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Lesson 6 - Carbon Emission Scenarios

The links below provide an outline of the material for this lesson. Be sure to carefully read through the entire lesson before returning to Canvas to submit your assignments.

Introduction

About Lesson 6

Now that we have explored the underlying workings of the climate system, experimented with actual climate models and validated their predictions, we are in a position to use climate models to make projections of future climate change. Before we can project human-caused climate changes, however, we must consider the various plausible scenarios for future human behavior, and resulting greenhouse gas emissions pathways.

What will we learn in Lesson 6?

By the end of Lesson 6, you should be able to:

- discuss the range of hypothetical pathways of future greenhouse gas emissions;
- distinguish between the concepts of CO_2 and CO_2 *equivalent* emissions;
- explain the *Kaya Identity;*
- explain the concept of *stabilization* of greenhouse gas concentrations; and
- discuss the *wedges* concept for controlling greenhouse gas emissions.

What will be due for Lesson 6?

Please refer to the Syllabus for specific time frames and due dates.

The following is an overview of the *required activities* for Lesson 6. Detailed directions and submission instructions are located within this lesson.

- Read
  - IPCC Fifth Assessment Report, Working Group 1 [1]
  - Summary for Policy Makers [2]
    - E Future Global and Regional Climate Change: p. 19-20
    - E.8 Climate Stabilization, Climate Change Commitment and Irreversibility: p. 27-29
    - Box SPM.1 Representative Concentration Pathways: p. 29
  - Dire Predictions, v.2: p. 92-93
- Begin Project #1: Design your own fossil fuel emissions scenario that would limit future warming by 2100 to 2.5°C relative to pre-industrial levels.
- Participate in Lesson 6 discussion: Carbon Emission Scenarios

Questions?

If you have any questions, please post them to our *Questions?* discussion forum (not e-mail), located under the Home tab in Canvas. The instructor will check that discussion forum daily to respond. Also, please feel free to post your own responses if you can help with any of the posted questions.

'SRES' Scenarios and 'RCP' Pathways

Scientists attempt to create scenarios of future human activity that represent plausible future greenhouse emissions pathways. Ideally, these scenarios span the range of possible future emissions pathways, so that they can be used as a basis for exploring a realistic set of future projections of climate change.

In previous IPCC assessments, the most widely used and referred-to family of emissions scenarios were the so-called SRES scenarios (for Special Report on Emissions Scenarios) that helped form the basis for the IPCC Fourth Assessment Report. These scenarios made varying assumptions ('storylines') regarding future global population growth, technological development, globalization, and societal values. One (the A1 'one global family' storyline chosen by Michael Mann and Lee Kump in version 1 of *Dire Predictions*) assumed a future of globalization and rapid economic and technological growth, including fossil fuel intensive (A1FI), non-fossil fuel intensive (A1T), and balanced (A1B) versions. Another (A2, 'a divided world') assumed a greater emphasis on national identities. The B1 and B2 scenarios assumed more sustainable practices ('utopia'), with more global-focus and regional-focus, respectively.

Let us now directly compare the various SRES scenarios both in terms of their annual rates of carbon emissions, measured in gigatons (Gt) of carbon (1Gt = 10^{12} tons), and the resulting trajectories of atmospheric CO_2 concentrations. Getting the concentrations actually requires an intermediate step involving the use of simple model of ocean carbon uptake, to account for the effect of oceanic absorption of atmospheric CO_2.

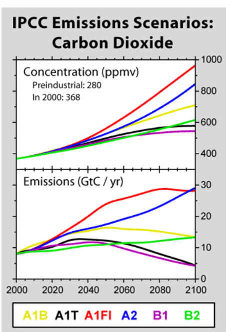
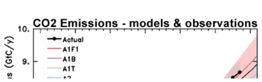


Figure 6.1: Estimated CO_2 concentrations (top) and Annual Carbon Emissions (bottom) for the Various IPCC SRES Scenarios.
Credit: Robert A. Rohde / Global Warming Art [3]

We can see from the above comparison how various trajectories of our future carbon emissions translate to atmospheric CO_2 concentration trajectories. From the point of view of controlling future CO_2 concentrations, these graphics can be quite daunting. Depending on the path chosen by society, we could plausibly approach CO_2 concentrations that are quadruple pre-industrial levels by 2100. Even in the best case of the SRES scenarios, B1, we will likely reach twice pre-industrial levels (i.e., around 550 ppm) by 2100. And to keep CO_2 concentrations below this level, we can see that we have to bring emissions to a peak by 2040, and ramp them down to less than half current levels by 2100.

