs and the economy.

Most importantly, the public is strongly opposed to any agreement that does not require mandatory commitments by the developing nations, particularly China and India. With the economy still weak there is fear that actions to limit emissions will harm US competitiveness, hurting both businesses and workers as profits and jobs move offshore even faster than they are now. Any agreement that puts the greatest economic burden of limiting climate change on the US is not politically acceptable. After the Kyoto Protocol was signed, the US senate passed a resolution opposing any international agreement limiting US GHG emissions unless there were also mandatory limits for China, India, and other developing nations. The resolution passed 95-0, and the Clinton administration never submitted Kyoto for ratification. The Bush administration then formally withdrew from Kyoto. The Obama administration proposed limits on US GHG emissions, but any treaty must be ratified by the US Senate, and enabling legislation passed by both the Senate and House. Cap and trade legislation designed to reduce US emissions died in 2010 without coming up for a vote, and there have been few proposals in Congress to reduce emissions since.

China is now emitting over 25% of global CO_2 emissions, more than the US, Mexico, and Canada combined, and its emissions and economy are growing far faster than ours…. The US cannot agree to action unless there are significant, verifiable agreements for emissions reductions from China and the rest of the world.

CONFIDENTIAL
Briefing for Upcoming Climate Negotiation

TO: Negotiators for ***China*** at UN conference on Climate Change
SUBJECT: Our negotiating goals

You head the Chinese delegation at the upcoming negotiations on climate change.

The best available science shows the risks of climate change are real and serious. China seeks to negotiate a global agreement to reduce greenhouse gas (GHG) emissions that can limit those risks, but seeks the best outcome for our economy and vital national interests. Many people in our country believe climate change is real, though fewer support agreements to address the risks of climate change. Besides environmental benefits, reaching an agreement to limit climate change would have some political benefits for China…. However, our average standard of living is still far less than that in the US, Europe, Japan, and other developed nations. Our top priority is economic development. Our people, like people everywhere, want to live in a healthy environment, but also want to increase their standard of living: a healthy environment includes having the means to provide for decent jobs, housing, food, healthcare, mobility and national security.

The developed nations of the world created the climate crisis, and must take responsibility for their past actions. Roughly three quarters of the total CO_2 released by burning fossil fuels since the start of the industrial revolution came from the developed nations. These nations used that energy to build their economies and enrich their populations, often by exploiting our natural resources…. Nevertheless we have made a commitment to reduce our emissions relative to our economic growth and are taking steps to support sustainable development and cleaner energy, and to pilot carbon trading. This is significant progress in addressing climate change. In an international agreement we expect developed nations to take the lead in dramatically reducing their emissions. At past climate summits, the developed nations pressured us to reduce our emissions because we are now the world's largest GHG emitter and because our economy and GHG emissions are growing faster than theirs. Emissions per capita in developed nations are far higher than ours (US emissions per capita are roughly 3 times higher than China's and an astounding 12.5 times higher than India's). Any agreement that puts the greatest burden of limiting climate change on us is not acceptable.

Table 2. Excerpts from briefing memoranda for the United States and China.

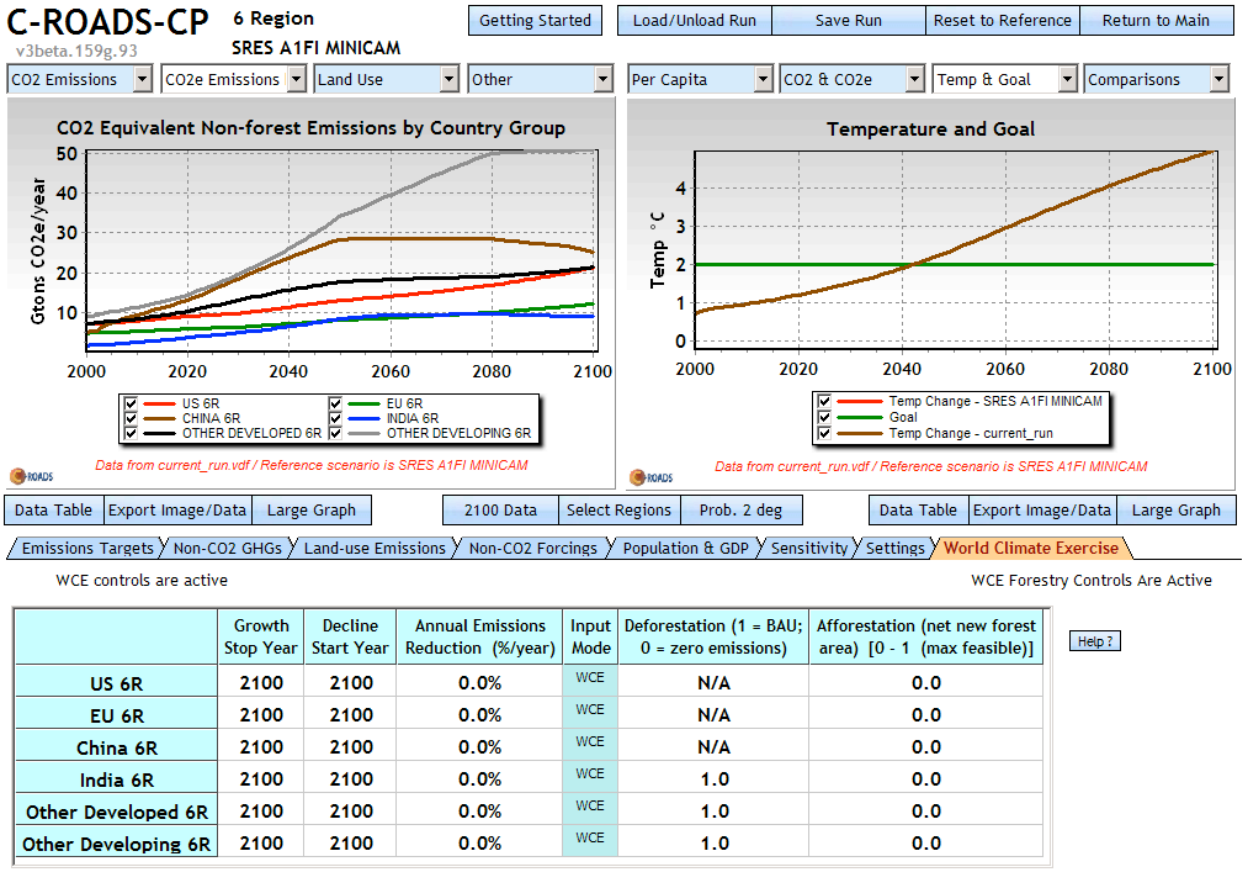
> "It would be difficult to overstate the gravity of this moment. Without exaggeration, we can say: the future of our planet is at stake. People's lives, the health of global economy, the very survival of some nations. The science is clear.…According to the International Energy Agency, we are nearing the "point of no return," and we must pull back from the abyss" (unfccc.int/meetings/durban_nov_2011/statements/items/6584.php).

The briefing slides, available online, demonstrate to participants that global emissions have been growing faster than the scenarios the IPCC used in the fourth assessment report (Peters *et al*. 2013). Briefing slides also show data for atmospheric CO_2 concentrations, and the risks of continuing Business-As-Usual (BAU) including declines in agricultural productivity and water availability, increases in extreme weather events including droughts and floods, more rapid extinction of species and greater chances of crossing tipping points that could cause climate change to become self-reinforcing, leading to large, abrupt and essentially irreversible changes in climate (IPCC AR4 SPM 2007, pp. 13-14, Solomon *et al*. 2009, IPCC 2011). Simulations (Sokolov *et al*. 2009, Prinn 2013) yield expected temperature increase under BAU of 5.3°C (9.5°F) by 2100, with a 90% confidence interval from 3.5 to 7.4°C (6.3 to 13.3°F). Since many people are unfamiliar with the concept of confidence intervals, we often explain as follows:

> "There is uncertainty about the impact of emissions on the climate. The expected warming under BAU is 5.3°C (9.5°F). The 90% confidence interval means that there is a 5% chance we could be lucky—continuing on the BAU path may only cause warming of 3.5°C (6.3°F) or a little less. On the other hand, there's also a 5% change that the climate is more fragile than we think, and could warm by 7.4°C (13.3°F) or more by 2100. In plain language, we are playing Russian roulette with the future, using a weapon in which 19 of 20 chambers are loaded. And the gun is not pointed at our own heads, but at the heads of our children and grandchildren."

