Maxwell Climate Change Workshop Background: The Nature of the Problem

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Some undisputed facts

- Greenhouse gases (GHGs) can trap energy
  - ⇨ *CO_2*
  - ⇨ *Methane (CH_4)*
  - ⇨ *Nitrous oxide (N_2O)*
  - ⇨ *Halocarbons (CFC, HFC, PFC), SF_6*
- Non-anthropogenic but important
  - ⇨ *Water vapor*

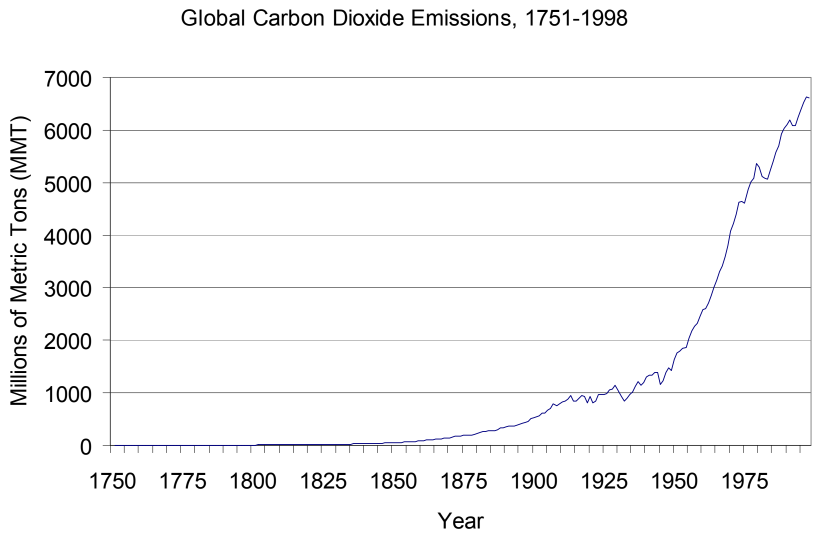
Gases vary in lifetime and effect

Gas	Atmospheric lifetime (years)	Global warming relative to CO2
Carbon dioxide (CO2)	50-200	1
Methane (CH4)	12	23
Nitrous oxide (N2O)	114	296
Halocarbons	260-50,000	5,700-22,200

Global Warming Potential (GWP)

Emissions of all GHGs have been rising

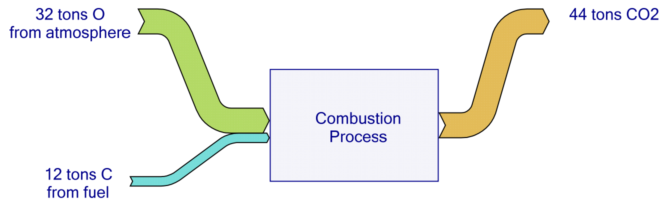
- Can see the pattern in CO2



Units of measurement

- Carbon dioxide emissions measured two ways
  - ⇨ *Tons of carbon -- tons of C*
  - ⇨ *Tons of carbon dioxide -- tons of CO2*
- Two are related by molecular weights
  - ⇨ *C molecular weight of 12*
  - ⇨ *O molecular weight of 16*
  - ⇨ *CO2 molecular weight of 12+16+16 = 44*
- Equivalent climate effect:
  - ⇨ *12 tons C ⇔ 44 tons CO2*

Why two measures?



- C more convenient for input fuels
- CO2 more convenient for output gas

- How to convert units:
  - ⇨ *1 ton of C = 44/12 or 3.67 tons of CO2*
  - ⇨ *1 ton of CO2 = 12/44 or 0.273 tons of C*

From emissions to concentrations…

- Greenhouse gas are trace gases
  - ⇨ *Very small fraction of total atmosphere*

- Emissions exceed natural removal
  - ⇨ *Accumulation raises concentrations*

- Concentrations have increased substantially
  - ⇨ *CO_2 up 35% since the industrial revolution*
  - ⇨ *Was 280 ppm in 1750*
  - ⇨ *Now about 379 ppm*

Future concentrations?

