Energy Summer School 2022

Economics of Climate Change
Latest CO2 readings.....450ppm equals 2C temperature rise.

January 2022: 418.19 ppm
January 2021: 415.52 ppm
Last updated: February 8, 2022
Increasing CO₂ causes Global Temp increase - 0.2°C/decade. Source NASA. Baseline below is 1951-1980. 2021 is 0.85C above baseline which is about 1.1C above late 19thC when industrial revolution underway. 6th hottest on record. (Nine of the ten hottest years on record have occurred in the past decade.) Animation [https://climate.nasa.gov/vital-signs/global-temperature/](https://climate.nasa.gov/vital-signs/global-temperature/)
CO2 emissions generally increasing bouncing back from Covid....
**Figure 2.10** Annual change in energy-related CO$_2$ emissions

Global CO$_2$ emissions are set to see one of the largest rises in history in 2021, erasing most of the gains realised during the pandemic.

Note: 2021e = estimated values for 2021.
Greenhouse effect not just CO$_2$ but CO$_2$ most important.
c) Contributions to 2010-2019 warming relative to 1850-1900, assessed from radiative forcing studies.
This graph shows the historical changes in CO₂ concentration, global temperature, and sea level over time. The CO₂ concentration is depicted on the left side, with a peak highlighted in red. The global temperature is shown in the middle, marked with significant events like the Eemian and Holocene periods. The sea level, on the bottom, also exhibits fluctuations over time. The time scale is represented as thousands of years before present.
Making progress towards 1.5-2C

Figure 1.4: CO₂ emissions in the WEO-2021 scenarios over time

Figure 1.5: Global median surface temperature rise over time in the WEO-2021 scenarios

The APS pushes emissions down, but not until after 2030; the SDS goes further and faster to be aligned with the Paris Agreement; the NZE delivers net zero emissions by 2050.

Note: APS = Announced Pledges Scenario; SDS = Sustainable Development Scenario; NZE = Net Zero Emissions by 2050 Scenario.

The temperature rise is 2.6 °C in the STEPS and 2.1 °C in the APS in 2100 and continues to increase. It peaks at 1.7 °C in the SDS and 1.5 °C in the NZE around 2050 and then declines.
Future emissions cause future additional warming, with total warming dominated by past and future CO₂ emissions

a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios

- Carbon dioxide (GtCO₂/yr)
- Selected contributors to non-CO₂ GHGs
  - Methane (MtCH₄/yr)
  - Nitrous oxide (MtN₂O/yr)
  - One air pollutant and contributor to aerosols
  - Sulfur dioxide (MtSO₂/yr)

b) Contribution to global surface temperature increase from different emissions, with a dominant role of CO₂ emissions

- Change in global surface temperature in 2081-2100 relative to 1861-1900 (°C)

Total warming (observed warming to date in darker shade), warming from CO₂, warming from non-CO₂ GHGs and cooling from changes in aerosols and land use
Tipping points: Not in Models but possible danger

• Increasing concern that “inert carbon pools can be mobilised and released into the atmosphere as CO$_2$ or methane, a much more potent greenhouse gas”

• Stores of carbon including tropical peat land carbon, Arctic permafrost and methane hydrates on ocean floor may be released into atmosphere as planet warms.

• Potentially huge amounts of CO$_2$ or methane could dramatically increase warming.

• A number of such tipping elements, any one of which, if triggered, would lead to societal disruption for very large numbers of people
Climate Scientists suggest best to keep temperature increase to 2°C (450ppm) 2001, 2009, 2014 IPCC reports.
Fossil fuel reserves are 3-5 times larger than the remaining carbon budget of 900 Gt CO₂

<table>
<thead>
<tr>
<th>Carbon budget emissions to 2100</th>
<th>Emissions implied by fossil fuel reserves</th>
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<tbody>
<tr>
<td>Billion tonnes of CO₂-eq.</td>
<td>1000 billion tonnes of CO₂-eq.</td>
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<tr>
<td>2C carbon budget</td>
<td>Reserves</td>
</tr>
<tr>
<td>Non-CO₂, 2015-2100</td>
<td>3.0-5.4</td>
</tr>
<tr>
<td>1750-1985</td>
<td>0.1-0.3</td>
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<tr>
<td>1985-2015</td>
<td>0.1-2.4</td>
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<tr>
<td>2016-2100</td>
<td>0.3-0.4</td>
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<tr>
<td>939</td>
<td>1.8-2.1</td>
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<tr>
<td>~900</td>
<td>0.9</td>
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<tr>
<td>790</td>
<td>0.2</td>
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Source: Slide from Stern talk
Overview