The Secretary General then introduces the C-ROADS model, briefly explaining the purpose and structure of the model, reviewing the model's fit to historical data for GHG emissions and concentrations, global mean surface temperature, sea level and other key variables and the conclusions of the scientific review panel. Full model documentation and the report of the scientific review committee are available at climateinteractive.org/simulations.

The facilitator next projects the model on the screen and presents the BAU scenario (Figure 2), starting with emissions. The default BAU scenario in C-ROADS as of 2013 is the IPCC SRES A1FI scenario (www.ipcc.ch/ipccreports/sres/emission/index.htm). A1FI portrays a rapidly developing world that remains largely dependent on fossil fuels for energy. C-ROADS includes many other scenarios you can use as the BAU case, including a user-defined option.



	Growth Stop Year	Decline Start Year	Annual Emissions Reduction (%/year)	Input Mode	Deforestation (1 = BAU; 0 = zero emissions)	Afforestation (net new forest area) [0 - 1 (max feasible)]
US 6R	2100	2100	0.0%	WCE	N/A	0.0
EU 6R	2100	2100	0.0%	WCE	N/A	0.0
China 6R	2100	2100	0.0%	WCE	N/A	0.0
India 6R	2100	2100	0.0%	WCE	1.0	0.0
Other Developed 6R	2100	2100	0.0%	WCE	1.0	0.0
Other Developing 6R	2100	2100	0.0%	WCE	1.0	0.0

Help ?

Figure 2. C-ROADS main screen, showing the emissions for each of the six nations/blocs (left graph) with projected future global mean surface temperature (right graph). This view shows the Table Entry format for WORLD CLIMATE through which facilitators can enter delegate decisions. More advanced modes of entering emissions pathways, and for sensitivity analysis, are available through the other tabs. C-ROADS is freely available for download from climateinteractive.org.

Next, the facilitator shows the likely impacts of BAU emissions, in the following sequence: atmospheric GHG concentrations, global mean surface temperature anomaly, ocean pH and sea level rise. Take questions from the delegates—it is important that they understand the dynamics of and connections among these variables. We recommend that facilitators show that the model easily enables sensitivity analysis. Although the base case represents the scientific consensus, uncertainty around the response of the climate to GHG emissions exists. C-ROADS does not require participants to accept any particular assumptions. C-ROADS includes sliders for key parameters including the rate at which CO_2 is removed from the atmosphere by the oceans and by biomass, climate sensitivity (the equilibrium rise in global mean surface temperatures given a doubling of CO_2 concentrations over preindustrial levels), sea level rise per degree of warming resulting from increased melting of the Greenland and Antarctic ice sheets, increased

GHG release from melting of permafrost and others. Showing how these uncertainties work, for example, illustrating the impact of varying climate sensitivity and ice sheet melt rates on sea level, helps participants understand climate dynamics, and, more importantly, shows that they can try any assumptions they like; they are not asked to accept any particular set of results.

Finally, re-emphasize the goal—to achieve emissions reductions that collectively are likely to limit warming to no more than 2°C above preindustrial levels.

First Round of Negotiation

The first round of negotiation begins after the Secretary General concludes his or her charge to the delegates (Table 1). A minimum of 20 minutes is recommended for the first round; larger groups require more time. Monitor the mood and progress of the group and adjust the time accordingly. At the end of that time, each delegation must specify what, if any, commitment they are willing to make to change their GHG emissions. If no pledge is received, that delegation's emissions follow the BAU scenario.

Hand out the Proposal Record Sheet (Figure 3) to each delegation to record their pledges. C-ROADS offers a variety of ways to enter emissions pathways for each delegation, allowing complete control over the emissions path through 2100. We recommend a simple method in which the delegates specify future emissions with three parameters: the growth stop year (when each nation/bloc is willing to cease the growth of its GHG emissions, if they are willing to do so); the decline start year (when each nation is willing to begin a decline in their emissions, if they are willing to do so); and the decline rate (the annual rate of decline in emissions after the decline begins). These parameters are easily explained and entered quickly into the model, and provide a good approximation to continuous emissions paths (Figure 4).

Delegates also have the option of proposing Reductions in Emissions from Deforestation and land Degradation (so-called REDD+ policies), including options to reduce deforestation and to implement afforestation programs.

Finally, the developed nations specify how much they will commit in aid to help the developing nations pay the costs of mitigation and adaptation. The declaration of the parties at the 2010 COP16 meeting established "a goal of…USD 100 billion per year by 2020 to address the needs of developing countries" (unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf, Section IV.A.98). That target was reaffirmed at COP17 and COP18, although pledges remain far below the goal. It is up to the delegates from the developed nations to decide how much, if anything, they pledge toward the $100 billion/year goal, while the developing

nations specify how much they require in annual aid to enable them to undertake their emissions reductions. Proposals for emissions reductions, REDD and funding can be unconditional or conditional on other delegations' emissions reductions and pledges.

Proposal Form

- **Region:** _____
- **CO_2 Emissions growth stop year:** _____
- **CO_2 Emissions decline start year:** _____
- **Fractional rate of decline (%/year):** _____
- **REDD+ (Reduction in Emissions from Deforestation and land Degradation)**_____
  India, Other Developed, Other Developing only:
  (1 = no reduction from BAU; 0 = max reduction)
- **Afforestation (net new forest area)** _____
  All nations/regions: (0 = no new afforestation area; 1 = maximum feasible)
- **Your region's contribution to fund for mitigation and adaptation ($B/year):** _____

Figure 3. Proposal form for each delegation (six delegation version).

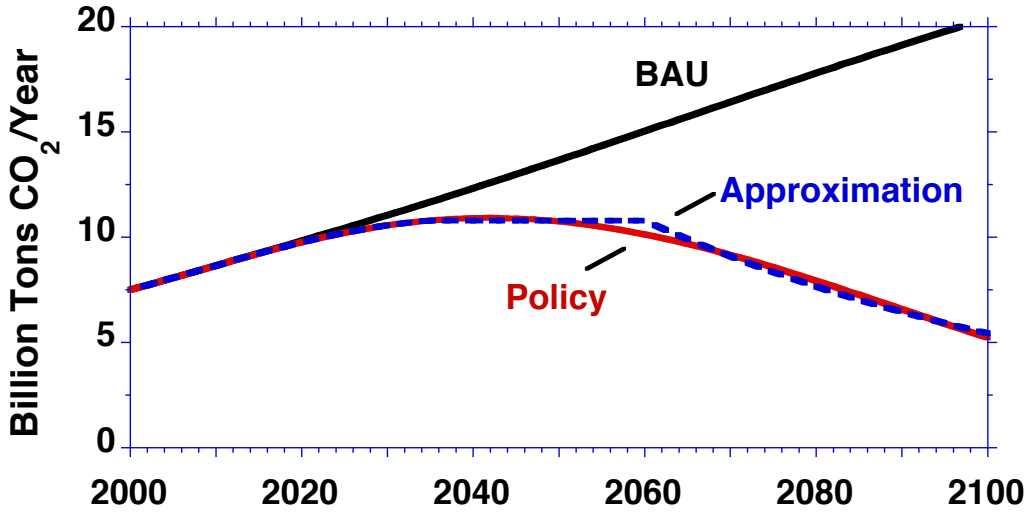


Figure 4. Hypothetical emissions path for the US, illustrating how specifying an emissions growth stop year, emissions decline start year and decline rate provide a good approximation to smooth projections of emissions under reductions policies. In the example, the growth rate in US CO_2 emissions under the hypothetical policy declines linearly from the BAU rate of 1.3%/year in 2012 to –2.5%/year in 2100, causing emissions to peak in 2042. The smooth Policy pathway is closely approximated by a growth stop year of 2035, a decline start year of 2060, and a fractional decline rate of 1.7%/year.

As the participants negotiate, move among the delegations, answering any questions that may arise. Delegates from the least developed nations (those sitting on the floor) often feel powerless and frustrated—their GHG emissions are currently very small, yet they will suffer the most from the consequences of climate change and have the least capacity to adapt. They often ask what they can do to influence the other delegations. Encourage delegates to be creative. In some sessions delegates from the developing nations have staged demonstrations, blocked exits from the room, led walkouts, and taken, without permission, the food of the developed nations—including, in one case, appropriating the entire table of the US delegation.

