Greenhouse Gas Emissions: Past, Present and Future

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Summary of the Session: *What are the human drivers of change?* During this session we will work through exercises using online resources for students to examine trends in greenhouse gas emissions for the world and selected countries, analyze their relation to population growth, income growth, and technological change using online databases, and discuss climate policy implications of cross-country differences in trends of these drivers. We will also examine alternative scenarios of future economic growth and technological change, their implications for future greenhouse gas emissions, and corresponding projections of climate change.

Background: This 90-minute session is part of a four-day workshop that brought together faculty from multiple colleges and diverse disciplines to work collaboratively on developing new and revised courses, explore engaged learning pedagogies, and add to their knowledge for interdisciplinary teaching about climate change within a liberal arts curriculum. The workshop was held twice on the campus of Dickinson College, first in summer 2010 and again in summer 2011. Participants came from more than 20 colleges and universities and with expertise in disciplines that span the sciences, social sciences and humanities. The workshops are part of a NASA supported project Cooling the Liberal Arts Curriculum, A Campaign for Climate Change Education (http://communities.earthportal.org/changingclimate/).

Objectives of the Session

- Gain literacy about greenhouse gas emissions sources, trends, future projections, and effects on global climate.
- Become familiar with the World Resource Institute's Climate Analysis Indicators Tool (CAIT) for exploring international data on GHG emissions. [*Note: CAIT was taken offline due to technical difficulties with the database. CAIT was still down as of June 2013. WRI is working to restore the database and make CAIT available to the public soon.*]
- Create student exercises that use CAIT to develop quantitative literacy about GHG emissions and stimulate inquiry about differences across countries, underlying causes, responsibilities for causing climate change, and implications for climate policy.
- Learn how to decompose growth in energy related CO2 emissions into population, income, energy intensity, and carbon intensity effects and use decompositions of emissions growth to analyze past trends and future projections.

Agenda for the Session

- Presentation: Past, present and future GHG emissions – 20 minutes
- Exercise: Explore CAIT – 15 minutes

- Presentation: Decomposition of CO2 growth into driving causes – 15 minutes
- Exercise: Use CAIT to decompose CO2 growth – 20 minutes
- Discussion – 20 minutes

Essential Principles of Greenhouse Gases (or what we would like our students to learn):

- CO_2, CH_4, N_2O have natural & human sources
    - Human sources: mostly burning fossil energy, clearing land, agriculture
- Emissions have grown rapidly since mid-19th century
    - Have exceeded capacity of Earth systems to process
- Concentrations growing
    - CO_2 concentration higher now than past 800,000 or more years
- It's not just about CO_2
    - Other gases responsible for >20% of the annual additions to warming potential
- 25 countries responsible for 80% of emissions
- Developed countries account for majority of past & current emissions
    - Per capita emissions several times higher than in developing countries
    - Developed countries responsible for >60% of increase in CO_2 concentration in the atmosphere
- Emissions growth most rapid in developing world
    - Driven by income and population growth
    - Reductions in energy/$gdp have offset some of the emissions growth
    - Changes in C/energy consumed has had mixed but mostly offsetting effects
- Globally, emissions of GHGs continue to rise
    - Concentrations are rising too
- Projected trends in GHG emissions would warm the planet an estimated 1-6^{o}C by 2100
- Halting the rise in GHG concentrations would require deep reductions in annual emissions
    - Stabilizing emissions near present level would not stabilize GHG concentrations

Topic Overview

Solar radiation that reaches and warms the Earth's surface is radiated back to the atmosphere as longer-wave infrared radiation. Some of the gases in the atmosphere absorb and re-emit infrared radiation and are called greenhouse gases (GHGs). Increases in the concentrations of GHGs increase the radiative balance of the atmosphere, causing more energy to be retained in the Earth system and the climate to warm.

Understanding the radiative properties of the main GHGs, the human and natural sources of GHG emissions, trends of past emissions and concentrations, and projections of future emissions are critical for identifying and analyzing effective solutions. Some of the key features are summarized below, and sources of additional information are listed at the end of this document.