• CO$_2$ around 420ppm. Going up by 3 ppm a year. Preindustrial was 280ppm.
• Business as usual will see this increase so that in 100 years CO$_2$ could be 800ppm+
• Business as usual- climate models suggest 50% chance of 4.5C increase by end of this century.
• Huge temperature change. Ice age was 5C lower temp than now.
• 5C increase - much of tropical regions uninhabitable which implies huge population displacement towards the poles.
Overview

• At 450 ppm CO$_2$ then temperature increase will be around 2C eventually (50/50 chance either side).
• At 550ppm temperature increase will be around 3C eventually.
• We are at 419 ppm already which is about 50/50 chance of 1.5C!
• Lags. Even if we stay at 419ppm takes decades before we get to 1.5C.
• Going up 3ppm a year so 450ppm in 10 years.
• Stock causes the problems. Flow each year adds to the stock.
• To stabilize stock means we can emit only what the environment can absorb.
IEA 450ppm scenario: Need to break the link of GDP and CO$_2$ emissions

Figure 4.3: Historical link between energy-related CO$_2$ emissions and economic output, and the pathway to achieving a 450 Scenario

Note: The projected trend approximates that required to achieve long-term stabilisation of the total greenhouse-gas concentration in the atmosphere at 450 ppm CO$_2$-eq, corresponding to a global average temperature increase of around 2°C. World GDP is assumed to grow at a rate of 2.7% per year after 2030.

Source: IEA databases and analysis.
Overview

• Achieving 450ppm by 2050 means a 50% reduction in world emissions by then.
• World GDP 3 times bigger by then.
• Population increases from 7.8 billion to 9.7 billion.
• Cost of achieving such reductions can be estimated reasonably accurately. Stern (Stern report) estimates a one off cost of 1% of GDP. (like a one off increase of CPI of 1%). No impact on world growth.
• Means going to zero carbon where we can (electricity and transport)
Economics of Climate Change

• What is optimal equilibrium stock of $\text{CO}_2^e$ (i.e. $\text{CO}_2 + \text{other gases as CO}_2$ equivalent)? (Scientists say 450ppm = 2C but what do economists say?)

• What is optimal path of emission reduction?

• Once these are agreed on then we need policies that will do this at least cost.
But it is the stock that is the problem so need to bring time into it.

Optimal CO$_2$ level and emission reduction path. Integrated Assessment Models. Nordhaus 2010

• IAM model looks at interaction of Economy ↔ Emissions (warming) over time. Economic activity leads to emissions and damages which impacts on the economy.
Why an Integrated assessment model?

• Why is such a combined model useful for analyzing economics of climate change?

  Because

• GHG emissions effect climate change
• Climate Change effects economy and welfare
• Economic production and welfare effects GHG emissions

• -> Continuous interaction between economy, welfare and GHGs

• A policy that changes one of these changes all aspects and how they interact over time!
Building blocks

• Equations for how production, investment and emissions vary with time.

• And equations how the stocks change with time. (1) Capital, (2) Greenhouse gases in atmosphere and hence temperatures.

• Find optimal savings rate over time (more investment but less consumption now but more output in the future)

• And optimal spending on mitigating climate change (more spending now less damages in the future)

• Discounted social welfare is maximized over time.
Where does RICE get values?

\[ Y_t = \frac{1 - \Lambda_t}{D_t} f(A_t, K_t, L_t) \]

- \( L_t \) is exogenous estimate of population growth
- \( K_t \) is endogenous (calculated from model)
- Technological change parameter \( A_t \) is estimated (exogenous)
  - equals long run per capita growth rate

- Damages \( D_t \) are estimated as a quadratic function of temperature
  \[ D_t = a_0 + a_1 T + a_2 T^2 \] *(Come back to this as has been criticized)*

- Cost of emissions reduction \( \Lambda_t (\mu_t) \) estimated
  as function of control rate \( \mu_t \)
Damages

• One of biggest impacts is on health. eg increase in Malaria in some areas, heat related respiratory disease.
• Increase in sea levels, flooding etc.
• Increase in storm damage
• Impact on agriculture uncertain for small increases – negative for large increase.
• Loss of biodiversity (difficulty to value)
Example catch declines

Climate change poses risks for food production

Change in maximum catch potential (2051-2060 compared to 2001-2010, SRES A1B)

(a)

(b)

Percentage of yield projections

Range of yield change
- 50 to 100%
- 25 to 50%
- 10 to 25%
- 5 to 10%
- 0 to 5%
- 0 to -5%
- -5 to -10%
- -10 to -25%
- -25 to -50%
- -50 to -100%
# IAMs: on Damages... (Stern Review)