You might wonder, what scenario do we actually appear to be following? Over the past ten years, observed emissions have actually been close to the most carbon intensive of the SRES scenarios—A1FI. This gives you an idea of how challenging the problem of stabilizing carbon emissions at levels lower than twice pre-industrial actually is.



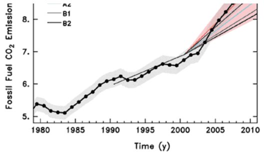


Figure 6.2: Observed Historic Emissions Compares with the Various IPCC SRES Scenarios.
Credit: The Copenhagen Diagnosis [4]

One problem with the SRES scenarios—indeed, a fair criticism of them—is that they do not explicitly incorporate carbon emissions controls. While some of the scenarios involve storylines that embrace generic notions of sustainability and environmental protection, the scenarios do not envision explicit attempts to stabilize CO_2 concentrations at any particular level. For the Fifth Assessment Report, a new set of scenarios, called Representative Concentration Pathways (RCPs), was developed. They are referred to as pathways to emphasize that they are not definitive, but are instead internally consistent time-dependent forcing projections that could potentially be realized with multiple socioeconomic scenarios. In particular, they can take into account climate change mitigation policies to limit emissions. The scenarios are named after the approximate radiative forcing relative to the pre-industrial period achieved either in the year 2100, or at stabilization after 2100. They were created with 'integrated assessment models' that include climate, economic, land use, demographic, and energy-usage effects, whose greenhouse gas concentrations were then converted to an emissions trajectory using carbon cycle models.

The RCP2.6 scenario peaks at 3.0 W / m^2 before declining to 2.6 W / m^2 in 2100, and requires strong mitigation of greenhouse gas concentrations in the 21st century. The RCP4.5 and RCP6.0 scenarios stabilize after 2100 at 4.2 W / m^2 and 6.0 W / m^2, respectively. The RCP4.5 and SRES B1 scenarios are comparable; RCP6.0 lies between the SRES B1 and A1B scenarios. The RCP8.5 scenario is the closest to a 'business as usual' scenario of fossil fuel use, and has comparable forcing to SRES A2 by 2100.

In all RCPs global population levels off or starts to decline by 2100, with a peak value of 12 billion in RCP8.5. Gross domestic product (GDP) increases in all cases; of note, the RCP2.6 pathway has the highest GDP, though it has the least dependence on fossil fuel sources. Carbon dioxide emissions for all RCPs except the RCP8.5 scenario peak by 2100.

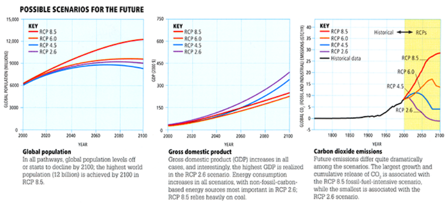


Figure 6.3a: RCP Global Population Scenarios
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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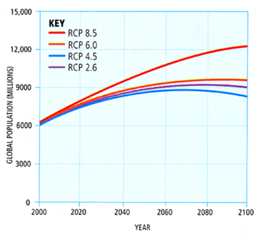

Figure 6.3b: RCP Global Population Scenarios
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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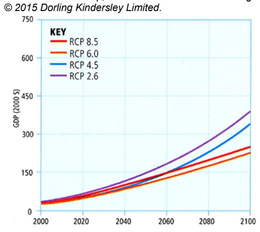

Figure 6.4: RCP Gross Domestic Product Scenarios.
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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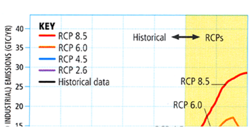

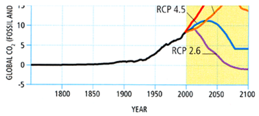

Figure 6.5: RCP Carbon Dioxide Emission Scenarios.
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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As with the SRES scenarios, however, stabilizing CO_2 concentrations requires not just preventing the increase of emissions, but reducing emissions. This leads naturally to our next topic—the topic of *stabilization scenarios*.