After the first round of negotiations one representative from each delegation makes a two-minute plenary address to the full conference describing and arguing for their proposal. We recommend that the facilitator continue in the role of the Secretary General during these presentations, formally calling each representative to the podium to address the delegates. Record the proposals of each delegation on the blackboard using the table shown in Figure 5. We have found an effective order of presentation to be the US, EU, Other Developed Nations, China, India, and Other Developing Nations (or Developed, Rapidly Developing, and Less Developed in the three-bloc version).

Proposal Summary

	Emissions Growth Stop Year	Emissions Reduction Start Year	Annual Emissions Reduction (%/year)	REDD (1 = BAU; 0 = zero emissions)	New Afforestation Area (0-1 [max feasible])	Contribution to (or Draw on) Fund ($ Billion/yr)
United States				**NA**		
European Union				**NA**		
Other Developed						
China				**NA**		
India						
Other Developing						
Example	*2075*	*2085*	*1.0%/year*	*0.8*	*0.1*	*$10 B/yr*

Figure 5. Summary table of delegate proposals to be projected or written on the blackboard and filled in as each delegation presents their proposals during their plenary presentations.

Encourage creativity in the plenary presentations. In one session, two participants assigned (by chance) to the Chinese delegation were fluent in Mandarin and English. Playing the role of lead negotiator and translator they presented their address in Chinese with consecutive translation in a highly formal manner. In another, the delegate representing the least developed nations gave an impassioned speech castigating the developed nations for failing to cut emissions, then led a silent walk out of the entire delegation.

After the presentations thank the delegates, then enter their proposals into C-ROADS. Before showing the results, ask the group how close to the 2°C goal their pledges will come. Typically, first round proposals lead to expected warming far above the 2°C target. Use C-ROADS to show the impact of the proposals, beginning with global GHG emissions, then GHG concentrations, expected temperature increase, ocean acidification (pH), and, finally, sea level rise.

First round proposals usually cause sea level to rise only slightly less than the BAU amount (approximately 1.25 meters by 2100). To show the impact of such a large increase, we take a large sheet and cover the participants from the developing nations, who are still sitting on the floor (Figure 6). When additional facilitators are present, we use sheets to cover up all the other delegations—coastal settlements in every region will suffer from rising sea level. Covering the delegates dramatically demonstrates the consequences of sea level rise. Next, we show the impact of sea level rise on particular regions of the world, using, e.g., flood.firetree.net, asking the group which regions to examine. Regions vulnerable to sea level rise in the US include the Mississippi delta and Gulf of Mexico region, the mid-Atlantic coast, and San Francisco bay area/Sacramento-San Joaquin deltas. In Europe, the Netherlands, Denmark, Venice, London and many other areas will be heavily affected. In Asia, many coastal areas will be inundated, including the deltas of the Indus, Ganges, Mekong, Yellow and Yangtze; major economic zones of China including Shenzhen and Shanghai and major coastal cities of Japan. Many island states will be completely inundated.

Figure 6. Often, the first round proposals lead to small emissions reductions and a large increase in sea level. To show the impact of sea level rise on their populations, the facilitator covers the delegates representing the developing nations (those sitting on the floor) with a large sheet. In some sessions, those covered by the sheet spontaneously become climate refugees, taking the seats of the other delegations, a highly effective illustration of the destabilizing impact of sea level rise.

Participants from regions far from the sea may remark that they will not be affected. We ask the group to discuss, elaborating only if the delegates are not able to explain. Sea level rise is only one impact of climate change; others include extreme heat, loss of winter snow pack and alpine glaciers, droughts, increased wildfire risk, and declines in agricultural production. Rising sea levels will also create knock-on impacts on all people, no matter where they live. Using, e.g., flood.firetree.net, we often focus on the Indus river delta, showing that much of this heavily populated and agriculturally important region will be inundated with even one meter of sea level rise. We ask participants to explain the likely consequences; they quickly note that the displacement of millions as climate refugees on the border of India and Pakistan increases the risk of conflict between these nuclear-armed nations with historic grievances against one another.

In several sessions the delegates from the least developed nations (those who were sitting on the floor and covered by the sheet) have gotten up and taken the seats and food of the delegates from the developed nations. As one group of climate refugees told the startled developed nation delegates, "We've been forced from our homeland by the climate change you caused. You tried to turn our boats away, but we are here. You must compensate us for the loss of our homes. We need jobs, housing, health care and education. We are desperate."

Bathtub Dynamics

Often the first-round proposals cause global CO_2 emissions to stabilize, yet the model will show a steady rise in atmospheric CO_2 and global mean temperature. Participants often ask why. If not, we ask the group. Research shows that most people, including highly educated elites with substantial training in STEM, often find this result surprising—they expect that stabilizing emissions should stabilize atmospheric CO_2 concentrations and halt further climate change (Sterman & Booth Sweeney 2007, Sterman 2008). System dynamics research, e.g., Booth Sweeney and Sterman (2000), Cronin, Gonzalez and Sterman (2009), further demonstrates that the failure to understand the accumulation of GHGs in the atmosphere is not a function of the unfamiliarity and complexity of the carbon cycle and climate system. Instead, many people with substantial STEM training do not understand or cannot apply basic principles of accumulation (stocks and flows) and make similar errors in familiar, everyday contexts such as cash flows into and out of a bank account, or water flowing into and out of a bathtub. Training in system dynamics can improve people's understanding of stocks and flows (Sterman 2010), but few people have the time to take a semester-long course in system dynamics.

C-ROADS and C-LEARN are designed to help people understand the stock-and-flow structure of CO_2 accumulation in the atmosphere. Both provide graphs showing both global emissions and the net flux of CO_2 removed from the atmosphere as it dissolves in the ocean and is taken up by biomass (Figure 7). Today, emissions are roughly twice as large as the net removal flux. The situation is analogous to a bathtub in which the flow in from the tap is twice as large as the flow out through the drain. Even if participants stop the growth of global CO_2 emissions, emissions remain substantially above net CO_2 removal from the atmosphere, so the CO_2 concentration continues to rise. Stabilizing atmospheric CO_2 requires emissions equal removal. Encourage discussion on this point to make sure people understand the "bathtub dynamics" governing CO_2 concentrations (Figure 8). After the discussion, participants should understand why stabilizing atmospheric GHG concentrations requires deep cuts in global emissions.