- Uncertain but clearly rising rapidly
- Summarized in scenarios generated by the IPCC

IPCC

- Intergovernmental Panel on Climate Change
  - ⇨ *Established in 1988 by the WMO and UNEP*
- Has issued 4 major "Assessment Reports"
  - First in 1990, Second ("SAR") in 1995, Third ("TAR") in 2001
  - Fourth report ("AR4") in 2007
- Numerous smaller and more specialized reports
  - ⇨ *E.g., Special Report on Emissions Scenarios (SRES)*
- Web site
  - ⇨ *http://www.ipcc.ch/*

IPCC SRES scenarios

- Special Report on Emissions Scenarios (SRES)
- IPCC TAR Working Group III, 2000

- Revised emissions trajectories for climate models
  - ⇨ *Replace previous IS92 scenarios*

- Explicitly avoid probabilities
  - ⇨ *"All are equally valid"*

SRES driving factors

- Primary
  - ⇨ *Population*
  - ⇨ *World economic growth*
  - ⇨ *Income convergence (developing -> developed)*

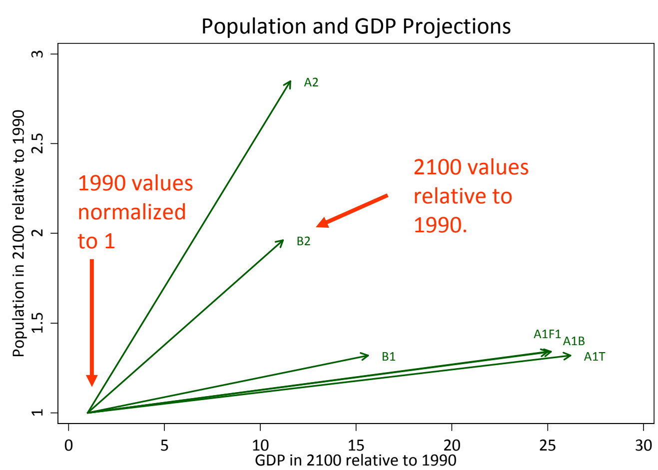
- Secondary
  - ⇨ *Energy intensity*
  - ⇨ *Total primary energy consumption*
  - ⇨ *Share of coal in primary energy*
  - ⇨ *Share of non-carbon primary energy*

Combining assumptions …

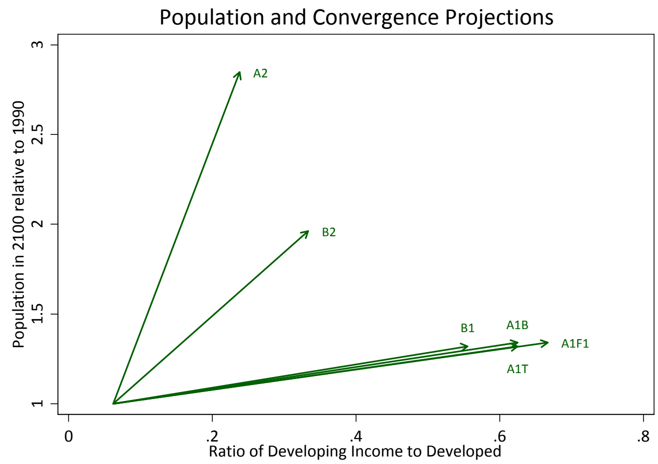
- Six families of scenarios
  - ⇨ *Will discuss in more detail shortly*

- A1 Family
  - ⇨ *A1F1* *Fossil-intensive energy*
  - ⇨ *A1T* *Primarily non-fossil energy*
  - ⇨ *A1B* *Balanced*
- A2 Family
- B1 Family
- B2 Family