Stabilizing CO2 Concentrations

Before we proceed, it is useful to cover a few more important details. You may recall from an earlier lesson [5] that the radiative forcing due to a given increase in atmospheric $\mathrm{CO_2}$ concentration, ΔF_{CO_2}, can be approximated as:

$$\Delta F_{CO_2} = 5.35 \ln\left(\frac{[CO_2]}{[CO_2]_0}\right)$$

where $[CO_2]_0$ is the initial concentration and $[CO_2]$ is the final concentration. This gives a forcing for doubling of $\mathrm{CO_2}$ from pre-industrial values (i.e., $[CO_2]_0$ = 280 ppm and $[CO_2]$ = 560 ppm) of just under $4\ Wm^{-2}$. Given the typical estimate of climate sensitivity we discussed during the past two lessons, we know that this forcing translates to about 3°C warming. That means, we get about 0.75°C warming for each Wm^{-2} of radiative forcing.

Think About It!

*Come up with an answer to this question and then click the words **Reveal answer** below.*

Thus far, $\mathrm{CO_2}$ has increased from pre-industrial levels of 280 ppm to current levels of around 400 ppm. Based on the relationships above, what radiative forcing and global mean temperature increase would you expect in response to our behavior so far?

Reveal answer.

If you successfully answered the question above, you know that the $\mathrm{CO_2}$ increases so far should have given rise to 1.4°C warming of the globe. Yet we have only seen about 0.8°C warming. Are the theoretical formulas wrong? Did we make a mistake? Actually, it is neither. First of all, we know that it takes decades for the climate system to equilibrate to a rise in atmospheric $\mathrm{CO_2}$, so we have not yet realized the expected *equilibrium warming* indicated by the *equilibrium climate sensitivity.* Models indicate that there is as much as another 0.5°C of warming still in the pipeline, due to the $\mathrm{CO_2}$ increases that have taken place already. That alone would essentially explain the 0.6°C discrepancy between the warming we expect, and the lesser warming we've observed.

However, we have forgotten two other things that—as it happens—roughly cancel out! First of all, $\mathrm{CO_2}$ is not the only greenhouse gas whose concentrations we have been increasing through industrial and other human activities. There are other greenhouse gases—methane, nitrous oxide, and others—whose concentrations we have increased, and whose concentrations are projected to continue to rise in the various SRES and RCP scenarios we have examined.

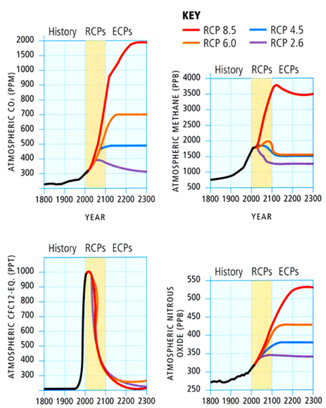

Figure 6.6: Greenhouse Gas Levels Resulting from Various Emissions Scenarios.
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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We need to account for the effect of all of these other greenhouse gases. We can do this using the concept of $\mathrm{CO_2}$ equivalent ($\mathrm{CO_2}$_eq). $\mathrm{CO_2}$_eq is the concentration of $\mathrm{CO_2}$ that would be equivalent, in terms of the total radiative forcing, to a combination of all the other greenhouse gases. If we take into account the rises in methane and other anthropogenic greenhouse gases, then the net radiative forcing is equivalent to having increased $\mathrm{CO_2}$ to a substantially higher, roughly 485 ppm! In other words, the current value of $\mathrm{CO_2}$_eq is 485 ppm. This fact has caused quite a bit of confusion, leading some commentators (see this RealClimate article [6]) to incorrectly sound the alarm that it is already too late to stabilize $\mathrm{CO_2}$ concentrations at 450 ppm and, hence, to avoid breaching the targets that have been set by some as constituting dangerous anthropogenic interference with the climate (see this article by Michael Mann [7] for a discussion of these considerations).

Nonetheless, if $\mathrm{CO_2}$_eq has reached 485ppm, does that mean that we are committed to the net warming that can be expected from a concentration of 485 ppm $\mathrm{CO_2}$? Well, yes and no. The other thing we have left out is that greenhouse gases are not the only significant anthropogenic impact on the climate. We know that the production of sulphate and other aerosols has played an important role, cooling substantial regions of the Northern Hemisphere continents, in particular, during the past century. The best estimate of the impact of this anthropogenc forcing, while quite uncertain, is roughly -0.8 W/m^2 of forcing, which is equivalent—in this context—to the contribution of *negative* 60 ppm of $\mathrm{CO_2}$. If we add -60 ppm to 485 ppm we get 425 ppm—which is closer to the current actual $\mathrm{CO_2}$ concentration of 400 ppm. So, in other words, if we take into account not only the effect of all other greenhouse gases, but also the offsetting cooling effect of anthropogenic aerosols, we end up roughly where we started off, considering only the effect of increasing atmospheric $\mathrm{CO_2}$ concentration through fossil fuel burning.