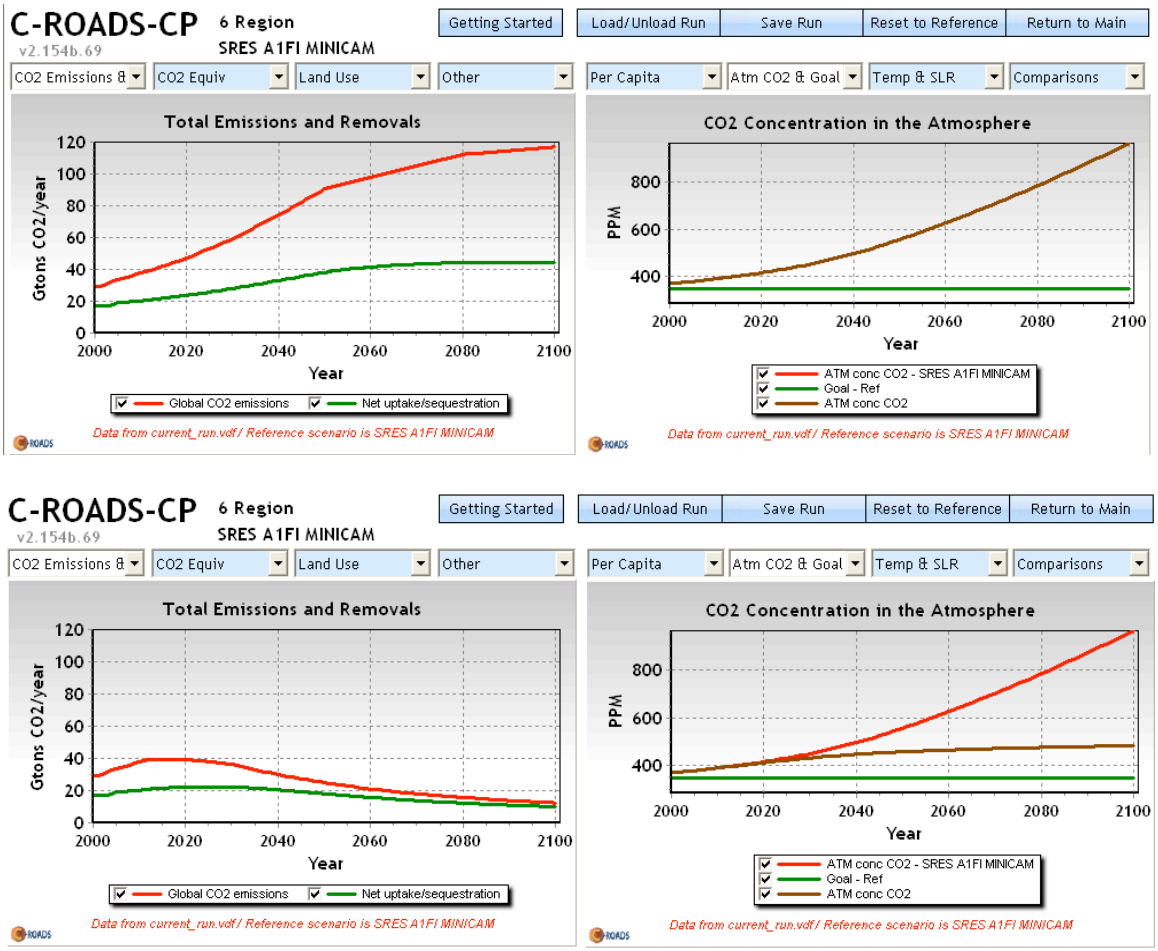


Figure 7. Carbon mass balance or "bathtub dynamics" illustrated by C-ROADS. Top: The graph on the left shows the inflow to the stock of atmospheric CO_2 (global CO_2 emissions; red line) and the outflow of CO_2 from the stock in the atmosphere (net CO_2 removal as it is taken up by biomass and dissolves in the ocean; green line). The inflow always exceeds the outflow, so the level of CO_2 in the atmosphere rises continuously. Further, the gap between inflow and outflow increases over time, so concentrations rise at an increasing rate, reaching 965 ppm by 2100. To stabilize atmospheric CO_2 concentrations, emissions must fall to net removal. Bottom: A scenario in which global emissions peak around 2020 and fall to roughly a third of the 2005 flux by 2100, by which time emissions and net removal are nearly in balance, so that CO_2 concentrations nearly stabilize (in this scenario, at about 485 ppm). Note that net emissions fall in the stabilization scenario: lower atmospheric CO_2 concentrations reduce net uptake of CO_2 by biomass and the oceans.

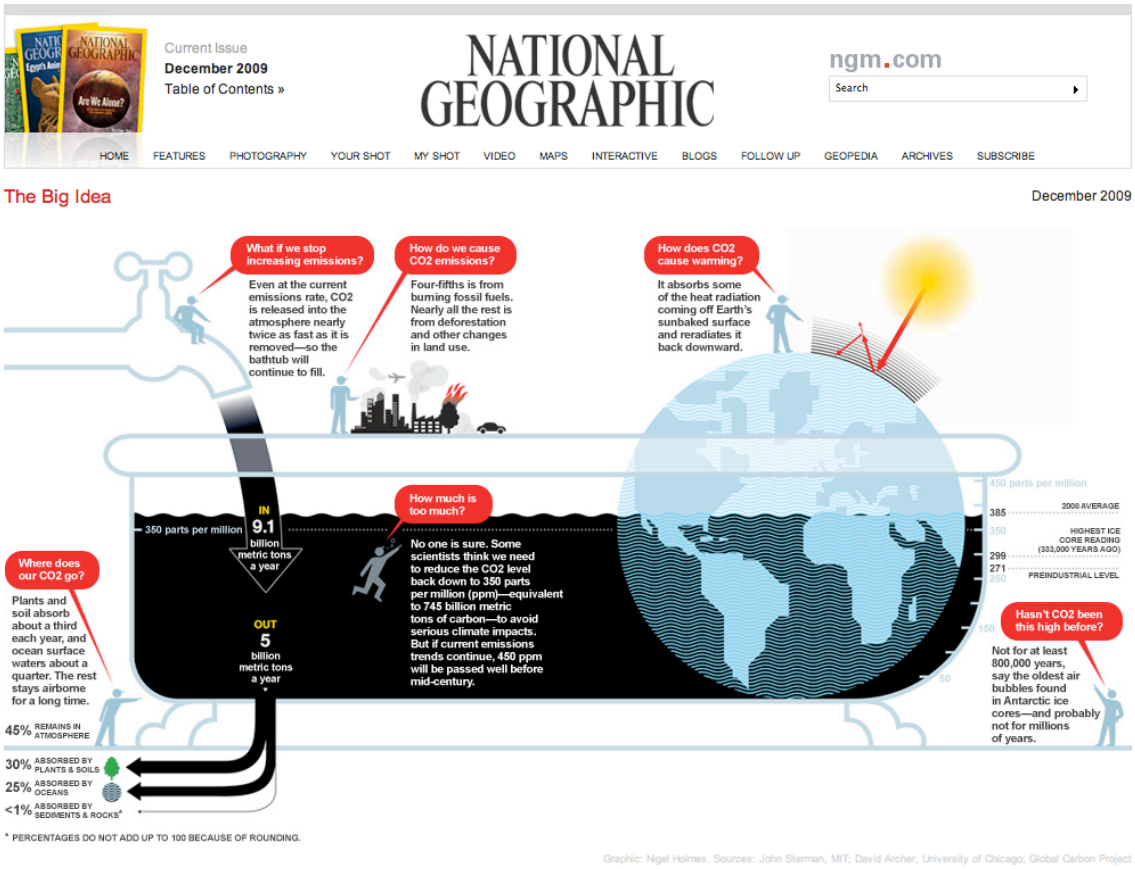


Figure 8. The Carbon Bathtub: The stock of CO_2 in the atmosphere is analogous to the level of water in a bathtub. Like any stock, atmospheric CO_2 rises only when the inflow to the tub (emissions) exceeds the outflow (net removal, primarily due to net CO_2 taken up by biomass and dissolving in the oceans), is unchanging only when inflow equals outflow, and falls only when outflow exceeds inflow.

Source: *National Geographic*, December 2009. Available at ngm.nationalgeographic.com/big-idea/05/carbon-bath. Reprinted with permission.

Further, the net removal of CO_2 from the atmosphere is not constant but depends on the state of the climate (Figure 7). Lowering emissions slows the rise in atmospheric CO_2, which reduces uptake by biomass and the oceans, making it harder to balance emissions and net removal. Delegates often ask why the removal flux does not increase in proportion to atmospheric CO_2 concentrations. Again, we ask the group. The carbon sinks absorbing CO_2 from the atmosphere have finite capacity. First, the ocean's ability to take up CO_2 declines as the CO_2 concentration in the surface layer of the ocean increases. Second, although higher CO_2 levels stimulate photosynthesis, the increase is less than proportional due to limits on other nutrients. Third, as plants die or shed their leaves they are consumed by animals and bacteria, releasing CO_2 and methane back into the atmosphere. Figure 9 shows two examples of these feedbacks: the balancing

(negative) feedback of CO_2 fertilization, and the reinforcing (positive) feedback whereby warming stimulates bacterial respiration, releasing more CO_2 and methane into the atmosphere and leading to still more warming, e.g., via permafrost melt (Schuur *et al*. 2011).

