SYSTEMS ENRICHMENT EXERCISE

Exploring Climate Models: C-Learn

Students use an online climate model to explore ways to address global climate change.

Objectives

After completing this exercise, students will be able to

- describe the delay between climate mitigation measures and climate response,
- explain the time scale involved when addressing climate change, and
- describe how policy responses reflect scientific projections regarding climate change.

Materials

- Exploring Climate Models: C-LEARN student page and access to computers with Internet

Introduction

One of the challenges involved in understanding the behavior of complex systems is that changes often happen on a scale that precludes learning from personal experience, which is how most of us come to know the world. We tend to expect immediate responses to our actions, but when dealing with something as large as the climate system, change comes more slowly than we might expect.

Systems thinking skills provide students with important insights about the behavior of complex systems. When systems include numerous variables and feedback loops, computer models can be used to make quantitative projections about how those systems will respond in different scenarios.

In this exercise, students manipulate an online climate model called C-LEARN to explore various scenarios for addressing climate change and meeting the United Nations' goal of limiting temperature increase to 2 degrees Celsius (° C) over preindustrial levels. C-LEARN is based on a more detailed model called C-ROADS (Climate Rapid Overview and Decision Support), which was designed to allow decision makers to explore policy scenarios with the help of a scientifically rigorous climate model. The world's top decision makers, including governmental and corporate leaders in the United States, Europe, and China, among others, have used C-ROADS in their discussions about climate change.

Doing the Exercise

1. This exercise is provided as a more challenging alternative to another Systems Enrichment Exercise, Understanding Climate Momentum. Using the C-LEARN model is more complicated than the slider used to manipulate the Climate Momentum model. The benefit of this complexity is the sophisticated set of options for changing variables included in the C-LEARN model. However, if you feel that your students may be confused by the added inputs and outputs included in the C-LEARN model, then the Climate Momentum exercise can convey the same basic lesson regarding the time delays involved with changing atmospheric greenhouse gas concentrations and global temperatures.

2. Distribute the student page as homework or in the computer lab. The directions are a WebQuest that guide students through manipulating the C-LEARN model in order to run multiple experiments with the simulated global system. Advanced students should be encouraged to go beyond the settings provided in these directions by developing their own set of experiments to test different hypotheses regarding global climate change.

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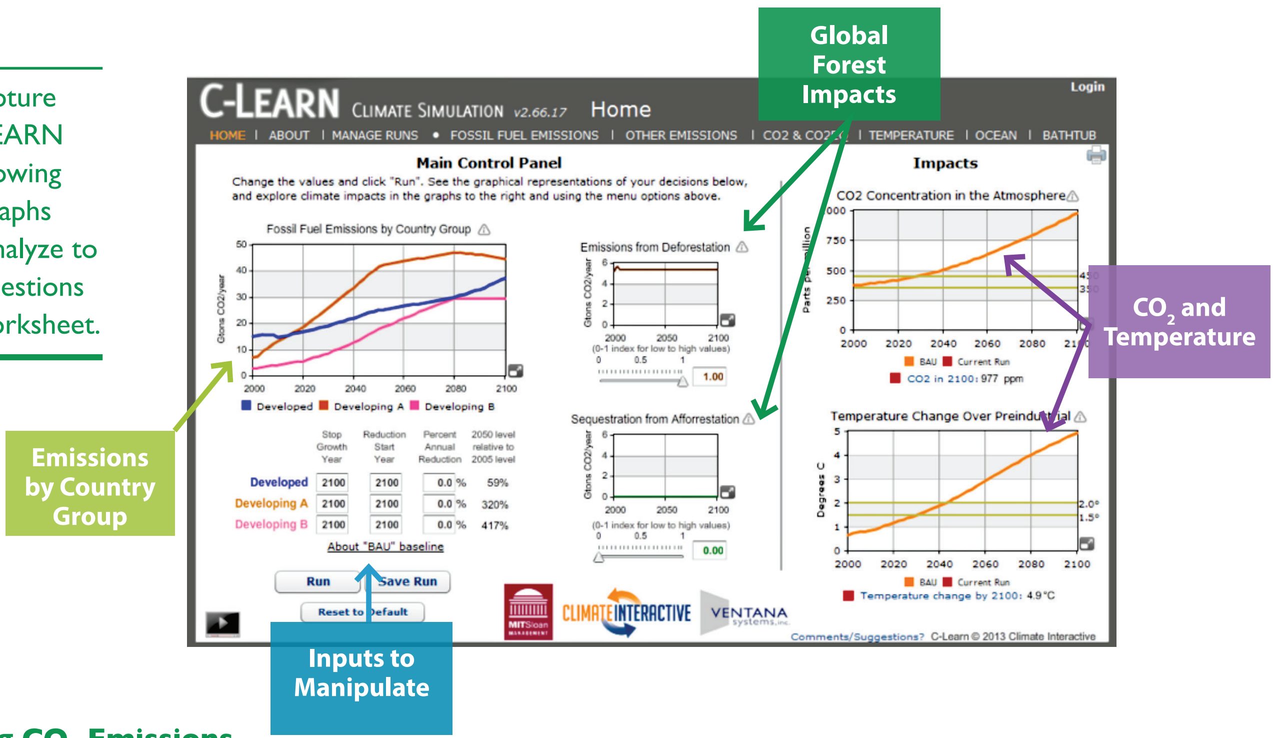
NAME DATE

