Where Does Electricity Come From

U.S. electricity generation by major energy source, 1950-2019

Note: Electricity generation from utility-scale facilities.
There are 6 distinct audiences in the United States.

Source: Yale Program on Climate Change Communication
Climate Change Believers/Deniers

- Alarmed
- Concerned
- Disengaged
- Doubtful
- Cautious
- Dismissive
Carbon Stabilization Revisited

The bad news:
• Business as usual (BAU) likely lead to disastrous consequences.

The good news:
• Stabilizing at roughly double current carbon levels seems possible.
• This will leave us until 2040ish to achieve a net-zero increase in $CO_2$ concentration.
• Most likely temperature change: $3^\circ C$ ($5.4^\circ F$)
Stern’s “Temperature Increases and Potential Risks”

- **Food**
  - Falling crop yields in many developing regions
  - Rising number of people at risk from hunger (25% – 50% increase in the 2020s in one study with weak carbon fertilization)
  - Severe impacts in marginal areas

- **Water**
  - Small mountain glaciers disappear worldwide – potential threat to water supplies in several areas
  - Significant changes in water availability

- **Ecosystems**
  - Coral reef ecosystems extensively and eventually irreversibly damaged
  - Large fraction of ecosystems unable to maintain current form

- **Extreme Weather Events**
  - Rising intensity of storms, forest fires, droughts, flooding, and heat waves
  - Small increases in hurricane intensity lead to a doubling of damage costs in the US

- **Runaway G. Effect**
  - Risk of weakening of natural carbon absorption and possible increasing methane releases and weakening of the Atlantic THC
  - Onset of irreversible melting of the Greenland ice sheet
  - Increasing risk of abrupt, large-scale shifts in the climate system (e.g. collapse of the Atlantic THC and the West Antarctic ice sheet)
The Kaya Identity

\[ F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} \]

\( F \) – CO\(_2\) Emissions
\( P \) – Population
\( G \) – Gross Domestic Product (GDP)
\( E \) – Energy
The Kaya Identity

\[ F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} \]

The Kaya Identity: States that the total \( CO_2 \) emission levels can be expressed as the product of four factors:

1. Population
2. GDP per Capita
3. Energy Intensity
4. Carbon Intensity
The Kaya Identity

\[ F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} \]

Set goal: reduce yearly carbon emissions to about 1/2 of today’s levels.

Claim: We need to reduce emissions per energy used \((F/E)\) by about a factor of 5.
The Energy Formula

\[ F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} \quad \Rightarrow \quad F \times \left( \frac{E}{F} \right) = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} \times \left( \frac{E}{F} \right) \]

Energy Formula: \[ E = P \times \frac{G}{P} \times \frac{E}{G} \]
Energy Formula

\[ E = P \times \frac{G}{P} \times \frac{E}{G} \]

Population:

• Can’t do much about this.

• Expected to continue to grow for about 20 - 40 years then slowly decrease.

• Expected to increase by 1.3 times by 2100.

• Medium Variant “plateau” forecast is about 9.2 - 9.8 billion.
Energy Formula

\[ E = P \times \frac{G}{P} \times \frac{E}{G} \]

GDP per-capita:

• Roughly proportional to standard of living.

• We want this to INCREASE.

Increased in last century by 1.6% per year to $4800/person in the year 2000.

World GDP is expected to increase by a factor of 8 by 2100.
Energy Formula

\[ E = P \times \frac{G}{P} \times \frac{E}{G} \]

Energy Intensity:

• This is decreasing all over the world at a rate of over 1% per year.

• Generally decreases as countries get richer.
World Energy Intensity

World energy intensity, 1990-2015
quadrillion British thermal units per trillion dollars gross domestic product

- non-OECD countries: -40%
- world average: -32%
- OECD countries: -28%

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Energy Formula

\[ E = P \times \frac{G}{P} \times \frac{E}{G} \]

By 2100 the energy intensity (E/G) is expected to **DECREASE** by about a factor of 4.
Using the energy formula to determine the expected increase in demand.

\[ E = P \times \frac{G}{P} \times \frac{E}{G} \]

Population \((P \rightarrow 1.3P)\) INCREASE by 1.3 times

GDP/Population) \((G/P \rightarrow 8G/P)\) INCREASE by 8 times

Energy Intensity \((E/G \rightarrow \frac{1}{4}E/G)\) 75% DECREASE

\[ \Delta E = 1.3 \times 8 \times \frac{1}{4} \]

Primary energy demand is expected to increase by a factor of about 2.6 by 2100.
Back to the Kaya Identity

\[ F = \left( P \times \frac{G}{P} \times \frac{E}{G} \right) \times \frac{F}{E} = E \times \frac{F}{E} \]
Goal: Emissions (F) in 2100 to be ½ the current value.

\[ F = \left( \frac{P \times G \times E}{P \times G} \right) \times \frac{F}{E} = E \times \frac{F}{E} \]

\[ F = 2.6 \times \frac{F}{E} \]

Goal: Emissions (F) in 2100 to be ½ the current value.

\[ \frac{F}{2.6} = \frac{F}{E} \quad \rightarrow \quad \frac{0.5}{2.6} = 0.2 \]

**MUST Reduce Carbon Intensity (F/E) by 80%**
Carbon Intensity

\[ \frac{F}{E} = \frac{\text{Emissions}}{\text{Energy}} \]

this is called **Carbon Intensity**

• This is something that we can do something about.
• Would like to reduce this by a factor of 5 by 2100.
QUESTION

Which of the following statements is FALSE:

a) By 2100 the Energy Intensity is expected to increase from its current value.
b) In the field of climate science, BAU stands for Business As Usual.
c) Humans are not the first species on Earth to alter its atmosphere.
d) By 2100 the GDP/population is expected to increase from its current value.
e) By 2100 the Primary Energy Demand is expected to increase from its current value.
In the Kaya identity, the factor that is expected to decrease in the (hopefully) near future is

a) Population (P)
b) GDP/Population (G/P)
[ ] c) Emissions/Energy (F/E)
d) GDP/Energy (G/E)
e) Primary Energy Demand
Activity