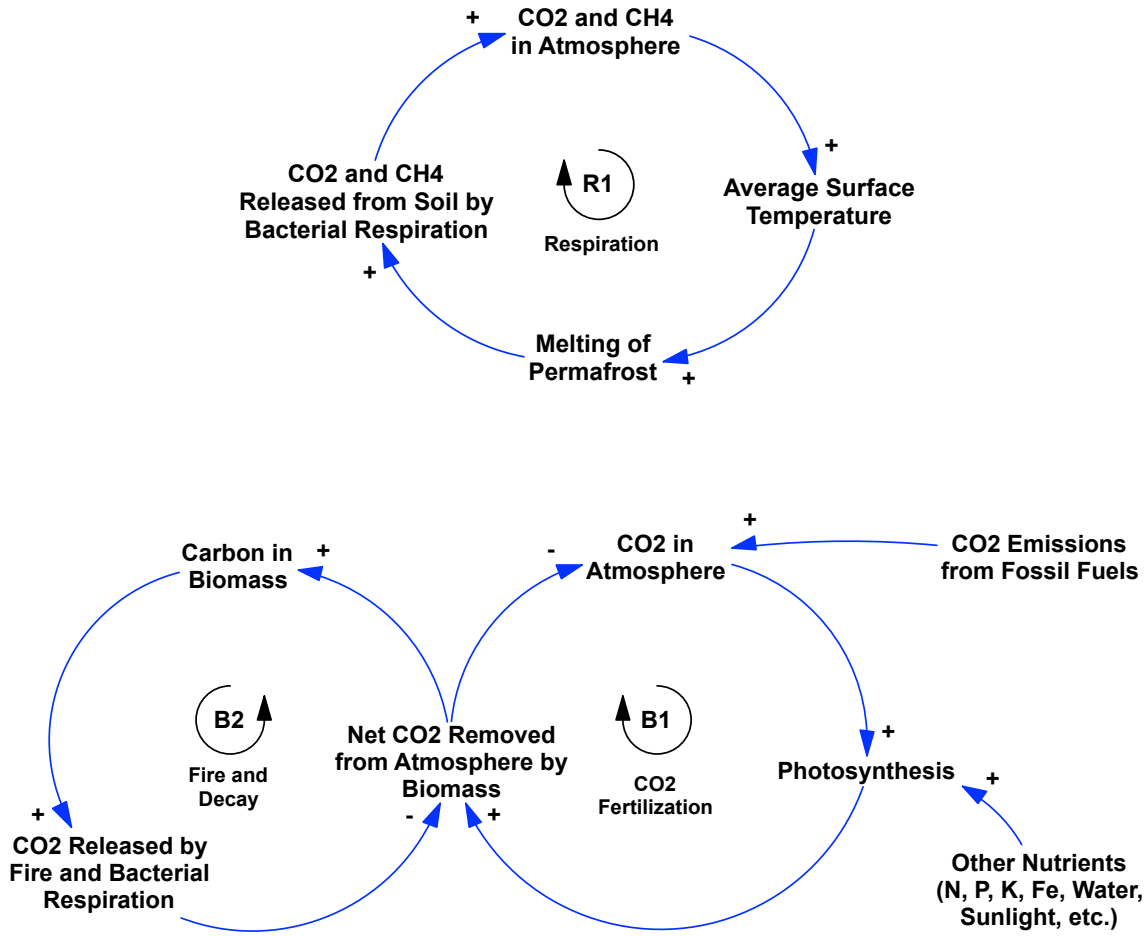


Figure 9. Causal diagrams illustrating feedback processes that affect net removal of GHGs from the atmosphere. Arrows indicate causal influence; arrow polarity, e.g., $x \xrightarrow{+} y$, indicates an increase in x raises y above what it would have been otherwise; $x \xrightarrow{-} y$ indicates an increase in x lowers y below what it would have been otherwise (Sterman 2000, ch. 5 provides formal definitions and examples). Top: Reinforcing (positive) ice-albedo feedback. For clarity, the diagram shows a single loop. Bottom: Balancing (negative) feedbacks around CO_2 fertilization. Diagram shows two loops to illustrate constraints on net CO_2 uptake by biomass as the biomass eventualy burns or dies and is metabolized by animals and bacteria, releasing CO_2 into the atmosphere. Limits on the availability of other macro and micro nutrients also constrain plant growth even as CO_2 concentrations rise.

Tipping Points and the Burning Candle Demonstration

Permafrost melt, the ice-albedo effect and other reinforcing (positive) feedbacks might dramatically accelerate climate change and create the possibility of irreversible regime shifts. Causal diagrams can illustrate these self-reinforcing processes, but presentation alone is not sufficient to help people understand how such nonlinear regime shifts arise. The "burning candle" demonstration developed by the first author provides an effective demonstration of these concepts. Begin by lighting a candle. Be sure to have permission, if needed, water and/or a fire extinguisher at hand. Making a show of being concerned about fire or triggering the alarm heightens the drama. Explain that many people believe that we can "wait and see" whether climate change will turn out to be more damaging to human welfare than it has been so far – if not, then we avoid the cost of mitigation; if so, then we can take action.

Wait-and-see is a useful strategy when short lags exist between the detection of a problem, the implementation of corrective policies and the impact of those actions. "For example, consider this candle; let the position of my hand represent the climate. As I lower my hand over the flame, it starts to get a bit warmer [do this as you explain]. Eventually, it becomes so hot that my hand will jerk away to avoid being burned. Unfortunately, GHG emissions and the climate respond with long delays. Let's simulate these delays by repeating the experiment, but now adding a ten second lag between when I feel the heat and when I can remove my hand." Start lowering your hand, then ask, "Do you mind if I use a piece of paper instead of my hand?" Next, say, "To capture the time delay, I'll now hand out these cards" and distribute seven numbered sheets of paper, folded over, to participants in the front of the room. The sheets say "1 Study the Issue", "2 Call for Emissions Reductions", "3 Negotiate an International Agreement", "4 Pass enabling legislation", "5 Increase Research and Development", "6 Deploy New Technologies", "7 Begin to Reduce Emissions." Ask people to open and read their sheets out loud, in sequence. As they do, gradually lower the paper to the flame so that it catches fire before the last card is read. At that point, raise the paper, saying "Emissions are now falling." Of course, the paper remains ablaze. Once your arm is fully extended, extinguish the fire in a cup of water. Explain that the delays in the response of the political and economic system, and in the response of the climate to emissions reductions, mean a wait-and-see policy guarantees that action, if needed, will come too late. The candle exercise makes a powerful demonstration of the impact of time delays, reinforcing feedbacks and tipping points and typically generates heated discussion [6].

Second and Third Rounds of Negotiation

First round results typically yield proposals from each delegation collectively insufficient to stabilize atmospheric GHG concentrations or limit expected warming to 2°C. Delegates commonly assert that although they are willing to make some reductions compared to BAU, the other parties must make larger cuts. The developed nations argue that China is now the world's largest emitter and must commit to large reductions, while China and India argue that the developed nations caused the problem and must bear the largest share of emissions reductions to pay for the harm they have caused and to allow the poor nations to develop their economies. Point out that these positions are similar to those taken in actual negotiations, as illustrated by Table 3, an excerpt from the transcript of the private head of state meeting during COP15 in Copenhagen. Secretly recorded and leaked to the media, the transcript reveals a highly charged atmosphere with the developed and developing nations blaming each other for the problem and demanding that the other make larger cuts. The arguments used by the delegates in the first round of WORLD CLIMATE are often strikingly similar.

German Chancellor Angela Merkel (addressing the Chinese representative): "Let us suppose 100 percent reduction, that is, no CO_2 [emissions] in the developed countries anymore. Even then, with the [target of] two degrees, you have to reduce carbon emissions in the developing countries. That is the truth."

Chinese deputy foreign minister He Yafei: "People tend to forget where it is from. In the past 200 years of industrialization developed countries contributed more than 80 percent of emissions. Whoever created this problem is responsible for the catastrophe we are facing."

US President Barack Obama: "If there is no sense of mutuality in this process, it is going to be difficult for us to ever move forward in a significant way."

French President Nikolas Sarkozy: "I say this with all due respect and in all friendship….With all due respect to China… [The developed countries have pledged to reduce greenhouse gas emissions by 80 percent.] And in return, China, which will soon be the biggest economic power in the world, says to the world: 'Commitments apply to you, but not to us.' This is utterly unacceptable! This is about the essentials, and one has to react to this hypocrisy!"

Chinese deputy foreign minister He Yafei: "Thank you for all these suggestions. We have said very clearly that we must not accept the 50 percent reductions. We cannot accept it."

Table 3. Excerpts from transcript of private heads of state meeting, Copenhagen Climate Conference, December 2009. Source: Der Spiegel, www.spiegel.de/international/world/0,1518,692861,00.html.

