HONR 229L: Climate Change: Science, Economics, and Governance

Reading for next Wed:

Discussion that Gustavo will lead.

Please read either

a) Chapter 2 (30 pages; solar PV)

*OR*

b) Chapter 3 (29 pages; concentrated solar)

Gustavo will have to read both. This material is a breeze to read.

Will post an AT for both chapters; please complete only one.
Briefly and in your own words, what are the two findings from the 1990 IPCC report that Nate Silver describes as being absolutely certain?

1) There is a natural greenhouse effect that keeps the Earth warmer than it otherwise would be.

2) Human activities are substantially increasing the atmospheric concentration of the greenhouse gases carbon dioxide, methane, CFC's, and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in the warming of the Earth's surface. In addition, water vapor will serve as positive feedback, furthering the warming of Earth.
HONR 229L: Climate Change: Science, Economics, and Governance

What are the "three prongs" of the critique of IPCC forecasts in the Armstrong and Green paper?

Armstrong and Green refute some aspects of the IPCC forecasts on the grounds that:

1) scientific consensus on climate models is not an accurate indication of the models validity

2) they posit that the global climate landscape is too complex to model accurately

3) IPCC does not adequately factoring in uncertainties into their models, leading to "overconfidence"
1a) This craving for belonging is what feeds into group think, the practice of drowning out the creativity and thoughts of individuals in the name of group decisions. The mentality of a group is translated into the first criticism of Armstrong and Green, relating the majority opinion to accuracy. Many scientists disregard the data of skeptics because within their "pack", their opinion is valid and encouraged. Popularity doesn't indicate truth, replicable data does.

1b) For example, when there is an individual who is esteemed within their field, other members of a group would be more likely to agree with the individual's findings rather than vouch for their own. In cases like these, consensus does not equate to accuracy, as several other factors influence a group's decision rather than the actual correctness of the findings.

2a) The reasoning behind this skepticism is due to the complexity of the climate and the programs used to model it. With so many factors contributing to climate (the biosphere, atmosphere, etc.), mathematical models over the years have grown increasingly complex as well. Many scientists contend that with such complex models, there are bound to be programming errors, on top of the many assumptions these models make about the climate.

2b) A simple linear regression equation along with the level of CO₂ measured in Antarctic ice cores and at the Mauna Loa Observatory could have predicted a global temperature increase in line with the actual data.
AT 10, Q4 Briefly summarize either Figure 12-3, 12-7, or 12-11 of the reading.

In a sentence or two, state what the figure shows, and then state how the chosen figure relates to the debate about climate change. Feel free to draw upon the book, other material, or your own intuition.

Figure 12-3 denotes the uncertainty for any system that changes over a long time period, but Silver specifically uses this for global warming data. The model has three parts. First, the initial condition uncertainty shows the short term factors that affect the underlying model, and this is primarily manifest in climate change with the unpredictability of the weather, among other factors. Second is the scenario uncertainty which is one that progresses and increases with time. The rate at which carbon dioxide is produced may be constant but this gas accumulates over time, increasing risk, and can be thought of as the integral of carbon dioxide produced over the time period. Lastly, there is structural uncertainty which is the risk inherent in the knowledge of the model, which may not include everything that affects the climate system. Because of these risks, climate change models may be unpredictable.
AT 10, Q4  Briefly summarize either Figure 12-3, 12-7, or 12-11 of the reading.

In a sentence or two, state what the figure shows, and then state how the chosen figure relates to the debate about climate change. Feel free to draw upon the book, other material, or your own intuition.

Figure 12-7 shows IPCC's predicted range for the global temperature over the next 100 years, though the graph only shows about 30 years. It displays the upper temperature they believe the temperature could reach if temperature is increasing by 5 degrees per century. The lower temperature is at an increase of 2 degrees per century. The other line that goes up and down at no constant rate is the actual temperature as the years have passed. It's easy to see that the global temperature is very difficult to predict because it can increase a lot one year and then drop for the next 2 years (as seen from 1997-2000).

It is also clear from the graph that average temperature is slowly rising, even though it fluctuates constantly. The accuracy of the graph should clear up some doubt about the uncertainty explained in question 3, and show that climate models of the future are accurate and shouldn't be ignored.
AT 10, Q4  Briefly summarize either Figure 12-3, 12-7, or 12-11 of the reading.

In a sentence or two, state what the figure shows, and then state how the chosen figure relates to the debate about climate change. Feel free to draw upon the book, other material, or your own intuition.