The main greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). All four of these gases occur naturally in the atmosphere, but humans have increased the concentrations of the latter three significantly through the burning of fossil energy, clearing land, farming, and other activities. Other greenhouse gases include sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydroflourocarbons (HFCs), all of which are man made.

The main greenhouse gases

Name	Pre-industrial concentration (ppmv *)	Concentration in 1998 (ppmv)	Atmospheric lifetime (years)	Main human activity source	GWP **
Water vapour	1 to 3	1 to 3	a few days	-	-
Carbon dioxide (CO_2)	280	365	variable	fossil fuels, cement production, land use change	1
Methane (CH_4)	0,7	1,75	12	fossil fuels, rice paddies waste dumps, livestock	23
Nitrous oxide (N_2O)	0,27	0,31	114	fertilizers, combustion industrial processes	296
HFC 23 (CHF_3)	0	0,000014	260	electronics, refrigerants	12 000
HFC 134 a (CF_3CH_2F)	0	0,0000075	13,8	refrigerants	1 300
HFC 152 a (CH_3CHF_2)	0	0,0000005	1,4	industrial processes	120
Perfluoromethane (CF_4)	0,00004	0,00008	> 50 000	aluminium production	5 700
Perfluoroethane (C_2F_6)	0	0,000003	10 000	aluminium production	11 900
Sulphur hexafluoride (SF_6)	0	0,0000042	3 200	dielectric fluid	22 200

* ppmv = parts per million by volume, ** GWP = Global warming potential (for 100 year time horizon).

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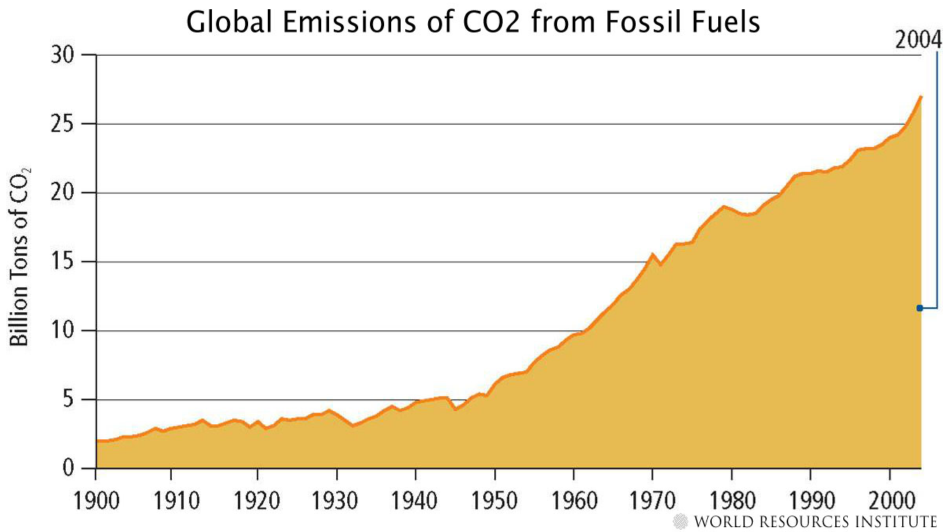
Emissions of the main greenhouse gases increased with the industrial revolution and growth has been particularly rapid since the mid-20th century. Total emissions worldwide of all greenhouse gases reached the equivalent of 44.1 billion metric tons of carbon dioxide (CO_2e) in 2005. The emissions are at levels that exceed the capacity of Earth systems to remove the gases from the atmosphere and consequently they are accumulating in the atmosphere. Concentrations in 2008 reached 384,800 ppb for CO_2, 1865 ppb for CH_4 and 322 ppb for N_2O, relative to preindustrial concentrations of 280,000, 700 and 270 ppb respectively (Blasing, 2009).