Still playing the role of Secretary General, we then send the delegates back for another round of negotiation, charging them to find an agreement that collectively reduces global emissions enough to limit expected warming to 2°C.

The second round ends with another set of plenary addresses during which each delegation presents their new proposal. Enter these into C-ROADS and show their impacts, including global emissions, GHG concentrations, the "bathtub" view of emissions and removal, expected temperature increase, ocean pH, and sea level rise. Second round global emissions are typically lower than in the first, but often fail to achieve the 2°C goal. After discussion, the Secretary General then sends the delegates back for a third round of negotiation. The Secretary General may depart from protocol at this point and moderate a negotiation among the group as a whole, similar to the last-minute, all night talks at many UNFCCC conferences.

One might imagine that participants in a climate policy simulation might propose emissions reductions that unrealistically ignore the national interests and political realities of the countries they represent in the role-play. The briefing memos and seating arrangements, however, including food for the developed nations and the floor for the developing nations, have proven effective in inducing the political interests of the nations each participant in the simulation represents. Delegates often begin the role-play in a distributive, zero-sum mode, blaming other nations for the problem and seeking to avoid (what they fear will be) free riding by others in a global common pool resource system. As in reality, participants representing the less-developed nations often argue that the developed nations generated the majority of GHG emissions to date and must therefore cut emissions, while the developed nations continue to insist that the developing nations commit to large, verifiable cuts before the developed nations will act. Participants in our sessions have never proposed unrealistically large emissions reductions in the first round of negotiations.

Interestingly, however, the negotiating posture of the delegates sometimes shifts from a distributive, blame-oriented frame to a more integrative frame emphasizing the common interests of all parties in limiting the risks of climate change (Hasselman *et al*. 2012 discusses distributive vs. integrative approaches to climate policy). Seeing the likely impacts of climate change through the model some participants realize how failure to reduce global emissions will hurt their own nations [7]. The developing nation delegates often realize that their people will suffer from sea level rise, droughts, and other climate impacts even if the developed nations cut their emissions dramatically. Similarly, those representing the developed nations see that such impacts will create refugees, political turmoil, and conflict, posing economic and national security

threats for them. When this shift in frame occurs, the delegates often propose earlier and deeper emissions cuts, significant commitments to REDD+ policies and larger pledges toward the $100 billion/year goal for mitigation and adaptation assistance, coming closer to the 2°C target.

Debriefing

As the negotiation ends, emotions among the delegates range from elation, if they reached an effective agreement, to skepticism and even despair about the feasibility of reaching agreement in the real world, the technical feasibility of cutting emissions or the costs of doing so. The debriefing should address these issues, cement key insights about the dynamics of the climate and connect the lessons participants learned to personal commitments to action (videos of debriefing sessions are available at http://climateinteractive.org/simulations/world-climate). If time permits, we begin by asking people to speak to each other in pairs about how they feel about the experience, then share their feelings with the group as a whole. Acknowledging their feelings helps participants look at possibilities for action, rather than becoming discouraged.

The debriefing slides available from Climate Interactive address the question of feasibility. Many participants do not know that significant reductions in emissions are technically feasible today, with off-the-shelf technology. Many actions, particularly efficiency measures, are economically attractive even at current energy prices. The slides also show the rapid cost declines for, and dramatic exponential growth of, renewable technologies such as wind and solar.

Participants often raise controversial issues such as geoengineering and nuclear power, equity and burden sharing among the developed and developing nations and the political difficulties of reaching an agreement. The latter point provides an opportunity to elicit participants' (often implicit) theories of social and political change. Some believe change must come from national leaders and governments; others that government should not be involved, with innovation and leadership arising from the private sector. Others argue that political and business leaders cannot act without sufficient grass-roots support, that change will come when enough people vote at the ballot box for leaders who support emissions reductions and vote with their dollars in the marketplace for businesses whose products and services are sustainable. Still others call for mass demonstrations similar to the civil rights movement or the 2011 demonstrations against the Canada-US Keystone XL pipeline. In the discussion we avoid advocating any particular theory of change but instead encourage participants to share and discuss their own beliefs about how significant change can be achieved

and how they, as individuals, can contribute to it.

We stress again that facilitators should not use WORLD CLIMATE as a platform for advocacy. We encourage participants to challenge the assumptions and scientific foundation of the model and to use the simulation to explore the sensitivity of the climate to different assumptions. A number of participants in our sessions have voiced the belief that climate change is not happening, or is a natural phenomenon, or that it does not pose serious risks. These beliefs contradict the best available science, but if the facilitators have done a good job, participants with these views feel safe enough to express them and engage in constructive dialogue with the other participants and facilitators about the science and the source of their (and others') beliefs.

Participants are free to propose any policies they like, including no action. Some do. However, WORLD CLIMATE should not be merely an exercise, but should connect with people at the personal level, including how they might change their behavior after the experience. Publicly committing to an action increases the likelihood that people will follow through (Cialdini 2009). We ask participants whether the results have changed their thinking about climate change, and what, if anything, they are willing to change in their professional and personal lives. Participants in our sessions have committed to insulating their homes, buying efficient lighting, bicycling instead of driving, promoting energy efficiency and renewables, joining activist organizations—and learning how to run WORLD CLIMATE for their own schools and communities.

Evaluations

We have carried out three types of evaluations of WORLD CLIMATE with different audiences. *Evaluation 1:* In 2011 and 2012 author J. Rooney-Varga taught an elective course entitled "Climate Change: Science, Communication, and Solutions" at the University of Massachusetts, Lowell. Students (N=43, 25 undergraduate and 18 graduate students; ages 19-26) completed various exercises, including writing an op-ed article on climate change science or policy, creating a public service announcement video on climate change, exploring climate models and climate science and playing WORLD CLIMATE. The course was formally assessed at the end of the semester by an independent external evaluator as a requirement of the NASA Global Climate Change Education grant that funded curriculum development. The assessment included a survey and focus group with the students. The evaluator reported, "When asked about which assignments to keep and which to eliminate, all respondents wanted to keep the WORLD CLIMATE exercise and the video script assignment." WORLD CLIMATE was cited as among the course activities "promoting the most

learning." A video of students describing their experience is available at climateinteractive.org/simulations/world-climate/media/videos.

After the course, 70% of respondents rated their depth of understanding of the UNFCCC negotiation process as "High" or "Very high," with all but two indicating that their depth of understanding "was influenced by the WORLD CLIMATE role-playing exercise." Asked how, written comments from the participants included:

- More understanding of the countries I represent
- Experience → Learning
- Everything just seemed to become real. Science didn't seem to make a difference though
- Better understanding of the views of other countries
- I just got a better feel for what happens during these summits
- I understood what was involved in negotiations
- Made me realize why getting this solved is hard globally
- Participating made me understand better than the lecture.
- It increased. Let me stress, I love this exercise
- The ability to participate in WORLD CLIMATE made me realize the challenges involved in agreeing to reduce emissions

Students' written comments on WORLD CLIMATE included:

> "Although this was just a simulation, I think everyone did a good job getting into their roles and holding true to the nation(s) they were assigned to. This made it all the more shocking. We all knew that after class, no matter what happened, we would be able to walk away and our outcome wouldn't matter. But what if it was real? I can see now why little gets done in negotiations, because there is so much at stake…."

> "The mock negotiation provided us with a great deal of insight into climate negotiations, and the methods used to reach decisions. The hands-on experience in class left a much deeper impression than simply reading or attending a lecture on the subject, and I am glad we performed this exercise in class."

After meeting with students in a focus group the evaluator reported:

> "The WORLD CLIMATE Exercise was also seen as a powerful experience, and no one had any negative things to say about it. They particularly appreciated the experience of approaching the issue from a point of view other than their own."

Evaluation 2: In 2010, the first author facilitated WORLD CLIMATE for approximately 100 mid-career executive MBA students at the MIT Sloan School of Management as part of the orientation program during their first week on campus. Two sessions of about 50 people each were run, using C-ROADS with six negotiating parties. In contrast to Evaluation 1, the participants were older (approximately 35-45), with extensive business and management experience. At the end of their program roughly a year later, the participants were asked to complete a survey on sustainability issues, including their WORLD CLIMATE experience. Participants responded on a five-point scale with anchors "1. Not important," "3. Indifferent," "5. Extremely important". Asked whether the WORLD CLIMATE exercise should be required in their curriculum, a total of 69% selected "Extremely important" (48%) or "Important" (21%), while a total of 20% selected "Not important" (15%) or "Somewhat unimportant" (5%). The written comments show that some

who rated the exercise "Not important" believe it should have been optional, not required. Others had strong reactions to the intensity of the interactive format:

> "It can be a bit shocking and might challenge the views of many as well as what they might consider to be an appropriate way to communicate a message. But it is a very important exercise to shake people up and get them thinking about important issues…that they often never think about because they are too busy…. Need more time for discussion after the simulation to give participants ideas about what they can do."