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<thead>
<tr>
<th>Global temperature change (relative to pre-industrial)</th>
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<tbody>
<tr>
<td>0°C</td>
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<td>Food</td>
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<th>Water</th>
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<td>Small mountain glaciers disappear – water availability in many areas, including Mediterranean and Southern Africa</td>
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<td>Sea level rise threatens major cities</td>
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<th>Ecosystems</th>
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<td>Extensive Damage to Coral Reefs</td>
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<td>Rising number of species face extinction</td>
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<th>Extreme Weather Events</th>
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<td>Rising intensity of storms, forest fires, droughts, flooding and heat waves</td>
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<th>Risk of Abrupt and Major Irreversible Changes</th>
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<td>Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system</td>
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DICE model

• Dynamic Integrated Climate-Economy model
• Max social welfare which is discounted sum of utility which depends (mainly) on Consumption. “r” is the discount rate

\[ W = \sum_{t} \frac{u(C_t)}{(1 + r)^t} \]

• Solve for optimal investment and emission reduction path.
• Heart of the model is tradeoffs.
  1. Consumption-savings
  2. CO\(_2\) mitigation costs, so less output today vs. future damages due to temperature increases.
• Discount rate very important because damages occur in the future. Nordhaus uses quite high rate (around 3% which decreases to around 1% as time goes on)
Results Nordhaus (2010)

- Nordhaus optimal emission reduction path typically gradual. “Slow Ramp”
- Model finds higher CO$_2$ levels and hence higher temperature increases optimal compared to say Stern or climate scientists.
- Results next few slides
Nordhaus Conclusions...
A review of the Stern review J. Ec Lit 2007

• “One of the major findings in the economics of climate change policy has been that efficient or optimal economic policies to slow climate change involve modest rates of emissions reductions in the near term, followed by sharp reductions in the medium and long term. We might call this the climate policy ramp....”
Scenarios

(i) **Baseline**: No climate-change policies are adopted.
(ii) **Optimal**: Climate-change policies maximize economic welfare, with full participation by all nations starting in 2010 and without climatic constraints.
(iii) **Temperature-limited**: The optimal policies are undertaken subject to a further constraint that global temperature does not exceed 2 °C above the 1900 average.
(iv) **Copenhagen Accord**: High-income countries implement deep emissions reductions similar to those included in the current US proposals, with developing countries following in the next 2 to 5 decades.
(v) **Copenhagen Accord with only rich countries**: High-income countries implement deep reductions as in scenario 4, but developing countries do not participate until the 22nd century.
Fig. 1. Projected emissions of CO₂ under alternative policies. Copen, Copenhagen.
Fig. 2. Atmospheric concentrations of CO$_2$ under alternative policies. Copen, Copenhagen.
Fig. 3. Global temperature increase (°C from 1900) under alternative policies. Copen, Copenhagen.
Fig. 3. Social cost of carbon and growth-corrected discount rate in DICE model. The growth-corrected discount rate equals the discount rate on goods minus the growth rate of consumption. The solid line shows the central role of the growth-corrected discount rate on goods in determining the SCC in the DICE model. The square is the SCC from the full DICE model, and the triangle uses the assumptions of The Stern Review (10). A further discussion and derivation of the growth-corrected discount rate is given in Supporting Information.
Criticisms of IAMs

• Stern
• Weitzman

• Stern Video Clip (8mins)
Wietzman Critiques

- Damage Function
- Discount Rate
- Irreversibility
- Fat tails
Modeling Myths:
On the Need for Dynamic Realism in DICE and other Equilibrium Models of Global Climate Mitigation

Michael Grubb† and Claudia Wieners‡

Working Paper No. 112

January 25, 2020
We identify fundamental flaws in both the descriptive and normative methodologies commonly used to assess climate policy, showing systematic biases, with costs of climate action overestimated and benefits underestimated. We provide an alternative methodology by which the social cost of carbon may be calculated, one which embraces the essential elements we have identified.
En –Roads Climate Simulation

https://en-roads.climateinteractive.org/scenario.html?v=2.7.19

Global Sources of Primary Energy

Temperature Change

+4.1 °C

Temperature Increase by 2100

Energy Supply
- Coal
- Oil
- Natural Gas
- Bioenergy

Renewables

Energy Efficiency

Transport
- Electrification

Buildings and Industry
- Energy Efficiency

Land and Industry Emissions
- Methane & Other

Afforestation

Carbon Removal
- Technological

Population

Economic Growth

En-ROADS Climate Ambassador Training
END

• QUESTIONS