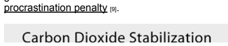
It is, therefore, a useful simplification to simply look at atmospheric $\mathrm{CO_2}$ alone as a proxy for the total anthropogenic forcing of the climate, but there are some important caveats to keep in mind:

> (1) the various scenarios assume that the sulphate aerosol burden remains unchanged. If we instead choose to clean up the atmosphere to the point of scrubbing all current sulphate aerosols from industrial emissions, we are left with the *faustian bargain* [8] of experiencing the additional climate change impacts of a sudden effective increase of atmospheric $\mathrm{CO_2}$ of 60 ppm;
> (2) not all greenhouse gases are created the same—some, such as methane, have far shorter residence times in the atmosphere (timescale of years) than does $\mathrm{CO_2}$, which persists for centuries.

That means that there is a far greater future climate change commitment embodied in a scenario of pure $\mathrm{CO_2}$ emissions than the same $\mathrm{CO_2}$ equivalent emissions consisting largely of methane. This has implications for the abatement strategies we will discuss later in the course.

These limitations notwithstanding, let us now consider the impact of various pure $\mathrm{CO_2}$ scenarios. Let us focus specifically on scenarios that will stabilize atmospheric $\mathrm{CO_2}$ at some particular level, i.e., so-called *stabilization scenarios*. Invariably, these scenarios involve bringing annual emissions to a peak at some point during the 21st century, and decreasing them subsequently. Obviously, the higher we allow the concentrations to increase and the later the peak, the higher the ultimate $\mathrm{CO_2}$ concentration is going to be. The various possible such scenarios are shown below in increments of 50 ppm. If we are to stabilize $\mathrm{CO_2}$ concentrations at 550 ppm, we can see that $\mathrm{CO_2}$ emissions should be brought to a peak of no more than 8.7 gigatons of carbon per year, by around 2050, and reduced below 1990 levels (i.e., 6 gigatons carbon per year) by 2100. For comparison, as we saw earlier that current emissions are at roughly 8.5 gigatons per year and rising at the rate of the carbon-intensive A1FI SRES emissions scenario, so we are already "behind the curve" so to speak, even for 550 ppm stabilization.

For 450 ppm stabilization, the challenge is far greater. According to the figure below, we would have had to bring emissions to a peak before 2010 at roughly 7.5 gigatons per year, and lower them to roughly 4 gigatons per year (i.e., 33% below 1990 levels) by 2050. Obviously, that train has already left the station. Alternatively, the RCP2.6 pathway is an example of a 450 ppm stabilization scenario consistent with where we are now, that involves bringing emissions to a peak within the next decade below 10 gigatons per year, and reducing them far more dramatically, to near zero 80% by 2100 through various mitigation policies. With every year we continue with *business-as-usual* carbon emissions, achieving a 450 ppm stabilization target becomes that much more difficult, and involves far greater reduction of emissions in future decades. It is for this reason that the problem of greenhouse gas stabilization has been referred to by some scientists as a problem with a very large procrastination penalty [9].



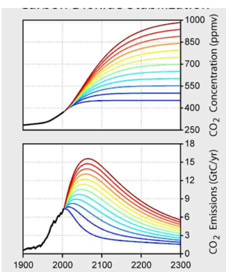


Figure 6.7: Annual CO_2 emissions and Resulting CO_2 concentrations for Various Stablization Scenarios.
Credit: Robert A. Rohde / Global Warming Art [3]

The "Kaya Identity"

We can actually play around with greenhouse gas emissions scenarios ourselves. To do so, we will take advantage of something known as the *Kaya Identify* [10]. Technically, the identity is just a definition, relating the quantity of annual carbon emissions to a factor of terms that reflect (1) *population*, (2) relative (i.e., per capita) *economic production*, measured by annual GDP in dollars/person, (3) *energy intensity,* measured in terawatts of energy consumed per dollar added to GDP, and (4) *carbon efficiency*, measured in gigatons of carbon emitted per terawatt of energy used. Multiply these out, and you get gigatons of carbon emitted. If the other quantities are expressed as a percentage change per year, then the carbon emissions, too, are expressed as a percentage change per year, which, in turn, defines a future trajectory of carbon emissions and CO_2 concentrations.