These instructions were developed to help you quickly get started with the exercise. More detailed instructions to the C-Learn simulation can be found in the "ABOUT" tab (between "HOME" and "MANAGE RUNS" on the C-Learn simulator page).

In this exercise, you will use the C-LEARN climate model to find a combination of decreased emissions and increased sequestration that might allow our society to stay within the limits of carbon dioxide (CO_2) concentrations and global temperature that were calculated by the International Panel on Climate Change (IPCC), an internationally recognized source of credible reports on the current state of scientific knowledge regarding climate change.

To begin this exercise, follow this link to the C-LEARN online climate simulation: http://climateinteractive.org/simulations/c-learn/simulation. Follow the instructions on the screen to log on as a guest or to create your own account.

Screen capture from C-LEARN model, showing the five graphs you will analyze to answer questions on this worksheet.



Adjusting CO_2 Emissions

The graph on the left side shows annual CO_2 emissions from three types of countries:

1. *Developed:* This group includes most developed nations (For example: United States, Japan, South Korea, most European countries)
2. *Developing A:* This group includes the world's faster developing countries and larger nations (For example: Brazil, China, India, Thailand, Pakistan)
3. *Developing B:* This group includes smaller developing countries (For example: Turkey, Costa Rica, Venezuela, Sri Lanka)

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You can manipulate the CO_2 emissions from each type of country by changing the following input variables in the table below the graph:

- *Stop Growth Year* sets the year in which emissions for a country group will stop growing.
- *Reduction Start Year* sets when emissions will start being decreased.
- *Percent Annual Reduction* sets the size of the decrease from year to year.

The fourth column of the table, *2050 level relative to 2005 level*, shows the percent change in annual CO_2 emissions based on a reference point in 2005.

UNDERSTANDING C-LEARN OUTPUTS

The right side of the window shows projected changes in atmospheric CO_2 and temperature over preindustrial levels. The light orange curves in these graphs allow you to view the effects of your input changes in comparison to the *Business as Usual (BAU)* reference, which is based on a projection from the IPCC in which current patterns of growth and high fossil fuel investment continue.

You can click on the *CO_2 Concentration in the Atmosphere* graph to see a larger version of it. By hovering your cursor over the plotted line, you can see the value at any given point in time. Notice that in the BAU scenario, the atmospheric concentration increases to just under 1,000 parts per million (ppm) by the year 2100 (top graph) and the global temperature rises to almost 5 degrees Celsius (° C) over preindustrial temperatures (bottom graph). Such conditions would likely result in an enormous loss of biodiversity, migration out of coastal cities, and changes in agriculture.

Notice the horizontal lines on the two *Impacts* graphs (at 450 ppm and 2.0° C, respectively). The IPCC has suggested these as the maximum levels we can sustain without significantly altering life on Earth.

Testing Different Scenarios in C-LEARN

Use the five graphs on the C-LEARN simulator to fill in the data tables and answer the questions for the different scenarios or "runs" described on this worksheet.

BUSINESS AS USUAL (BAU)

The results from the initial *Business as Usual* run have already been filled in on the results table. You can confirm these results yourself to make sure you are reading the graphs correctly. The steps in this section will teach you how to read results from the graphs.

→ Click on the link at the bottom right corner of the *CO_2 Concentration in the Atmosphere* graph to see a larger version.

→ Hover the cursor over the plot at 2100 to see the precise projection for CO_2 concentration at 2100. You should see 977 ppm, which is already entered into the table.

