Energy Summer School 2020

Economics of Climate Change
CO$_2$ from burning fossil fuels (note there are other GHGs)

Feb 2021 416.75
Feb 1 2020 414.34
Total all GHGs = 440ppm
Increasing CO$_2$ causes Global Temp increase - 0.2°C/decade. Source NASA. There are several different data sets which differ slightly but similar story. Baseline below is 1900-2000. 2020 +1.02°C

Animation [https://data.giss.nasa.gov/gistemp/animations/5year_2y.mp4](https://data.giss.nasa.gov/gistemp/animations/5year_2y.mp4)

CO2 emissions generally increasing

Annual CO2 emissions
Carbon dioxide (CO2) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Source: Global Carbon Project; Carbon Dioxide Information Analysis Centre (CDIAC)  OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY
Note: CO2 emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.
But CO2 emissions fell last year from 33.4Gt in 2019 to 31.5Gt in 2020
Global energy-related CO2 emissions and annual change, 1900-2020
Greenhouse effect not just CO$_2$ but CO$_2$ most important.
Other GHGs include methane, NO$_2$ increase warming to CO$_2$ equivalent = 485 ppm

Source: NOAA [http://www.esrl.noaa.gov/gmd/aggi/](http://www.esrl.noaa.gov/gmd/aggi/)
CO$_2$ Concentration

Global Temperature

Sea Level (Ft.) Temperature (°F)

Time (thousands of years before present)

For copy of slide, email: 3graph400k@johnenglander.net
www.johnenglander.net
IPCC projections. Business as usual 4.0°C by 2100. Stabilization scenarios much lower.

2100: RCP2.6=421ppm ;RCP8.5=1313ppm
Tipping points: Not in Models but possible danger

• Increasing concern that “inert carbon pools can be mobilised and released into the atmosphere as CO\textsubscript{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\textsubscript{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

Carbon budget emissions to 2100
Billion tonnes of CO₂-eq.

<table>
<thead>
<tr>
<th>Year</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2C carbon budget</td>
<td>3,670</td>
</tr>
<tr>
<td>Non-CO₂, 2015-2100</td>
<td>790</td>
</tr>
<tr>
<td>1750-1985</td>
<td>1,060</td>
</tr>
<tr>
<td>1985-2015</td>
<td>939</td>
</tr>
<tr>
<td>2016-2100</td>
<td>~900</td>
</tr>
</tbody>
</table>

Emissions implied by fossil fuel reserves
1000 billion tonnes of CO₂-eq.

<table>
<thead>
<tr>
<th>Source of Emissions</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserves</td>
<td>1.8-2.1</td>
</tr>
<tr>
<td>2 °C carbon budget</td>
<td>0.9</td>
</tr>
<tr>
<td>1.5 °C carbon budget</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: Slide from Stern talk
Overview

• CO$_2$ equivalent today around 444ppm. 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 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 414 ppm already which is about 50/50 chance of 1.5C!
- Lags. Even if we stay at 414ppm takes decades before we get to 1.5C.
- Going up 2.5ppm a year so 450ppm in 16 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)
Overview

- 37 Gt/year CO$_2$e current emissions means average of 7 tons/person
- World population is 7.8 billion
- Expected world population 2050 is 9.7b

- Want to cut CO2 emissions in half with By 2050
- Means 1.9 tons/person
- Means 90% reduction for US
- 70% for NZ/Europe.
- Means reduction for China as well.

<table>
<thead>
<tr>
<th>Country</th>
<th>CO2 per person Tonnes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>16.5</td>
</tr>
<tr>
<td>Europe</td>
<td>6.4</td>
</tr>
<tr>
<td>China</td>
<td>7.5</td>
</tr>
<tr>
<td>India</td>
<td>1.7</td>
</tr>
<tr>
<td>Africa</td>
<td>&lt;1</td>
</tr>
<tr>
<td>NZ</td>
<td>7.7(14)</td>
</tr>
<tr>
<td>Australia</td>
<td>15.4</td>
</tr>
</tbody>
</table>

https://data.worldbank.org/indicator/EN.ATM.CO2E.PC
Economics of Climate Change

• What is optimal equilibrium stock of $\text{CO}_2^e$ (i.e. $\text{CO}_2$ + other gases as $\text{CO}_2$ 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!
Highly Schematic Diagram of the Model

Source: Penn State University
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

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

(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)

<table>
<thead>
<tr>
<th>Global temperature change (relative to pre-industrial)</th>
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<tbody>
<tr>
<td>o°C</td>
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### Food
- 0°C: Falling crop yields in many areas, particularly developing regions
- 1°C: Possible rising yields in some high latitude regions
- 2°C: Falling yields in many developed regions

### Water
- 0°C: Small mountain glaciers disappear – water supplies threatened in several areas
- 1°C: Significant decreases in water availability in many areas, including Mediterranean and Southern Africa
- 2°C: Sea level rise threatens major cities

### Ecosystems
- 0°C: Extensive Damage to Coral Reefs
- 1°C: Rising number of species face extinction

### Extreme Weather Events
- 0°C: Rising intensity of storms, forest fires, droughts, flooding and heat waves

### Risk of Abrupt and Major Irreversible Changes
- 0°C: Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system

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The Economics of Climate Change – C 175
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

\[ W = \sum_{t=0}^{\infty} \frac{u(C_t)}{(1+r)^t} \]

• Solve for optimal investment and emission reduction path.
• Heart of the model is tradeoffs.
  1. Consumption-savings
  2. CO₂ 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 CO₂ 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)
CO2 reductions needed to keep global temperature rise below 1.5°C

Annual emissions of carbon dioxide under various mitigation scenarios to keep global average temperature rise below 1.5°C. Scenarios are based on the CO₂ reductions necessary if mitigation had started – with global emissions peaking and quickly reducing – in the given year.