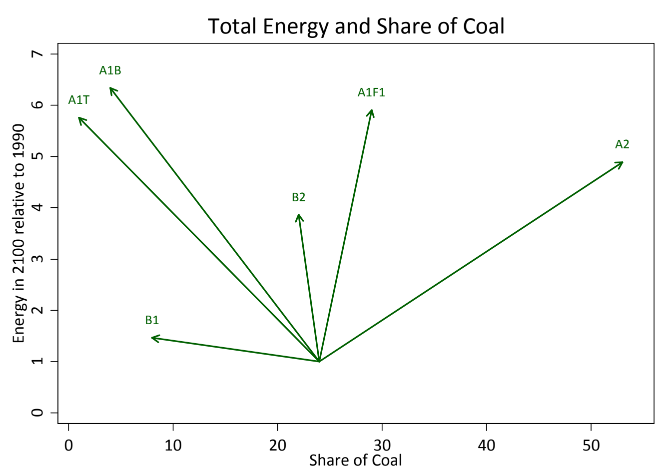
Variation in population and income



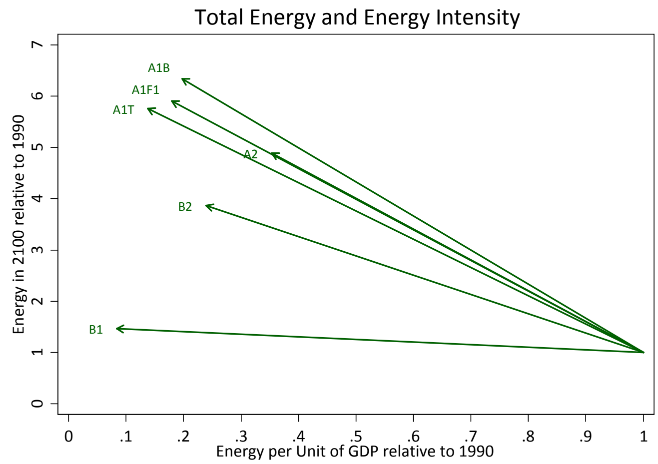
Significant catch-up in most scenarios



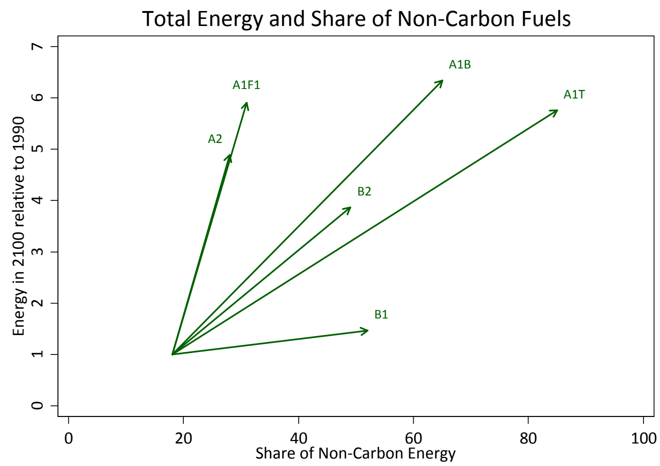
Major variations in energy and coal



Substantial declines in energy intensity



Substantial variation in non-carbon fuels



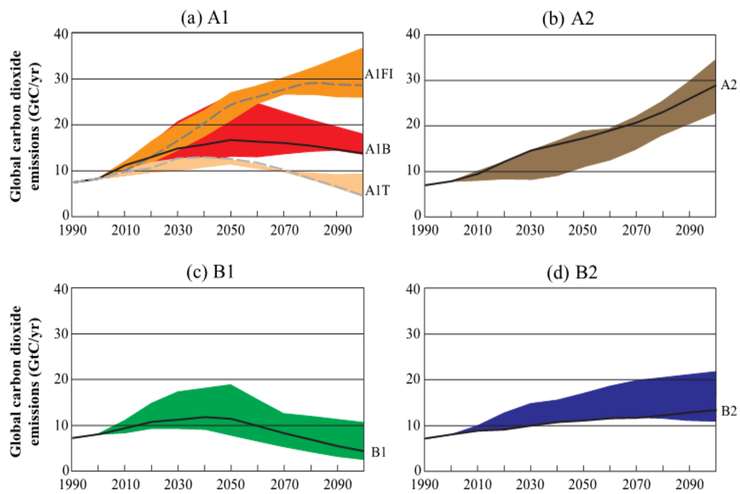
Summarizing the scenarios

- A1: Common Characteristics
  - ⇨ *Strong GDP growth*
  - ⇨ *Rapid income convergence*
  - ⇨ *High energy intensity*
- A1F1
  - ⇨ *Mostly coal, fossil energy*
- A1T
  - ⇨ *Mostly non-carbon energy*
- A1B
  - ⇨ *Mix of fossil, non-carbon*
- A2
  - ⇨ *Rapid population growth*
  - ⇨ *Slow income convergence*
  - ⇨ *High energy intensity*
  - ⇨ *Heavy use of coal*
- B1
  - ⇨ *Moderate GDP growth*
  - ⇨ *Rapid income convergence*
  - ⇨ *Low energy intensity*
  - ⇨ *Clean fuels*
- B2
  - ⇨ *Between A2 and B1*