Mathematically, the Kaya identity is expressed in the form:

$$F = P * (G/P) * (E/G) * (F/E)$$

where

F is global CO_2 emissions from human sources
P is global population

G is world GDP
E is global energy consumption

By projecting the future changes in *population (P)*, *economic production* (G/P) , *energy intensity* (E/G) , and *carbon efficiency* (F/E) , it is possible to make an informed projection of future *carbon emissions* (F) . Obviously, *population* is important as, in the absence of anything else, more people means more energy use. Moreover, *economic production* measured by GDP per capita plays an important role, as a bigger economy means greater use of energy. The *energy intensity* term is where technology comes in. As we develop new energy technologies or improve the efficiency of existing energy technology, we expect that it will take less energy to increase our GDP by and additional dollar, i.e., we should see a decline in energy intensity. Last, but certainly not least, is the *carbon efficiency*. As we develop and increasingly switch over to renewable energy sources and non-fossil fuel based energy alternatives and improve the carbon efficiency of existing fossil fuel sources (e.g., by finding a way to extract and sequester CO_2), we can expect a decline in this quantity as well, i.e., less carbon emitted per unit of energy production.

Fortunately, we do not have to start from scratch. There is a convenient online calculator [11] here, provided courtesy of David Archer of the University of Chicago (and a RealClimate [12] blogger). Below a brief demonstration of how the tool can be used. After you watch the demonstration, use the link provided above to play around with the calculator yourself.

- Part One [13]
- Part Two [14]
- Part Three [15]
- Part Four [16]

The "Wedges" Concept

An increasingly widespread approach to characterizing greenhouse gas emissions reductions is the so-called *Wedges concept* [17] introduced by Princeton researchers a few years ago. The concept is relatively straightforward. First, one defines the current path of *business-as-usual* emissions. We can think of that ramp-like path as defining a *stabilization triangle*, as shown below.

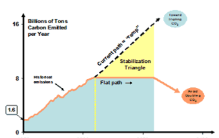


Figure 6.8: Schematic of "Wedges" Approach to Defining Carbon Emissions Reduction Strategies.
Credit: Carbon Mitigation Initiative, Princeton University [18]

Based on the past one to two decades, the business-as-usual pathway corresponds to an increase of about 1.5 gigatons per decade [19]—which, if we extrapolate linearly, amounts to about 7 gigatons of carbon emissions over the next 50 years. The stabilization triangle can thus be split into 7 "wedges" that each represent 1 gigaton of carbon over the next 50 years. The first step to stabilizing greenhouse gas concentrations is to freeze annual emissions so that they do not rise any further. To accomplish this, we would need to replace 7 gigaton wedges of projected greenhouse gas emissions that would be required to meet the forecasted business-as-usual global energy requirements over the next 50 years. The individual wedges could be derived from greater energy efficiency, decreased reliance on fossil fuels, new technologies aimed at sequestration of CO_2, etc.

Of course, as we have seen from our discussion of stabilization scenarios [20], simply freezing greenhouse emissions at current levels is not adequate to stabilize concentrations. The emissions must be decreased, eventually to zero, or at least close enough to zero so that they are balanced by the natural rates of uptake of carbon from the ocean and biosphere. So, the wedge approach must be supplemented by an actual decrease in emission rates. In one idealization of the approach, the wedges are used to freeze greenhouse annual emissions for 50 years, after which technological innovations that have been developed over the intervening half century presumably make the problem of fully phasing out fossil fuel-based energy more tractable, and emissions can be reduced over the subsequent 50 years as necessary to avoid breaching, e.g., twice pre-industrial CO_2 levels. Alternatively, more additional wedges, beyond the original 7, can be used, to not only freeze annual CO_2 emissions at current levels during the next 50 years, but instead, bring them down.

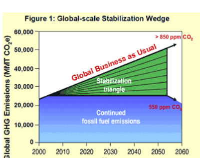
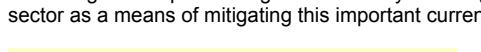


Figure 6.9: Diagram Showing the Individual "Wedges" in the Wedge Strategy.
Credit: EPA [21]

The wedge concept can be generalized beyond the global CO_2 stabilization problem. For example, the U.S. EPA has introduced *wedge-based* plan for reducing emissions in the U.S. transportation sector as a means of mitigating this important current contribution to U.S. greenhouse gas emissions.