**Figure 12-11 shows how much the global temperature has changed year to year from 1900 to 2010. It shows that there are often downward trends in temperature from one year to the next, that give the *illusion that there is no global warming*, but when you look at the change over a century, it becomes more obvious that on average, the temperature of the earth is increasing.**
M. King Hubbert: Shell geophysicist

1956: presented a paper “Nuclear Energy and Fossil Fuels” that predicted US oil production would peak in 1970

Paper was met with skepticism & ridicule

But: this prediction was remarkably accurate!
Extensive Literature on This Subject
Extensive Literature on This Subject

Hubbert's Peak
The Impending World Oil Shortage

Peak Oil Paradigm Shift
The Urgent Need for a Sustainable Energy Model
by Bilal Abdullah

The Coming Economic Collapse
How You Can Thrive When Oil Costs $200 a Barrel
STEPHEN LEEB, Ph.D.
Author of THE OIL FACTOR
with GLENN STRATFORD
Global Oil Production Predicted to Peak Next Decade!

Hubbert-like analysis applied global oil supply predicts peak production in 2022

**Table 2** Peak time and peak yield, $10^6$ tonnes

<table>
<thead>
<tr>
<th>Peak time</th>
<th>Peak yield</th>
<th>Yield in 2020</th>
<th>Yield in 2030</th>
<th>Yield in 2040</th>
<th>Yield in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>2022</td>
<td>4340</td>
<td>4330</td>
<td>4215</td>
<td>3760</td>
<td>3110</td>
</tr>
</tbody>
</table>

Jin et al., Petroleum Science, 2017

[https://link.springer.com/article/10.1007/s12182-017-0168-z](https://link.springer.com/article/10.1007/s12182-017-0168-z)
Global Oil Production Predicted to Peak Next Decade!

On the other hand, strategic oil cooperation with Africa is still a key support for China’s economic and social development in the short term. In addition to cooperation with Nigeria, cooperation with Sudan, Congo and other countries in the field of energy must be strengthened to achieve win–win situations and energy security.

Jin et al., Petroleum Science, 2017

https://link.springer.com/article/10.1007/s12182-017-0168-z
Hydraulic Fracturing

- Pumping of chemical brine to loosen deposits of natural gas from shale
- Extraction of CH$_4$ from shale gas became commercially viable in 2002/2003 when two mature technologies were combined: horizontal drilling and hydraulic fracturing
- High-pressure fluid is injected into bore of the well at a pressure that fractures the rock


Shale gas fracturing of 2 mile long laterals has been done only in the past decade
Hydraulic Fracturing

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Marcellus Shale in Penn, WV, & Ohio is major source of fracking

http://akrondave.files.wordpress.com/2011/01/marcellus-shale.jpg
Concern #1: Earthquakes

Concern #2: Water Quality
Concern #3: Methane Leakage

Global Warming Potentials of CH$_4$ and N$_2$O on a per mass basis

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>100 Year Time Horizon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH$_4$</td>
<td>21</td>
<td>23</td>
<td>25</td>
<td>28, 34*</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>310</td>
<td>296</td>
<td>298</td>
<td>265, 298*</td>
</tr>
<tr>
<td>20 Year Time Horizon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH$_4$</td>
<td>56</td>
<td>62</td>
<td>72</td>
<td>84, 86*</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>280</td>
<td>275</td>
<td>289</td>
<td>264, 268*</td>
</tr>
</tbody>
</table>

*Allowing for carbon cycle feedback

Note: due to the respective molecular weights of CO$_2$ (44) and CH$_4$ (16), CH$_4$ has a GWP of 10.2 (28 × 16/44) on a 100 year time horizon according to IPCC (2013)

Table 1.1: Salawitch et al., Paris Climate Agreement: Beacon of Hope, 2017
Fossil Fuel Reserves

Brendan DeMilt

11 October 2017
First thing’s First...

Which article do you think was easiest to understand? Why?
Total CO₂ emissions since 1860?

1510 Giga tons

Coal is a lead source of CO₂ emissions lately
The Carbon Budget

What is it?

The amount of Carbon that can be emitted which has a high probability of keeping temperature change within a certain level.

According to the IPCC, what is our ‘carbon budget’ for keeping temperature change below 2°C by 2050?

870–1,240 Giga (billion!!) tons, but McGlade and Ekins use 1,100 Gt as reference
Fossil Fuel Production

Notice anything particularly scary?

"...we estimate there to be 100 billion barrels of oil (including natural gas liquids) and 35 trillion cubic metres of gas in fields within the Arctic Circle that are not being produced as of 2010." (McGlade and Ekins, 190)

However, none of it can be burned to meet climate goals.
Resources vs. Reserves

What’s the difference?

Resources: Fossil fuels that can have the ability to be recovered and produced (regardless of technological capability)

Reserves: resources that can be recovered under current economic conditions and will likely be produced or refined
How do we prevent global meltdown?

The amount of carbon that makes it into the atmosphere depends on if CCS is used.