Next step: ran simulations

- Used six different models
- Many slight variations on the assumptions
- Generated a range of emissions trajectories

Emissions by scenario family



Greenhouse gas concentrations in 2100

- Accumulated effect
  - ⇨ *As of 2100*
- Total burden expressed in terms of CO2 equivalent (CO2e)

IPCC Scenario	Concentration
B1	600 ppm
A1T	700 ppm
B2	800 ppm
A1B	**850 ppm**
A2	1250 ppm
A1F1	1550 ppm

… from concentrations to consequences

- Higher GHG concentrations lead to …
  - ⇨ *Temperature changes*
- Temperature changes lead to …
  - ⇨ *Sea level rise*
  - ⇨ *Changes in precipitation*
  - ⇨ *Extreme weather events and storm severity*
  - ⇨ *Changes in ecosystems*
  - ⇨ *Expanded range of tropical diseases*
  - ⇨ *…*

Current emissions to future effects

Today's concentration

⇩

Current emissions

⇩

Future concentrations

⇩

Temperature change

⇩

Ecological effects

⇩

Economic effects

Capsule summary

- Greenhouse gas emissions
  - ⇨ *High and rising*
- Concentrations
  - ⇨ *Result of accumulated emissions over many years*
  - ⇨ *Rising at current rates of emissions*
  - ⇨ *Will accelerate if emissions continue to rise*
- Temperature
  - ⇨ *Depends on concentration, not directly on emissions*

Key implications

- Stabilizing emissions will not stabilize temperature
  - ⇨ *Concentrations would continue to rise*
  - ⇨ *Temperature rises as a result*
- To stabilize concentrations ...
  - ⇨ *Need very large cuts in worldwide emissions*
- Even stabilizing concentration does not stabilize T
  - ⇨ *"Committed warming" due to existing concentration*

Will need a suite of actions

- Abatement
  - ⇨ *Reducing greenhouse emissions*
- Adaptation
  - ⇨ *Preparing for unavoidable changes*
- Geoengineering
  - ⇨ *Deliberate modification of the climate*

Impacts of policies

Today's concentration
⇩ ⇦Mitigation
Current emissions
⇩
Future concentrations
⇩ ⇦Geoengineering
Temperature change
⇩
Ecological effects
⇩ ⇦Adaptation
Economic effects

Many uncertainties remain

- Future emissions
- Amount and timing of temperature change
- Consequences of warming
- Potential for adaptation

Some potential areas of uncertainty

Today's concentration

⇩

Current emissions ⇦SRES

⇩

Future concentrations

⇩ ⇦GCM Climate Sensitivity

Temperature change

⇩

Ecological effects

⇩

Economic effects

Concentration to temperature

- Translating change in concentration to change in temperature
  - ⇨ *General circulation models (GCMs)*

- Summary of uncertainties in GCMs is the "climate sensitivity":
  - ⇨ *Predicted temperature rise when CO2 concentrations double*
    Pre-industrial levels of 280 ppm to 550 ppm

Very difficult problem …

- Amount and timing of temperature increase unclear
  - ⇨ *Feedback from water vapor*
  - ⇨ *Cloud formation*
  - ⇨ *Speed of ocean response*
  - ⇨ *Aerosols*

- Estimated effect of doubling CO2 concentration
  - ⇨ *1896 estimate was 4-6 degrees C*
  - ⇨ *Current estimate (AR4) is 2-4.5 degrees C*
  - ⇨ *Mean estimate has fallen somewhat*
  - ⇨ *Range of estimate has not decreased*

Main effect of ΔT is higher risks

- Example: sea level rise

⇨ *If ΔT is 1 °C*	*chance of SMALL rise:*	*high*
	chance of moderate rise:	*medium*
	chance of LARGE rise:	*low*
⇨ *If ΔT is 6 °C*	*chance of SMALL rise:*	*low*
	chance of moderate rise:	*high*
	chance of LARGE rise:	*medium*

- Increases probabilities of bad outcomes

Implications

- Each ton of emissions raises risks a little
  - ⇨ *Every ton has some effect*
  - ⇨ *No single ton triggers a catastrophe*
- Not a threshold problem
  - ⇨ *No "safe" level below which risks are zero*

Really no threshold?