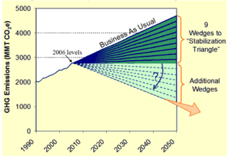


Figure 6.10: Application of Wedge Concept to Greenhouse Emission Reductions in the U.S. Transportation Sector.
Credit: EPA [22]

The Wedge Concept is an increasingly popular way to go about achieving the required greenhouse gas emissions in the decades ahead, by thinking about each of the individual mitigation approaches that might buy us a wedge, or some fraction of a wedge, of reductions. It is a way to think about how to take a seemingly intractable problem and break it up into many smaller, potentially tractable problems which collectively can help civilization achieve the daunting emissions reductions necessary for avoiding potentially dangerous climate change.

Project #1: Fossil Fuel Emissions

Scenario for Limiting Future Warming

Climate Change mitigation is an example of the need for *decision making in the face of uncertainty*. We must take steps today to stabilize greenhouse gas concentrations if we are to prevent future warming of the globe, despite the fact that we do not know precisely how much warming to expect. Furthermore, it is a problem of *risk management*. We do not know precisely what potential impacts loom in our future, and where the threshold for dangerous anthropogenic impacts on the climate lies. Just like in nearly all walks of life, we must make choices in the face of uncertainty, and we must decide precisely how risk averse we are. Most homeowners have fire insurance, yet they don't expect their homes to burn down. They simply want to hedge against the catastrophe if it does happen. We can, in an analogous manner, think of climate change mitigation as hedging against dangerous potential impacts down the road. This project aims to integrate a number of themes we have already explored—energy balance and climate modeling, and our current lesson on carbon emissions scenarios—to quantify how to go about answering critical questions like, "How do we go about setting emissions limits that will allow us to hedge against the possibility of dangerous anthropogenic impacts (DAI) on our climate?"

Activity

Note:

For this assignment, you will need to record your work on a word processing document. Your work must be submitted in Word (.doc or .docx), or PDF (.pdf) format so the instructor can open it.

For this project, you will design your own fossil fuel emissions scenario that would **limit future warming by the year 2100 to 2.0°C relative to the pre-industrial level**.

Directions

1. Defining the threshold for DAI with the climate is a value judgment, as much as a scientific one. The European Union has defined 2°C warming relative to pre-industrial conditions to be the threshold of DAI (and this has been adopted in the recent Paris agreement). Use the zero-dimensional EBM [23] with the standard, i.e., *mid-range* values of the *gray body parameters* (and default settings for solar constant and albedo) to estimate the $\mathrm{CO_2}$ concentration for which we would achieve such warming when equilibrium is reached. [*Hint*: you already did this particular calculation in Problem Set #3]
2. As discussed above, where we choose to set our emissions limits is also a matter of risk management. How risk averse are we? Let us assume that we want to limit the chance of exceeding DAI to only 5%, which is a typical threshold used in risk abatement strategies. Let us also assume that the *low end* and *high end* IPCC sensitivities define our best estimate of the 90% confidence interval for climate sensitivity, that is, there is a 5% chance that the true sensitivity is lower than the *low end* value, and a 5% chance that the true sensitivity is higher than the *high end* value. Now, revisit the calculation that you did in Step 1, and use *high-end* setting of the *gray body parameters* to calculate the highest $\mathrm{CO_2}$ concentration that we can reach and still keep the chance of exceeding DAI below 5%.
3. That was the easy part! Now is where things really get interesting. You have to come up with *your own emissions scenario* to stabilize $\mathrm{CO_2}$ concentrations below the dangerous $\mathrm{CO_2}$ threshold that you calculated in Step 1 (i.e., using the mid-range values). Recall that based on Step 2 we are not being particularly risk-averse under this assumption. By stabilizing, we will mean that by the year 2100 the $\mathrm{CO_2}$ concentration curve should be flat or nearly flat, indicating that any peak in $\mathrm{CO_2}$ concentrations has been reached before 2100 - and that the value of that peak should not exceed the threshold found in Step 1. You should make use of the on-line Kaya calculator [11] that we examined earlier in this lesson. Begin with the default settings in the Kaya calculator to figure out what baseline emissions scenario you are starting with and how much you need to do to achieve the required reduction in emissions to stabilize the concentration (given by the 'pCO2' curve when you choose 'ISAM pCO2' in the selector for the display on the right). You then have several knobs you can tune to achieve an alternative emissions scenario; specifically, you can do the following.
    - (1) You can take measures to control global *population growth*, which are consistent with the spread of the population trajectories [24] of the various SRES scenarios (e.g., A1, A2, B1, B2); though note that you cannot set the limit below the current global population of 7.4 billion.
    - (2) You can change the *rate of economic expansion* (measured by GDP per capita) by up to 75% from the default value of 1.6% per year; that is, you can choose a value within the range of 0.4 to 2.8 % per year.
    - (3) You may change the rate of decline in *energy intensity* (measured in Watts per dollar) through new technology and/or the improvement of existing technology. You are permitted to change this value by 100% form its default setting of -1% per year, that is you can choose a value within the range of 0 to -2 % per year.
    - (4) You may change the decline in *carbon intensity* by 100% from the default value of -0.3 % per year, that is you can choose a value within the range of 0 to -0.6 % per year. This would would reflect efforts to shift from the current reliance on fossil fuel sources, or the improved carbon efficiency of fossil fuel energy sources, e.g., through sequestration of $\mathrm{CO_2}$, etc.