CCS: Carbon Capture (and) Storage

The removal of waste Carbon that is removed from the atmosphere and stored

Carbon price: Charging for CO₂ emissions

How do we prevent global meltdown?

Must leave a fraction of the following reserves “unburnable”:

<table>
<thead>
<tr>
<th></th>
<th>Oil: 30%</th>
<th>Gas: 50%</th>
<th>Coal: 80%</th>
</tr>
</thead>
</table>

Can we do it?!
Any idea what this means?

Relationship between fossil fuel productions

Green: Stays below a 2 degree change

Yellow: Between 2 and 3 degree change

Red: More than 3 degree change
(Pack sunscreen)
Well, let’s think about it...

Canada has 13 billion barrels of oil that are “burnable”

The U.S. imports 3.80 million barrels per day (1.39 billion per year)

How long can the United States continue to import oil from Canada? Less than 13 years.
The oil sands of Canada! (tar sands)

Mixture of crude oil, sand, and clay

Not often included in reserve estimates

Although previously untapped, the technology now exists to harvest the oil

Could possibly represent $\frac{2}{3}$ of global petroleum supplies

Devastating to natural forests and water supply


http://www.capp.ca/canadian-oil-and-natural-gas/oil-sands/what-are-oil-sands
Well, let’s think about it...

Canada has 13 billion barrels of oil that are “burnable”

The U.S. imports 3.80 million barrels per day (1.39 billion per year)

How long can this relationship last?
Less than 13 years.

What needs to change?

What are some suggested “transition fuels”?
Unconventional gases (shale, natural, etc.)
Enforcing change

“We in Africa, we should not be in the discussion of whether we should use coal or not. In my country of Tanzania, we are going to use our natural resources because we have reserves which go beyond 5 billion tons.” – Muhongo Sospeter

<table>
<thead>
<tr>
<th>Country or region</th>
<th>2 °C with CCS</th>
<th>2 °C without CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil</td>
<td>Gas</td>
</tr>
<tr>
<td></td>
<td>Billions of</td>
<td>Trillions of</td>
</tr>
<tr>
<td>Africa</td>
<td>barrels</td>
<td>cubic metres</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Is it right to force countries to limit their fossil fuel production?
Enforcing change

Is it realistic that policy makers will be on board with leaving all that fuel underground?

Climate rent: Some sort of financial aid in helping developing countries “skip” the use of fossil fuels and move onto renewable energy
Fossil Fuel Reserves: The Last Word

Ross Salawitch

![Graph showing fossil fuel reserves](image-url)

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GHG emissions: US, China, and India

How do GHG emissions from the US compared to RCP projections, over the past decade?
GHG emissions: US, China, and India
GHG emissions: US, China, and India

U.S. Without Land Use CO₂

China Without Land Use CO₂

India Without Land Use CO₂
Per-capita (left) and cumulative (right) emissions from the U.S. far exceed those of China, India and (most for per-capita) the rest of the world.
Factors governing US GHG emissions

Why have US GHG emissions declined over the past decade?
Factors governing US GHG emissions

U.S. GHG Emission Mitigation
- Actual Emissions
- Projected Emissions

Cumul. Contrib. (%)
- Economic Growth 56.5
- Renewable Energy 17.5
- Coal to Gas 15.4
- Carbon Efficiency 6.9
- Vehicle Efficiency 3.7

Gt CO₂-eq

US Clean Power Plan (CPP)

The CPP of Obama’s EPA creates state-by-state targets for carbon emission reductions, under section 111(d)* of the Clean Air Act (CAA), the

Each state’s requirement is based on their unique circumstance and energy portfolio.

- Target for MD was 30% reduction in CO₂ emissions by 2030, relative to 2012 baseline

Overall Target of the CPP

- 35% reduction in carbon emissions, all electricity sectors by 2030, with respect to 2005 baseline

State Emission Reduction Options

- Natural gas
- Renewable energy
- Energy efficiency
- Nuclear
- Emission trading

* Section 111(d) requires each state, with assistance from EPA, to develop “standards of performance” for existing power plants and an implementation plan to achieve those standards. The term “standard of performance” is defined as “the degree of emission limitation achievable through the application of the best system of emission reduction, taking into account the cost of achieving such reduction”.