→ Click on the *HOME* link just under the C-LEARN logo to get back to the main simulation page. (Note: Do not click on the *home* link at the top left of the page. This will take you away from the simulation.)

→ Back on the simulation homepage, click on the link at the bottom right corner of the *Temperature Change Over Preindustrial* graph.

→ Hover the cursor over the plot at 2100 to see the precise increase in temperature for that year. You should see 4.9° C, which is entered on your table. Click the home link again after confirming the temperature.

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Now let's look at the *Fossil Fuel Emissions by Country Group* graph on the left side of the page to see what's causing the high atmospheric CO_2 concentrations and temperature change.

→ Click on the link at the bottom right of the *Fossil Fuel Emissions by Country Group* graph to see a larger version. This graph divides the world's countries into three groups.

1. The *Developed* group includes the most developed countries in the world, including the United States, Canada, and all European Union members, among others.
2. The *Developing A* group includes larger, fast-developing countries, such as China and India.
3. The *Developing B* group includes more slowly developing countries such as the Middle East and many Latin American and African countries. You can click on the group names on the main page for a more detailed description of each category.

→ Hover your cursor over the *Developed* plot to find the maximum emissions from fossil fuels. For *Developed* countries, the maximum occurs in 2100, where the value is 37.3 gigatons/year. For the *Developing A* group, the maximum value (47.2 gigatons/year) occurs in 2080. And for the *Developing B* group, the maximum value (29.6 gigatons/year) occurs in 2100.

→ Still on the large graph screen, click the *EMISSIONS PER CAPITA* link in the box on the upper left side of the screen. This allows you to see a plot of how many emissions are projected to be produced annually by each person in each of the three country groups. Use this chart to answer the two questions below the Business as Usual data table.

Business as Usual Data Table and Questions

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
BAU	Developed	2100	2100	0.0	37.3	977	4.9
	Developing A	2100	2100	0.0	47.2		
	Developing B	2100	2100	0.0	29.6		

1. Which country group has the highest level of emissions for most of the 21st century?

2. Which country group has the highest emissions per capita over the entire 21st century?

In order to avoid these conditions, you need to decrease the emissions and change foresting practices to increase carbon sequestration. The rest of this worksheet will guide you through several runs of the model to find a set of input values that would keep society under 450 ppm of atmospheric CO_2.

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RUN 1

Now you're ready to begin changing the model settings and to collect your own results. Start by seeing what would happen if you limited the developed countries' greenhouse gas emissions.

→ Fill in the settings using the information in the Run 1 Data Table (Stop Growth Year = 2016; Reduction Start Year = 2018; and Percent Annual Reduction = 3). Notice that only the *Developed* settings change. Both developing groups are kept at *Business As Usual* for this run.

→ Click the *RUN* button beneath the settings to see the results of these new inputs.

→ As with the BAU run, fill in the results in the date table and use the *EMISSIONS PER CAPITA* graph to answer the Run 1 questions.

Run 1 Data Table and Questions

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
1	Developed	2016	2018	3.0			
	Developing A	2100	2100	0.0			
	Developing B	2100	2100	0.0			

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

2. In *Business As Usual (BAU)*, the *Developed* emissions rose steadily throughout the century. Describe how the *Developed* curve differs from that description now. When do emissions from developed countries reach their peak? Describe the shape of the *Developed* plot after that time.

3. Which country group has the highest emissions per capita at the beginning of the century? When does that change?

Exploring Climate Models: C-LEARN (5 of 8)

RUN 2

Clearly, just addressing emissions in the *Developed* countries is not going to keep us under the recommended limit of 450 ppm of atmospheric CO_2. In this run, keep the reduced emissions from the *Developed* countries and institute reductions in the *Developing A* countries.

→ Run the simulation using Run 2 settings provided in the table.

→ Fill in the results table and answer the Run 2 questions.

Run 2 Data Table and Questions

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
2	Developed	2016	2018	3.0			
	Developing A	2016	2020	2.8			
	Developing B	2100	2100	0.0			

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

2. Describe the shape of the *Developed* and *Developing A* emissions curves. When do they peak? What do they do following the peak?

3. Under these conditions, when would *Developing B* countries have the highest emissions levels of the three groups?

4. Under these conditions, when would emissions per capita from *Developing B* countries increase to a level larger than current per capita levels from *Developed* countries?