Annual carbon dioxide emissions account for roughly 77% of the increase in radiative forcing that is attributed to humans. Methane is 25 times more powerful as a greenhouse gas than carbon dioxide and nitrous oxide is 298 times more powerful. But because they are less plentiful in the atmosphere, their contributions to radiative forcing are smaller, 14% for methane and 7% for nitrous oxide (Baumert, Herzog and Pershing, 2005). Sulfur hexafluoride, perfluorocarbons and hydroflourocarbons are a few hundred to several thousand times more potent than carbon dioxide, but so far are present in the atmosphere only in minute quantities and collectively contribute only 1% of the increase in radiative forcing attributed to humans. Other pollutants that have important effects on radiative balance are aerosols (which reflect solar radiation to space and have a counteracting effect on global warming) and black carbon, which recent research suggests may account for a larger share of changes in the global energy balance than previously thought.



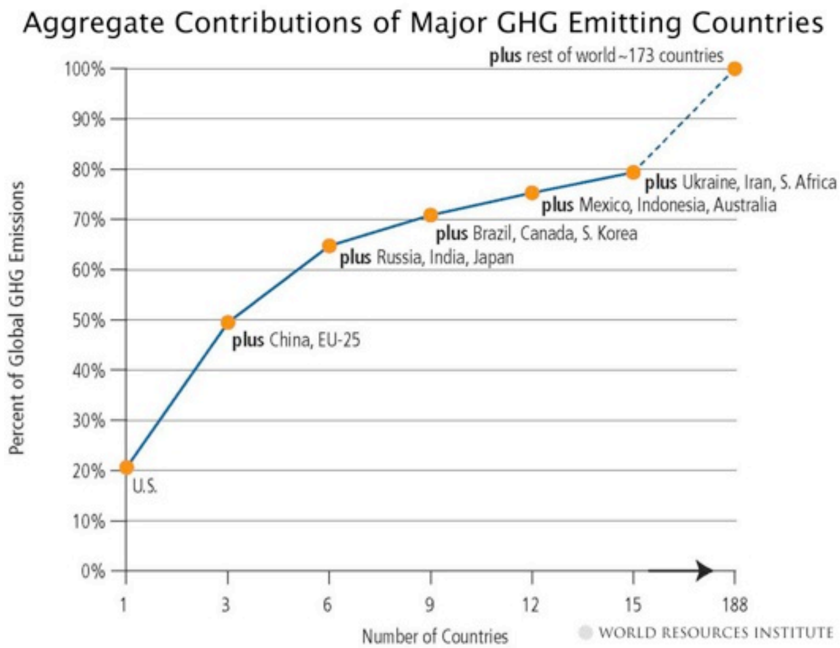
Source: Baumert, Herzog and Pershing (2005)

Consumption of fossil energy contributes about 60% of global GHG emissions, much of which is used for electricity generation, heat and transportation. Land use change contributes about 18% of GHG emissions as a result of the removal of forests and other vegetation, which decompose and release CO2 to the atmosphere. Agriculture accounts for about 13% in the form of methane and nitrous oxide.

A relatively small number of countries is responsible for a large portion of GHG emissions. China recently passed the US as the largest emitter of GHGs; together China and the US account for 37% of global GHG emissions (WRI, 2009). The 25 countries that are the largest emitters of GHGs collectively contribute about 80% of the world total. The list includes both developed and developing countries, all of which are large countries in terms of population and/or economy.

Historically, developed countries have been responsible for the majority of GHG emissions, accounting for over 70% of the cumulative emissions of CO_2 from energy since 1900. But emissions are growing faster in the developing world than in the developed. Over the period 1990 to 2005, global emissions of greenhouse gases grew at an average annual rate of 1.2% per year. Emission growth rates vary considerably across countries: 1.0% per year in the US, 4.3% in China, 3.5% in India, 0.8% in Brazil, 0.1% in France, -1.3% in Germany, and -2.6% in Russia. Growth has been greater in the developing countries (2.4% per year) than in developed countries (-0.1%). But in per capita terms, emissions are more than a factor of

10 greater in developed countries than in developing countries. (Source of data: Climate Analysis Indicators Tool, version 7.0: http://cait.wri.org/).