US Clean Power Plan Timeline

- November 2006 to April 2007: U.S. Supreme Court case, Massachusetts v. EPA. 12 states and several cities successfully sue the EPA to force the agency to regulate CO₂ and other GHGs as pollutants
- June 2013: President Obama directs EPA to issue regulations on carbon pollution from existing power plants under section 111(d) of the Clean Air Act (CAA)
- June 2014: U.S. Supreme Court case, Utility Air Regulatory Group v. EPA. Ruling validates EPAs authority to regulate GHG emissions with some limitations
- August 2015: Clean Power Plan (CPP) is finalized by the EPA to limit carbon emissions from power plants
- February 2016: U.S. Supreme Court places a hold on the CPP until a lower court can rule on the merits and the Supreme Court either refuses to hear the case or rules on the merits
- September 2016: An en banc session of the US Court of Appeals for the DC Circuit case, West Virginia v. EPA. Several states, Industry, and the Chamber of Commerce challenge the EPAs authority to regulate CO₂ emissions from power plants
- March 2017: President Trump signs the Presidential Executive Order on Promoting Energy Independence and Economic Growth which issues a review of the CPP, and requests Court of Appeals delay their decision (i.e., held in abeyance)
- 10 October 2017: A repeal proposal of the CPP is submitted to the Federal Register by the EPA

Maryland Total GHG Emissions versus Time

CH₄: 100 yrs (SAR)
N₂O: 100 yrs (SAR)
SF₆: 100 yrs (SAR)
HFCs/PFCs: 100 yrs (SAR)

Carbon Dioxide: 93.8%
Methane: 2.1%
Etc: 4.1%

Carbon Dioxide: 94.0%
Methane: 1.9%
Etc: 4.0%

Carbon Dioxide: 92.1%
Methane: 2.6%
Etc: 5.2%

MDE target 2020
MD CPP target 2030
MDE target 2030
Maryland Total GHG Emissions versus Time

- **CH₄**: 20 yrs (AR5)
- **N₂O**: 100 yrs (SAR)
- **SF₆**: 100 yrs (SAR)
- **HFCs/PFCs**: 100 yrs (SAR)

*Graph showing Maryland GHG Emissions from 2006 to 2030, with emissions for different years (MDE 2006, MDE 2011, MDE 2014, Target 2020, Target 2030) and targets for 2020 and 2030.*

- **CO₂**:
  - 2006: 68.3% of emissions
  - 2011: 68.9%
  - 2014: 65.4%
  - Etc: 3.9%

- **CH₄**:
  - 2006: 7.3% of emissions
  - 2011: 7.8%
  - 2014: 9.8%
  - Etc: 4.8%

- **Etc**:
  - 2006: 24.8% of emissions
  - 2011: 26.3%
  - 2014: 25.3%
  - Etc: 21.8%

*Graph showing trends in Maryland GHG Emissions from 2005 to 2030, with targets for 2020 and 2030.*

- **MDE target 2020**
- **MD CPP target 2030**
- **MDE target 2030**
Maryland Total GHG Emissions versus Time

CH$_4$: 20 yrs (AR5)
N$_2$O: 20 yrs (AR5)
SF$_6$: 20 yrs (AR5)
HFCs/PFCs: 20 yrs (AR5)

- CO$_2$: 86.4%
- CH$_4$: 7.7%
- Etc.: 5.9%

- CO$_2$: 87.1%
- CH$_4$: 7.2%
- Etc.: 5.7%

- CO$_2$: 83.5%
- CH$_4$: 9.5%
- Etc.: 6.9%

Maryland GHG Emission [MtCO2e]

MDE target 2020
MD CPP target 2030
MDE target 2030

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Maryland In-State Electricity Generation versus Time, Major Sources

- Total
- Coal
- Nuclear
- Petroleum
- Natural gas

MD In-State Annual Electricity Generation (thousands MWhr)

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Maryland In-State Electricity Generation versus Time, Major Sources

- Total
- Coal
- Nuclear

MD In-State Annual Electricity Generation (thousands MWhr)

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Maryland Net Electricity Generation by Source, June 2017

[Bar chart showing electricity generation by source.]

- Petroleum-Fired: Very small contribution.
- Natural Gas-Fired: Moderate contribution.
- Coal-Fired: Significant contribution.
- Nuclear: Dominant contribution.
- Hydroelectric: Small contribution.
- Nonhydroelectric Renewables: Small contribution.

https://www.eia.gov/state/?sid=MD#tabs-4
Maryland Converting Electricity from Coal to Natural Gas

About CPV St. Charles

The St. Charles Energy Center (SCEC) is a 725 megawatt natural gas-fueled combined-cycle power generation facility located in Waldorf, Maryland. The SCEC generates enough electricity to power more than 700,000 homes, helping Maryland to safely meet its demand for energy with reliable, cost-effective and environmentally-responsible low emissions generation.

- 725-megawatt (MW) natural gas facility (can power up to 700,000 homes)
- Located in Walford Md, 25 miles southeast of Washington, DC
- Opened February 2017

http://mdewin76.mde.state.md.us/MDEMeetings/ARMA_Audio_Files/AQCAC_09_18_17.MP4