Source: Robbie Andrews (2019); based on Global Carbon Project & IPCC SR15
Note: Carbon budgets are based on a >66% chance of staying below 1.5°C from the IPCC's SR15 Report.
En–Roads Climate Simulation

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

+4.1°C
Temperature Increase by 2100

Energy Supply
- Coal: status quo
- Oil: status quo
- Natural Gas: status quo
- Bioenergy: status quo
- Renewables: status quo

Transport
- Energy Efficiency: status quo
- Electrification: status quo

Buildings and Industry
- Energy Efficiency: status quo
- Electrification: status quo

Land and Industry Emissions
- Deforestation: status quo
- Methane & Other: status quo

Carbon Removal
- Afforestation: status quo
- Technological: status quo

Growth
- Population: status quo
- Economic Growth: status quo
END

• QUESTIONS
Policy Instruments for mitigation
Stern report

• Price on carbon important. (tax or cap& trade)
• But not enough. Need to encourage new technology (due to uncertainty in carbon price and fact that costs come down with scale and experience). R&D spend or subsidies.
• Energy efficiency projects not being done. Market imperfection. Information and transaction costs. Financial Instruments
• Regulation important as well.
Plan for a global deal: Stern

- Commit to 50% reduction by 2050 (rich countries 75%)
- Price on carbon
- International trading in carbon credits important to establish flow of funds from rich to developing countries.
- Deforestation. Need $10-$15 billion a year to achieve 50% reduction.
- Funds for developing and sharing technology $12-25 billion
- Adaption funds.
Policy Approaches

• Previously dominated by environmental law and regulation. New policy should be market based.
• Mandated pollution control technologies (for example only certain types of coal could be burnt – reduced smog in London and other cities dramatically)
• More recent approach favored are market-based schemes such as cap and trade or carbon tax combined with some regulated standards and subsidies to R&D.
Costs of abatement are well established
Exhibit 1

Global GHG abatement cost curve beyond business-as-usual – 2030

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO₂e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0
Carbon Price

Figure 1.1 ▶ Selected carbon pricing schemes in place as of mid-2016

Countries put a wide range of prices on carbon in different parts of the energy sector.
“Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels”

How is this goal to be achieved? The main mechanism is via Nationally Determined Contributions (NDCs),

Pledges made in advance of Paris that outlined climate ambitions, The first round of NDCs for the period from 2020 are formalized when countries ratify or accede to the Agreement; subsequent NDCs will be communicated every five years, with the next round set by 2020”
Quite possible to stabilize temperature increase to 2 degrees through wedges.

Figure 13.18: World energy-related CO₂ emission savings by policy measure in the 450 Scenario compared with the New Policies Scenario

- **Current Policies Scenario**
- **New Policies Scenario**

<table>
<thead>
<tr>
<th></th>
<th>Abatement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2020</td>
</tr>
<tr>
<td>Efficiency</td>
<td>76%</td>
</tr>
<tr>
<td>Renewables</td>
<td>14%</td>
</tr>
<tr>
<td>Biofuels</td>
<td>2%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4%</td>
</tr>
<tr>
<td>CCS</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Total (Gt CO₂)</strong></td>
<td><strong>1.8</strong></td>
</tr>
</tbody>
</table>
2C scenarios.

Figure 1: Three scenarios, each of which would limit the total global emission of carbon dioxide from fossil-fuel burning and industrial processes to 750 billion tonnes over the period 2010–2050. Source: German Advisory Council on Global Change, WBGU (2009) http://thinkprogress.org/climate/2012/09/01/784931/realistically-what-might-the-future-climate-look-like/
Stern Report

• 700 page report [http://www.webcitation.org/5nCeyEYJr](http://www.webcitation.org/5nCeyEYJr)
• Conclusion “benefits of strong, early action on climate change considerably outweigh the costs”.
• 1% per year of GDP needs to be invested to reduce CO$_2$ emissions to prevent GDP being up to 20% less in the future.
• 2008 Stern revised this in light of evidence that climate change is happening faster than previously thought means tougher emission targets required...500ppm
• Implies costs of 2% a year of GDP
Stern report

• "our actions over the coming few decades could create risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century.

• “And it will be difficult or impossible to reverse these changes. Tackling climate change is the pro-growth strategy for the longer term and it can be done in a way that does not cap the aspirations for growth of rich or poor countries."
• QUESTIONS