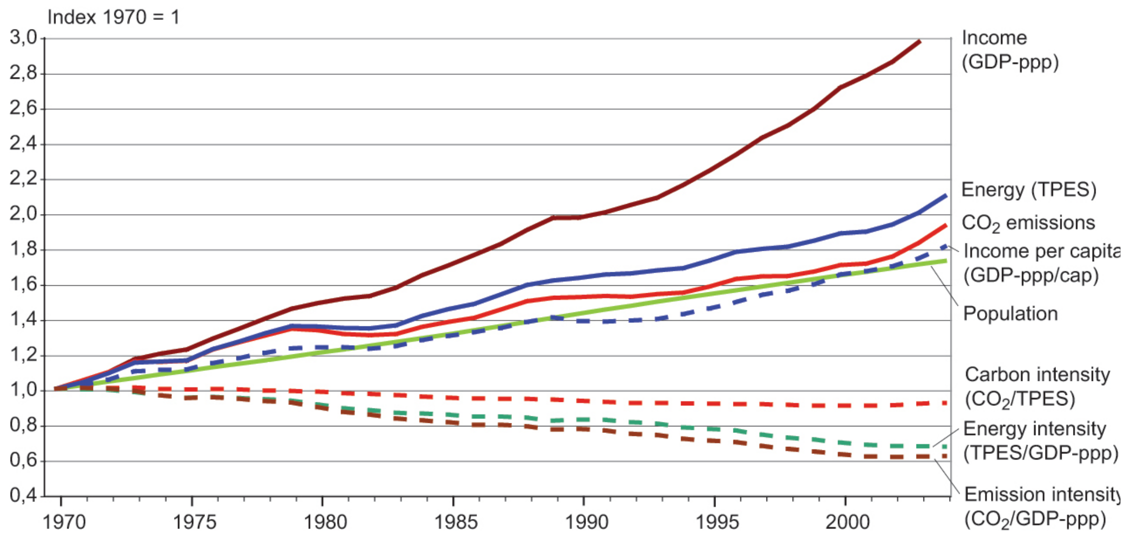
Source: Baumert, Herzog and Pershing (2005).

The causes of the different GHG emission trends across countries are varied and complex. A general understanding, however, can be gained by applying an identity attributed to Kaya (1990) that is an example of an IPAT model (Impact = Population x Affluence x Technology). The Kaya identity is given by the equation:

$$C = P * (I/P) * (E/I) * (C/E)$$

where C is CO_2 emissions, P is population, I is income, and E is total energy consumption. As can be seen from the identity, growth in emissions is a product of population growth, per capita income growth, changes in the energy intensity of the economy, and changes in the carbon intensity of the energy mix. For very small changes, a percentage change in CO_2 emissions can be decomposed as the sum of the percentage changes of the four factors of the Kaya identity. For larger changes, this simple decomposition is inaccurate and other methods such as the Logarithmic Mean Divisia Index (LMDI) should be used (see Ang, 2005).

Decompositions of emissions growth data have shown that, for most countries, per capita income growth has been the most powerful engine driving CO_2 emissions upward. Population growth has also been a factor that has pushed emissions higher. In contrast, most countries have experienced decreases in the energy intensity of their economies, which has had a countervailing influence on emissions. The influence of changes in fuel mix is varied across countries, depending on whether a country has shifted its energy mix toward or away from coal. See Bacon and Bhattacharya (2007) for their decomposition analysis for 70 countries.



Global trends in CO2 emissions, income, population, energy intensity, and carbon intensity. Source: IPCC 2007 a. Figure SPM-2.

Projections of future emissions of greenhouse gases span a wide range, reflecting a high degree of uncertainty about future population and income growth and changes in energy intensity and mix of energy technologies. However, it is cleat that, in the absence of major policy changes, emissions and concentrations of GHGs will grow substantially over coming decades.