Exploring Climate Models: C-LEARN (6 of 8)

RUN 3

You are getting closer to our goal, but you will need help from the *Developing B* countries as well. With the other two groups limiting their greenhouse gas emissions, *Developing B* countries would have the largest impact over the course of the century. Run 3 maintains decreased emission levels from *Developed* and *Developing A* countries while adding restrictions to *Developing B* countries.

→ Run the simulation using Run 3 settings provided in the table.

→ Fill in the results table and answer the Run 3 questions.

Run 3 Data Table and Questions

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
3	Developed	2016	2018	3.0			
	Developing A	2016	2020	2.8			
	Developing B	2020	2030	2.0			

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

2. Which country group has the largest per capita emissions throughout the century?

Exploring Climate Models: C-LEARN (7 of 8)

RUN 4

You have reduced fossil fuel emissions from all three country groups, but you are still not below our goal of 450 ppm of atmospheric CO_2. Fortunately, you still have two more variables to work with.

→ Look just to the right of the *Emissions from Fossil Fuels* graph, to see two smaller graphs: *Emissions from Deforestation* and *Sequestration from Afforestation*. The *Emissions from Deforestation* graph shows the projected yearly greenhouse gas emissions resulting from loss of forests. Notice that according to *Business as Usual* conditions, this amounts to almost 6 gigatons (or 6 billion tons) of carbon every year.

→ Cut those emissions to only 25% of business as usual by setting the slide tool to 0.25 instead of 1.

→ The *Sequestration from Afforestation* graph works similarly. This graph shows the amount of carbon that can be sequestered each year by planting new forests. The default value of 0 assumes no new forests. The value of 1 assumes the maximum amount of sequestration that scientists believe is feasible (about 5 gigatons/year).

→ Enter 0.75 for this value, which suggests a level of afforestation below the maximum feasible amount (Figure 2).

→ Once you have run the simulation using Run 4 settings, fill in the results table and answer the Run 4 question.

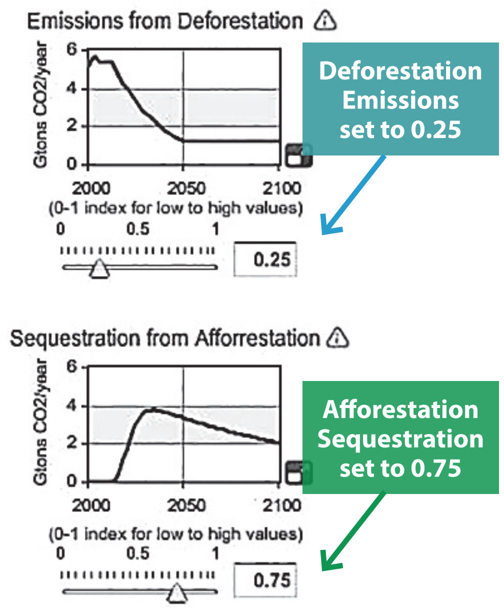

Figure 2: Deforestation and Afforestation Settings

Run 4 Data Table and Questions

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
4*	Developed	2016	2018	3.0			
	Developing A	2016	2020	2.8			
	Developing B	2020	2030	2.0			

* Index for Emissions from Deforestation set to 0.25 and index for Sequestration from Afforestation set to 0.75

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

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RUN 5

Now set your own input values that maintain the limits of 450 ppm atmospheric CO_2 and 2° C temperature change. Record your inputs and your outputs in the table below.

Run 5 Data Table and Questions

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
5	Developed						
	Developing A						
	Developing B						

1. Explain your reasoning behind your inputs. Are your inputs fair? Are they feasible? How would they impact the different types of countries?

2. What reasons might countries give to support a policy that leads to this result? Why might some nations not support such a policy?

3. What can we do to help countries work together to meet these goals?

Exploring Climate Models: C-LEARN (1 of 3)

RUN	Countries	Stop Growth Year	Reduction Start Year	Percent Annual Reduction	Maximum Emissions from Fossil Fuels (Gtons)	CO_2 Concentration in the Atmosphere in 2100 (ppm)	Temperature Change over Preindustrial (° C)
	Developed	2100	2100	0.0	37.3		
BAU	Developing A	2100	2100	0.0	47.2	977	4.9
	Developing B	2100	2100	0.0	29.6		
	Developed	2016	2018	3.0	15.9		
1	Developing A	2100	2100	0.0	47.2	821	4.2
	Developing B	2100	2100	0.0	29.6		
	Developed	2016	2018	3.0	15.9		
2	Developing A	2016	2020	2.8	16.4	595	3.0
	Developing B	2100	2100	0.0	29.6		
	Developed	2016	2018	3.0	15.9		
3	Developing A	2016	2020	2.8	16.4	486	2.2
	Developing B	2020	2030	2.0	5.6		
	Developed	2016	2018	3.0	15.9		
4*	Developing A	2016	2020	2.8	16.4	449	2.0
	Developing B	2020	2030	2.0	5.6		