    Through some combination of tuning these knobs within the indicated ranges, it should be possible to stabilize $\mathrm{CO_2}$ concentrations at the necessary threshold level. (The concentration time-evolution curves corresponding to different specific stabilization scenarios are shown in the 'ISAM pCO2' plot.)
4. As you write up your results, please discuss the reasoning that you used in arriving at the various choices for the factors in the Kaya identity, i.e., provide justification for why your choices reflect plausible policies that governments could in principle implement to achieve the necessary reductions. If your projections depart from what might be expected based on an extrapolation of past historic trends, provide some justification. Your discussion here might, for example, be guided by the plot of the required amounts of carbon-free energy to meet the requirements of your scenario, which is provided by the Kaya calculator tool. You will probably want to do some additional background reading. A good place to start would be the original 2001 IPCC report on SRES scenarios: Special Report on Emissions Scenarios [25].
5. Save your word processing document as either a Microsoft Word or PDF file in the following format:

    Project1_AccessAccountID_LastName.doc (or .pdf).
    For example, student Elvis Aaron Presley's file would be named "P1_eap1_presley.doc"—This naming convention is important, as it will help the instructor match each submission up with the right student.

Submitting your work

- Upload your file to the Project 1 assignment in Canvas by the due date indicated in the Syllabus.

Grading rubric

The instructor will use the general grading rubric for problem sets [26] to grade this project.

Lesson 6 Discussion

Activity

Directions

Please participate in an online discussion of the material presented in Lesson 6: Carbon Emission Scenarios.

This discussion will take place in a threaded discussion forum in Canvas (see the Canvas Guides [27] for the specific information on how to use this tool) over approximately a week-long period of time. Since the class participants will be posting to the discussion forum at various points in time during the week, you will need to check the forum frequently in order to fully participate. You can also subscribe to the discussion and receive e-mail alerts each time there is a new post.

Please realize that a discussion is a group effort and make sure to participate early in order to give your classmates enough time to respond to your posts.

Post your comments addressing some aspect of the material that is of interest to you and respond to other postings by asking for clarification, asking a follow-up question, expanding on what has already been said, etc. For each new topic you are posting, please try to start a new discussion thread with a descriptive title, in order to make the conversation easier to follow.

Suggested Topics

- Discuss the concept of SRES scenarios and RCP pathways. How are these scenarios used for projecting future climate change? Given what we know about the current greenhouse emissions, which scenarios and/or pathways appear to best represent the real world?
- Discuss potential reasons for the switch from SRES scenarios to RCP pathways in the latest IPCC report. How useful do you think the change was?
- What is the difference between $\mathrm{CO_2}$ emissions and $\mathrm{CO_2}$ equivalent emissions?
- Atmospheric $\mathrm{CO_2}$ increases observed so far should have given rise to 1.3°C warming, but we have only seen about 0.8°C warming. Why?
- What are stabilization scenarios?
- Do you find the Wedges Concept a useful tool for characterizing greenhouse gas emissions reductions?

Submitting your work

1. Go to Canvas.
2. Go to the Home tab.
3. Click on the *Lesson 6 discussion: Carbon Emission Scenarios.*
4. Post your comments and responses.

Grading criteria

You will be graded on the quality of your participation. See the online discussion grading rubric [28] for the specifics on how this assignment will be graded. Please note that you will not receive a passing grade on this assignment if you wait until the last day of the discussion to make your first post.