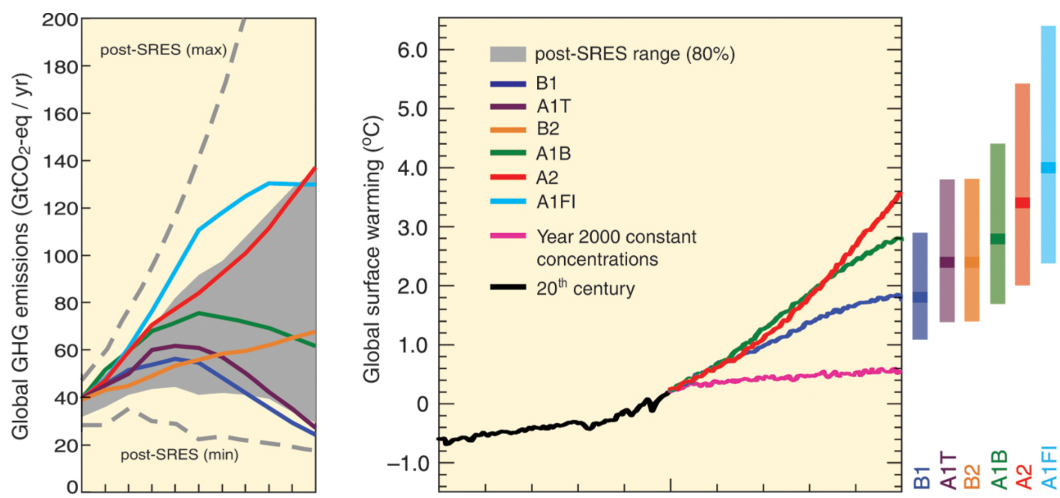
Scenarios of future GHG emissions developed by the Intergovernmental Panel on Climate Change (IPCC) are the scenarios most commonly used by climate modeling centers from which to derive inputs of GHG concentrations for their climate modeling experiments. The scenarios grouped into four different families according to the assumptions adopted for the emphasis given to economic versus environmental goals and the degree to which economic development is regionally or globally oriented.

Using the IPCC emission scenarios, climate modelers have projected increases in global mean surface temperature by 2100 ranging from about 1°C to more than 6°C.

Assumptions behind IPCC SRES scenarios.

	Economic Goals		Ecological Goals	
Global Integration	**A1**		**B1**	
	Strong economic growth Convergence Developed & Developing Country incomes Rapid innovation Improvements energy intensity Low population growth	Year 2100 Population: 7.1 billion GDP/person: $75,000 Energy/GDP: 3.29 million joules	Moderate economic growth Convergence Developed & Developing country incomes Strong improvements energy intensity Low population growth	Year 2100 Population: 7.1 billion GDP/person: $46,500 Energy/GDP: 1.39 million joules
Regional Fragmentation	**A2**		**B2**	
	Weak economic growth Greater regional disparities Slower innovation Limited improvements energy intensity High population growth	Year 2100 Population: 15.1 billion GDP/person: $16,100 Engery/GDP: 5.89 million joules	Low economic growth Regional disparities Moderate improvements energy intensity Low carbon energy Moderate population growth	Year 2100 Population: 10.4 billion GDP/person: $22,500 Energy/GDP: 4.05 million joules

Projections of GHG emissions and changes in global mean surface temperature. Source: IPCC 2007b, Figure SPM5.



Greenhouse Gas Exercises

We will work through parts of two sample exercises during the workshop session:

- Exploring Greenhouse Gas Emissions Data
- Decomposing Growth of CO2 Emissions

The sample assignments are provided as separate documents.

References

Ang, B.W. (2005). "The LMDI Approach to Decomposition Analysis: A Practical Guide." *Energy Policy* 32:1131-39.

Bacon, R.W., and S. Bhattacharya (2007). *Growth and CO2 Emissions: How do Different Countries Fare?* The World Bank Environment Department, Washington, DC.

Baumert, K., T. Herzog, and J. Pershing (2005). *Navigating the Numbers, Greenhouse Gas Data and International Climate Policy*. World Resources Institute, Washington, DC.