* Index for Emissions from Deforestation set to 0.25 and index for Sequestration from Afforestation set to 0.75

BUSINESS AS USUAL

1. Which country group has the highest level of emissions for most of the 21st Century?

   Developing A

2. Which country group has the highest emissions per capita over the entire 21st Century?

   Developed

Exploring Climate Models: C-LEARN (2 of 3)

RUN 1

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

   No, both CO_2 levels and temperature change far exceed these limits.

2. In business as usual (BAU), the Developed emissions rose steadily throughout the century. Describe how the Developed curve differs from that description now. When do emissions from developed countries reach their peak? Describe the shape of the Developed plot after that time.

   The curve peaks at 2018 (the year set to begin emissions reduction). From there we see a relatively steep decrease in emissions that becomes shallower. It gets down to 1.3 gigatons/year by 2100.

3. Which country group has the highest emissions per capita at the beginning of the century? When does that change?

   Initially, Developed countries have the highest emissions per capita (about 11 tons of CO_2 per year). This changes around 2016, when the decreasing per capita emissions of Developed countries cross below the increasing per capita emissions of Developing A countries.

RUN 2

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

   No, both CO_2 levels and temperature change still exceed these limits.

2. Describe the shape of the Developed and Developing A emissions curves. When do they peak? What do they do following the peak?

   Both curves peak in 2016 at around 16 gigatons of carbon per year. From 2020 on, they both decrease gradually following almost the same path down to about 1 gigaton per year by 2100.

3. Under these conditions, when would Developing B countries have the highest emissions levels of the three groups?

   Around 2035, decreasing emissions from Developing A countries cross below increasing emissions from Developing B countries.

4. Under these conditions, when would emissions per capita from Developing B countries increase to a level larger than current per capita levels from Developed countries?

   Never. Even without any regulated limits, Developing B per capita emissions would not exceed 10 gigatons per year, which is less than current per capita emissions from Developed countries. However, due to the increased population of Developing B countries over the course of the century, their total emissions would still be significant.

Exploring Climate Models: C-LEARN (3 of 3)

RUN 3

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

   No, but we're much closer now.

2. Which country group has the largest per capita emissions throughout the century?

   Developed, though per capita emissions from all three groups are very close by 2100.

RUN 4

1. Does the reduction in emissions result in atmospheric levels under the limit of 450 ppm of CO_2 and 2° C rise in temperature?

   Yes, we have successfully stayed within the limits.

RUN 5

1. Explain your reasoning behind your inputs. Are your inputs fair? Are they feasible? How would they impact the different types of countries?

   Answers will vary here. Point out to students that policymakers must consider how the numbers put into this model could be achieved in the real world. The science can tell us what must be done to stay within certain concentration limits, but passing policy requires us to consider values as well. This allows policymakers to identify a fair policy that sets reasonable expectations. Encourage students to consider which countries may be ethically bound to reduce their emissions and which countries are most capable of reducing their emissions.

2. What reasons might countries give to support a policy that leads to this result? Why might some nations not support such a policy?

   Answers will vary here, depending on how students answered question 1 of this run. All three types of countries would likely claim that the restrictions would be too severe for their economies. Also, Developing B countries may point out their low relative contribution to total emissions to argue against restrictions on them. Arguments for heavily restricting Developed country emissions might include their historical emissions (i.e., over the past 200 or so years, developed countries have caused most of the greenhouse gas emissions) or claims that Developed countries are in the best position to implement alternatives to carbon-emitting practices. Arguments for heavily restricting Developing A countries might point to the recent increases in emissions from these countries. Arguments for severe restrictions on Developing B countries might include claims of the need to keep these countries from becoming major carbon emitters.

3. What can we do to help countries work together to meet these goals?

   Answers will vary here. Use this question as a chance to review other actions and policies that you have covered in the context of climate change (e.g., purchasing sustainable products, decreasing our carbon footprints, and supporting sustainable forestry).