Lesson 6 Summary

In this lesson, we looked at the science underlying greenhouse gas emissions scenarios. We learned that:

- up through the Fourth Assessment Report, the IPCC employed, for the purpose of projecting future greenhouse gas concentrations, a set of emissions scenarios, known as the SRES scenarios. These scenarios reflect a broad range of alternative assumptions about how future technology, economic growth, demographics, and energy policies will evolve over the next century, and, therefore, plausibly reflect the diversity of potential future global greenhouse emissions pathways;
- the SRES scenarios embody a range of projected increases in atmospheric CO_2 by 2100 from a lower end of approximately doubling the pre-industrial levels to reach 550 ppm (B1) to a near quadrupling of pre-industrial levels (A1FI). Current emissions place us on a pathway close to the upper-end A1FI scenario;
- in the Fifth Assessment Report, the IPCC switched to the use of Representative Concentration Pathways, or RCPs. These pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) were chosen to be representative scenarios named for their total radiative forcing in the year 2100 (in watts per meter squared), and reflect a range of policies, from strong mitigation (RCP 2.6) to approximately business-as-usual (RCP 8.5);
- the *stabilization scenarios* are designed to stabilize atmospheric CO_2 concentrations at a particular level. The lower the desired stabilization level, the lower and sooner the peak in emissions must be. To stabilize below twice the pre-industrial levels, emissions must be brought to a peak within the next few decades and rapidly brought down by the end of the century, falling below 1990 levels by mid-century. To stabilize below 450 ppm, CO_2 levels must be brought to a peak within the next decade, and brought down to 80% below 1990 levels by mid-century;
- an increasingly widely used approach to defining the required carbon emissions reductions is the *Wedge* approach. This approach involves freezing emissions at current rates by offsetting projected business-as-usual emissions over the next 50 years (roughly 7 gigatons), envisioned, e.g., as 7 strategies for 1 gigaton carbon emission reductions. After 50 years, emission rates are brought down, but how abruptly and rapidly depends on the stabilization targets desired. Additional wedges can be used to achieve lower stabilization targets by bringing down, rather than freezing, annual carbon emission rates over the next 50 years.

Reminder - Complete all of the lesson tasks!

You have finished Lesson 6. Double-check the list of requirements on the first page of this lesson [29] to make sure you have completed all of the activities listed there before beginning the next lesson.

Source URL: https://www.e-education.psu.edu/meteo469/node/144

Links

[1] https://www.ipcc.ch/report/ar5/wg1/
[2] https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf
[3] http://berkeleyearth.org/team/robert-rohde

[4] http://www.copenhagendiagnosis.com/
[5] https://www.e-education.psu.edu/meteo469/node/210
[6] http://www.realclimate.org/index.php/archives/2007/10/co2-equivalents/
[7] http://www.meteo.psu.edu/%7Emann/shared/articles/MannCommentaryPNAS09.pdf
[8] http://en.wikipedia.org/wiki/Deal_with_the_Devil
[9] http://rsta.royalsocietypublishing.org/content/365/1853/897.abstract
[10] http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/050.htm
[11] http://forecast.uchicago.edu/Projects/kaya.html
[12] http://www.realclimate.org/index.php/archives/2004/12/david-archer/
[13] https://www.e-education.psu.edu/meteo469/sites/www.e-education.psu.edu.meteo469/files/lesson06/kaya_part_one.html
[14] https://www.e-education.psu.edu/meteo469/sites/www.e-education.psu.edu.meteo469/files/lesson06/kaya_part_two.html
[15] https://www.e-education.psu.edu/meteo469/sites/www.e-education.psu.edu.meteo469/files/lesson06/kaya_part_three.html
[16] https://www.e-education.psu.edu/meteo469/sites/www.e-education.psu.edu.meteo469/files/lesson06/kaya_part_four.html
[17] http://cmi.princeton.edu/wedges/
[18] http://cmi.princeton.edu/wedges/intro.php
[19] https://www.e-education.psu.edu/meteo469/node/145
[20] https://www.e-education.psu.edu/meteo469/node/146
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[23] https://www.e-education.psu.edu/meteo469/sites/www.e-education.psu.edu.meteo469/files/lesson03/0d_EBM.html
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[26] https://www.e-education.psu.edu/meteo469/sites/dev.e-education.psu.edu.meteo469/filesGradingRubricforProblemSets.pdf
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[29] https://www.e-education.psu.edu/meteo469/node/144