Blasing, T.J. (2009). Recent Greenhouse Gas Concentrations. Carbon Dioxide Information Analysis Center: http://cdiac.ornl.gov/pns/current_ghg.html. Accessed July 7, 2010.

IPCC (2007a). *Climate Change 2007: Mitigation of Climate Change*. B. Metz, O. Davidson, P. Bosch, R. Dave and L. Meyer, eds. Cambridge University Press, Cambridge, UK. http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html.

IPCC (2007b). *Climate Change 2007, Synthesis Report*. Core Writing Team, R.K. Pauchauri, and A. Reisinger, eds. Cambridge University Press, Cambridge, UK. http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html.

Kaya, Y. (1990). "Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation and Proposed Scenarios." Paper presented to IPCC Energy and Industry Subgroup, Response Strategies Working Group.

World Resources Institute (2009). Climate Analysis Indicators Tool. COP15 Brochure. Washington, DC. http://cait.wri.org/downloads/CAIT_7.0_COP15.pdf.

Useful resources

Climate Analysis Indicators Tool (CAIT): http://cait.wri.org/cait.php
Database of ghg emissions, social & economic data etc. Can create tables and graphs for single or multiple countries or regions. Includes projection database.

EarthTrends, the Environmental Information Portal: http://earthtrends.wri.org/
Databases, graphics and maps of wide range of environmental, social and economic variables for most countries. Useful for developing profiles of countries to understand factors affecting GHG emissions growth, capacity to reduce emissions, and vulnerability to climate change.

Baumert, K., T. Herzog, and J. Pershing (2005). *Navigating the Numbers, Greenhouse Gas Data and International Climate Policy*. World Resources Institute, Washington, DC. http://www.wri.org/publication/navigating-the-numbers.

Excellent and detailed overview of past, current, and projected greenhouse gas emissions – at global, national and sector levels – with examination of implications for international policy.

US Climate Action Report 2010. US Department of State. Washington, DC, Global Publishing Services. http://www.state.gov/g/oes/rls/rpts/car5/index.htm.
As a signatory to the UN Framework Convention on Climate Change (UNFCCC), the US is required to submit periodic national communications to the UNFCCC. The 2010 report is the 5th national communication of the US. It provides information about US greenhouse gas emissions, climate policies and measures, vulnerability and adaptation, financial resources, research, and education.

USEPA Climate Change Website: http://www.epa.gov/climatechange/
The EPA provides access to information about greenhouse gas emissions, climate change science, health and environmental effects of climate change, climate economics, US climate policy, and ideas for what you can do.

US Environmental Protection Agency (2010). Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2008. USEPA, Washington, DC. http://www.epa.gov/climatechange/emissions/usinventoryreport.html.
This is the definitive, official report of US greenhouse gas emissions. The report includes a description of methodologies, emission trends, and detailed emissions data by sector of the US economy. The full report is 457 pages; check out the shorter 26 page executive summary.

IPCC Special Report on Emission Scenarios, 2000, N. Nakicenovic and R. Swart, eds. Cambridge University Press. http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0.
This report provides detailed description, analysis, and methods of the IPCC SRES scenarios of future emissions of greenhouse gases. Data tables showing detailed breakdown of GHG emissions by region and by sector for 40 different scenarios can be downloaded as excel spreadsheet from the report website.

Kaya identity calculator: http://www.wired.com/wired/st_formula.html
Change values of factors in the Kaya identity, see how they change global CO2 emissions.

Carbon budget simulation 1960-2100: http://profhorn.meteor.wisc.edu/wxwise/carboncycle/cc.html
Can change path of emissions from fossil fuels and land use, also C uptake by oceans and land, and see how it affects CO2 concentration and global surface temperature.

Wedges game: http://cmi.princeton.edu/wedges/game.php
Hosted by Princeton U, Carbon Mitigation Project. Players choose technology options (wedges) to reduce projected 2055 emissions to present level.

Climate challenge game: http://www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge/ Hosted by BBC. Policy game, play online. Players select policies, participate in international negotiations to set targets etc. Game runs from 2000 to 2100, played in 10 year turns