- Discontinuous health problems are familiar
  - ⇨ *Cancer*
  - ⇨ *Heart attacks*
- No sharp threshold in causes
  - ⇨ *Which cigarette?*
  - ⇨ *Which ice cream cone?*
- Will have important implications for abatement policies

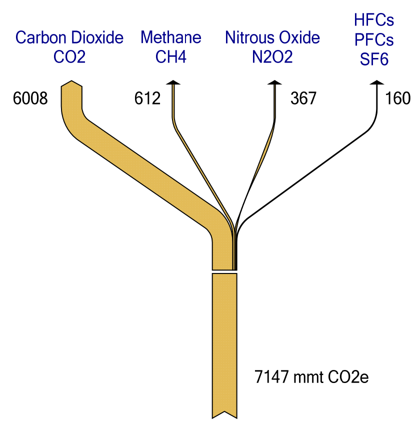
Examine mitigation in detail

CO2 is especially important

- World emissions (weighted by GWP)
  - *73% CO_2*
  - *14% methane*
  - *8% nitrous oxide*
  - *5% other*
- US emissions (weighted by GWP)
  - *84% CO_2*
  - *9% methane*
  - *5% nitrous oxide*
  - *2% other*

US GHG emissions in 2005

Gas	Mmt	Mmt CO2e
Carbon Dioxide	6008	6008
Methane	27	612
Nitrous Oxide	1.2	367
Halocarbons	--	160



Controlling CO2 emissions

- Result of combustion of fossil fuels
  - ⇨ *Natural result of combustion*
  - ⇨ *Not an impurity like sulfur*
  - ⇨ *Not from poor combustion (ozone, NOx, particulates)*

- Reductions require either or both of the following
  - ⇨ *Reduction in fuel use*
  - ⇨ *Capture and sequestration of CO2*

- Need to understand the energy sector in detail

Units again: what is a "quad"?

- US national energy use is measured in quadrillions of BTU
  - ⇨ *BTU = British Thermal Unit*
  - ⇨ *Quadrillion = 10^15*
  - ⇨ *1 quad = 10^15 BTU*

- Metric equivalent is an Exajoule (10^18 J)
  - ⇨ *1 quad = 1.055 EJ*

- How big is a quad?
  - ⇨ *Energy in 45 million tons of coal OR*
  - ⇨ *1 trillion cubic feet of natural gas OR*
  - ⇨ *170 million barrels of crude oil*

Putting a quad in perspective …

- Coal delivered by "unit trains"
  - ⇨ *100 cars, about 1 mile long*
- 1 train = 10,000 tons of coal
  - ⇨ *Fuels a 500 MW power plant for about 2.5 days*
- 1 quad = 4,500 unit trains
- Powder River Basin in WY:
  - ⇨ *60 trains a day*

How many supertankers?

- 1 tanker = 1 million barrels of oil

- 1 quad = 170 tankers
- US used 21 million barrels *per day* (57% imported) in 2005

Translating energy into CO2

- Natural gas
  - ⇨ *14.5 mmt C per quad*
  - ⇨ *Lowest carbon per quad of fossil fuels*
- Oil
  - ⇨ *About 20 mmt C per quad*
  - ⇨ *38% more carbon than gas*
- Coal
  - ⇨ *26 mmt C per quad*
  - ⇨ *80% more carbon than gas*

How much energy is used?

- Total primary energy
  - ⇨ *Includes fossil fuels used to generate electricity*
- World energy consumption is about 400 quads
  - ⇨ *1 quad every 22 hours*
- US consumption is about 100 quads
  - ⇨ *Equivalent barrels of oil: 46 million per day*
  - ⇨ *Equivalent tons of coal: 12 million per day*

How much CO_2 is produced?

- Worldwide in 2004
  - ⇨ *CO_2 from fossil fuels: 27.7 Gt*
- US in 2005 emissions
  - ⇨ *CO_2 from fossil fuels: 6.0 Gt*