> "I think this was a very powerful exercise. Even if it made some people uncomfortable, it is important."

The positive evaluations from the executive MBA participants are noteworthy because these executives were not admitted to the program based on any pre-existing interest in climate change or environmental issues and were required to participate in WORLD CLIMATE, ruling out selection bias as an explanation for favorable evaluations.

Evaluation 3: We designed a survey to elicit participant knowledge of and attitudes about climate change, and administered it in a pre-test, post-test design to participants in WORLD CLIMATE. Table 4 provides selected questions and responses for 173 individuals in five different WORLD CLIMATE sessions, from experienced managers to high school teachers to undergraduates, ranging in age from 19 to 52, including executive MBA students at MIT (N=64), MBA students at Nanyang Technological University of Singapore (N=21), US high school science teachers (N=32), and undergraduates at the University of Wisconsin, Milwaukee (N=31) and University of Massachusetts, Lowell (N=25; a different group from Evaluation 1). The survey covered factual, dynamical, and policy questions. Factual questions elicit participant knowledge about climate change. Dynamical questions ask participants about fundamental dynamic processes relevant to climate change, testing their understanding of the process of accumulation, time delays, and potential tipping points. Policy questions elicit participant values and opinions about climate change. Contact the first author for the complete survey or to arrange its use.

Question	Responses				H_0: Pre = Post	
	Pre-Test		Post-Test			
	N	%	N	%	Test	p
1. Do you think that global warming or climate change is occurring? [**Yes**/No]	**169**/2	***98.8***/*1.2*	**130**/2	***98.5***/*1.5*	FE	1
2. Which of the following emits the largest total amount of carbon dioxide each year? [**China/**European Union/India/Russia/ United States/Don't know]	**96**/74	***56***/*44*	**98**/35	***74***/*26*	FE	.0025
3. Which of the following emits the largest total amount of carbon dioxide per person each year? [China/European Union/India/Russia/ **United States**/Don't know]	**155**/18	***90***/*10*	**124**/9	***93***/*7*	FE	.313
4. Roughly how much carbon dioxide is in the atmosphere today? [150/280/350/**390**/450 parts per million]	**123**/49	***72***/*28*	**107**/23	***82***/*18*	FE	.0301
5. Assuming that climate change is happening, do you think it is…						
Caused mostly by human activities	**76**	***43.9***	**68**	***52.3***	$\chi^2(4)$	.0425
Caused by both human activities and natural changes	**89**	***51.4***	**58**	***44.6***		
Caused mostly by natural changes in the environment	5	*2.9*	0	*0.0*		
None of the above because global warming isn't happening	2	*1.2*	0	*0.0*		
Don't know	1	*0.6*	4	*3.1*		
6. How worried are you about climate change?						
Very worried	77	*44.5*	80	*60.2*	$\chi^2(3)$	.0096
Somewhat worried	72	*41.6*	47	*35.3*		
Not very worried	16	*9.2*	3	*2.3*		
Not at all worried	8	*4.6*	3	*2.3*		
7. How important is the issue of climate change to you personally?						
Extremely important	45	*26.2*	49	*36.8*	$\chi^2(4)$	.0155
Very important	65	*37.8*	58	*43.6*		
Somewhat important	46	*26.7*	20	*15.0*		
Not too important	13	*7.6*	3	*2.3*		
Not at all important	3	*1.7*	3	*2.3*		
8. What would be the most important action(s) to reduce climate change?						
We should not take action, because climate change is not happening.	1	*0.6*	0	*0.0*	$\chi^2(5)$	.0377
We should not take action, because climate change is a natural process.	3	*1.8*	0	*0.0*		
We should wait and see whether climate change causes harm to our economy and, if it does, then take action.	0	*0.0*	2	*1.5*		
We should take action gradually, because the climate changes slowly.	16	*9.4*	4	*3.1*		
We should take immediate action.	141	*82.9*	121	*92.4*		
It's too late: there's nothing we can do to prevent climate change.	9	*5.3*	4	*3.1*		

Table 4. Pre- and Post-test survey results. **Bold** = correct answer(s). FE = Fisher Exact test.

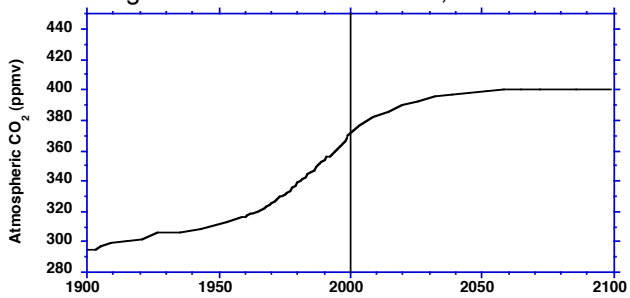
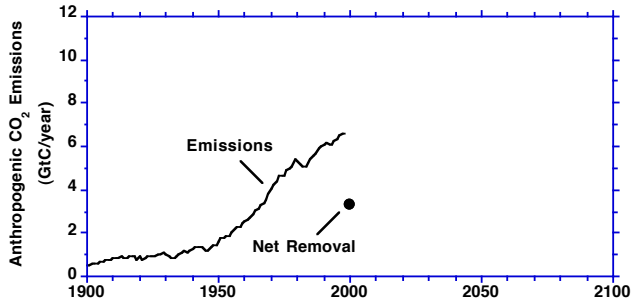
Question	Responses				H_0: Pre = Post	
	Pre-Test		Post-Test			
	N	%	N	%	Test	p
9. Now consider a scenario in which the concentration of CO_2 in the atmosphere gradually rises to 400 ppm, about 8% higher than the level in 2000, then stabilizes by the year 2100, as shown here:  The graph below shows anthropogenic CO_2 emissions from 1900-2000, and current net removal of CO_2 from the atmosphere by natural processes. 						
9a. In the future (through 2100) net removal of CO_2 from the atmosphere will:						
drop substantially below current rates	19	*11.8*	18	*14.3*	$\chi^2(4)$	.8423
drop somewhat below current rates	53	*32.9*	37	*29.4*		
stay approximately constant at current rates	36	*22.4*	25	*19.8*		
rise somewhat above current rates	34	*21.1*	27	*21.4*		
rise substantially above current rates	19	*11.8*	19	*15.1*		
9b. To stabilize the concentration of CO_2 in the atmosphere at the level in the graph above, future CO_2 emissions would have to:						
grow steadily above current rates	1	*0.6*	1	*0.8*	$\chi^2(5)$	.0004
grow, but gradually stabilize by 2100 somewhat above current rates	22	*13.8*	5	*3.9*		
stop growing immediately and stay constant at current rates	22	*13.8*	17	*13.4*		
fall, gradually stabilizing by 2100 somewhat below current rates	33	*20.6*	9	*7.1*		
fall, gradually stabilizing by 2100 substantially below current rates	68	*42.5*	76	*59.8*		
fall gradually to zero by 2100	14	*8.8*	19	*15.0*		
10. If we were to decrease the rate at which fossil fuel burning grows, the amount of carbon dioxide in the atmosphere would decrease almost immediately						
[Definitely true/Probably true/Probably false/**Definitely false**/Don't know]	**93**/79	***54****/46*	**98**/35	***74****/26*	FE	.0005
11. If we were to decrease the rate at which fossil fuels are burned, the amount of carbon dioxide in the atmosphere would decrease almost immediately [Definitely true/Probably true/Probably false/						
Definitely false/Don't know]	**90**/82	***52****/48*	**88**/44	***67****/33*	FE	.0137
12. If we were to stop burning fossil fuels today, climate change would stop almost immediately						
[Definitely true/Probably true/ Probably false/**Definitely false**/Don't know]	**116**/56	***67****/33*	**103**/29	***78****/22*	FE	.0528

Table 4 (cont.) Pre- and Post-test survey results. **Bold** = correct(s) answer. FE = Fisher Exact test.

Participants had several days to complete the pre-test before their session, and several days afterwards to complete the post-test. Participants were thus able to apply whatever level of cognitive effort they felt was appropriate in answering the factual and dynamical questions without feeling time pressure that might lead to guessing or use of heuristic short-cuts.

Questions 1-5 in Table 4 are selections from the factual questions in the survey. About 99% of participants correctly respond in both the pre-test and post-test that climate change is occurring now (Q1), a higher fraction than in the US population at large (Gallup 2012), likely a reflection of their high level of education compared to the general population and possibly selection effects for the undergraduate participants, who experienced WORLD CLIMATE in elective courses. Pre-test performance on more specific factual questions is not as high. On the pre-test, 56% correctly identified China as the largest emitter of CO_2 among nations (Q2), 90% correctly identified the US as the largest per capita emitter (Q3), and 72% correctly identified the concentration of CO_2 in the atmosphere as about 390 ppm (as of 2011-2012, when the data were collected; Q4). Performance on these questions improves in the post-test, to 74%, 93% and 82%, respectively, and the improvement is statistically significant for Q2 and Q4 (Fisher Exact test, p = .0025 and .03, respectively). After WORLD CLIMATE more participants correctly indicate that climate change is caused mostly by human activities (Q5); the improvement is statistically significant ($\chi^2(4) = 9.88, p = .0425$).

Questions 9-12 address participant understanding of climate dynamics, specifically the process of accumulation and other key concepts of system dynamics. Question 9 presents a scenario used in prior research (Sterman & Booth Sweeney 2007, Sterman 2008) in which participants are asked about the flows of CO_2 emissions into and removal from the atmosphere that would be required to stabilize the concentration of atmospheric CO_2. Question 9a elicits participant beliefs about the future net removal flux of CO_2 from the atmosphere, as it is taken up by biomass and dissolves in the ocean. Question 9b asks participants what emissions must be to stabilize atmospheric CO_2 at 400 ppm, as shown in the graph, given their estimate of future net removal. Stabilization requires emissions equal net removal. Since emissions are now roughly

double net removal, either emissions must fall dramatically or net removal must rise dramatically. However, in the pre-test, two-thirds believe net removal will fall, or remain at, current rates, while only 12% believe net removal will rise "substantially." Given flat or falling net removal, emissions must fall by at least half to stabilize atmospheric CO_2. Although most participants believe net removal will fall, in the pre-test only 51% assert that emissions would, by 2100, stabilize "substantially below current rates" or "gradually fall to zero by 2100." Fully 28% claim that concentrations would stabilize even though emissions rise or remain constant at current rates, a clear violation of mass balance, which requires emissions equal removal. As in prior research, many participants assert in the pre-test that atmospheric CO_2 could be stabilized even as emissions remain far higher than net removal from the atmosphere, analogous to arguing a bathtub continuously filled faster than it drains will not overflow. The incidence of error falls substantially after WORLD CLIMATE: in the post-test, 75% of participants now correctly state that emissions would have to stabilize by 2100 "substantially below current rates" or "gradually fall to zero by 2100", an increase of nearly 50% over the pre-test. The fraction erroneously claiming stabilization is consistent with constant or rising emissions falls to 18%, a drop of more than one-third from the pre-test. The improvement in the distribution of responses is highly statistically significant ($\chi^2(5) = 22.8$, $p = .0004$).

Questions 10-12 provide further evidence that WORLD CLIMATE improved participant understanding of climate dynamics. Q10 asks if it is true that "if we were to decrease the rate at which fossil fuel burning grows, the amount of carbon dioxide in the atmosphere would decrease almost immediately." Since declining emissions growth means emissions continue to rise, and emissions are roughly double current net removal, this statement is definitely false. Q11, "If we were to decrease the rate at which fossil fuels are burned, the amount of carbon dioxide in the atmosphere would decrease almost immediately," is also definitely false: even if emissions began to decline, it would take time for emissions to fall to equal net removal. Finally, Q12, "If we were to stop burning fossil fuels today, climate change would stop almost immediately," is definitely false: A sudden drop in emissions would cause atmospheric CO_2 to begin to decline,

but net radiative forcing would remain positive, and global mean surface temperature would therefore continue to rise for some decades; sea level would continue to rise for centuries, at least (Solomon *et al*. 2009). WORLD CLIMATE induces large and statistically significant improvements on all three questions.

Finally, after WORLD CLIMATE participants are more worried about climate change (Q6), believe it to be more important to them personally (Q7), and are more likely to recommend immediate action (Q8); Fisher Exact test, $p = .0005, .0137, .0528$, respectively.

Overall, the three evaluations provide some confidence that WORLD CLIMATE is effective with diverse audiences. A few caveats are necessary, however. First, post-test response rates are slightly lower than in the pre-test, raising the possibility of selection bias. Second, although the participants in these evaluations were diverse, evaluations with other audiences are needed. Third, although the pre- and post-test comparisons show improved understanding and changed attitudes, research should explore whether participants also improve their general understanding of complex systems, including feedback, stocks and flows, and delays, and whether they can apply that understanding to problems other than the climate. Finally, longitudinal follow-up studies should explore whether the cognitive and attitudinal impacts of WORLD CLIMATE endure, including whether participants changed their personal carbon footprints and behavior.

Summary

WORLD CLIMATE is an interactive role-play simulation of global climate negotiations designed to help people learn about the science of climate change and the economic, social and political challenges in reaching agreements to limit the risks of anthropogenic climate change. The role-play combines a highly interactive face-to-face negotiation with the C-ROADS climate policy simulation to provide participants with immediate feedback on the implications of their proposals on likely changes in the climate. WORLD CLIMATE enables participants to explore the dynamics of the climate and impact of proposed policies in a way that is consistent with the best available peer-reviewed science but that does not prescribe what should be done.

Participants are free to try any policies they desire and examine a wide range of assumptions about the processes governing climate change. The combination of the role-play with a simulation model rigorously grounded in the best available science enables participants to learn, for themselves, about the dynamics of the climate, and the ecological, economic and geopolitical issues involved in climate policy. WORLD CLIMATE has been used successfully with a wide range of participants, including students, business executives and political leaders.

All the materials needed to learn and run WORLD CLIMATE, including the C-ROADS and C-LEARN simulation models, are freely available from climateinteractive.org.

Notes

1. unfccc.int/essential_background/convention/background/items/1349.php
2. The 2°C target was first articulated in the Bali Declaration (www.climate.unsw.edu.au/news/2007/Bali.html). More recent statements by the UNFCCC Secretariat argue for no more than 1.5°C (unfccc.int/files/press/press_releases_advisories/application/pdf/pr20110606sbs.pdf).
3. http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf.
4. Mayer (2009) argues that effective games and models will be integrative, dynamic, interactive, transparent, flexible and reusable, fast and easy to use, communicative and educational, and authoritative.
5. In the six-party mode, the "other developed nations" include non-EU Europe, Russia and former Soviet states, Japan, Canada, South Korea, New Zealand and Australia. The "other developing nations" include South Africa, Mexico, Brazil, Indonesia, and all other developing nations in the Middle East, Latin America, Africa and Asia. In the three-party mode, the developed nations include the US, Europe, Russia and the former Soviet states, Japan, Canada, South Korea, New Zealand and Australia. The rapidly developing bloc includes China, India, South Africa, Mexico, Brazil, Indonesia, and other large developing Asian countries. The least developed bloc spans the rest of the world, including developing countries in the Middle East, Latin America, Africa, and Asia.
6. A video of the candle demonstration by the first author in testimony before the City Council of Cambridge, Massachusetts is available at www.youtube.com/watch?v=Pn-Sn2nWa_o and another from a presentation at MIT at http://techtv.mit.edu/collections/mitmuseum/videos/21208-soapbox-climate-and-conflict, starting at 27:45.
7. Although C-ROADS does not estimate impacts at the national or regional level, the local effects of sea level rise (discussed above) provide delegates with information about risks specific to their nations. Downscaled information related to water availability, extreme weather, and other impacts are available in reports from the IPCC, the US Global Change Research Program (www.globalchange.gov) and other sources.

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