The Kaya Identity: Energy Use, Conservation and Efficiency

EES 3310/5310

Global Climate Change

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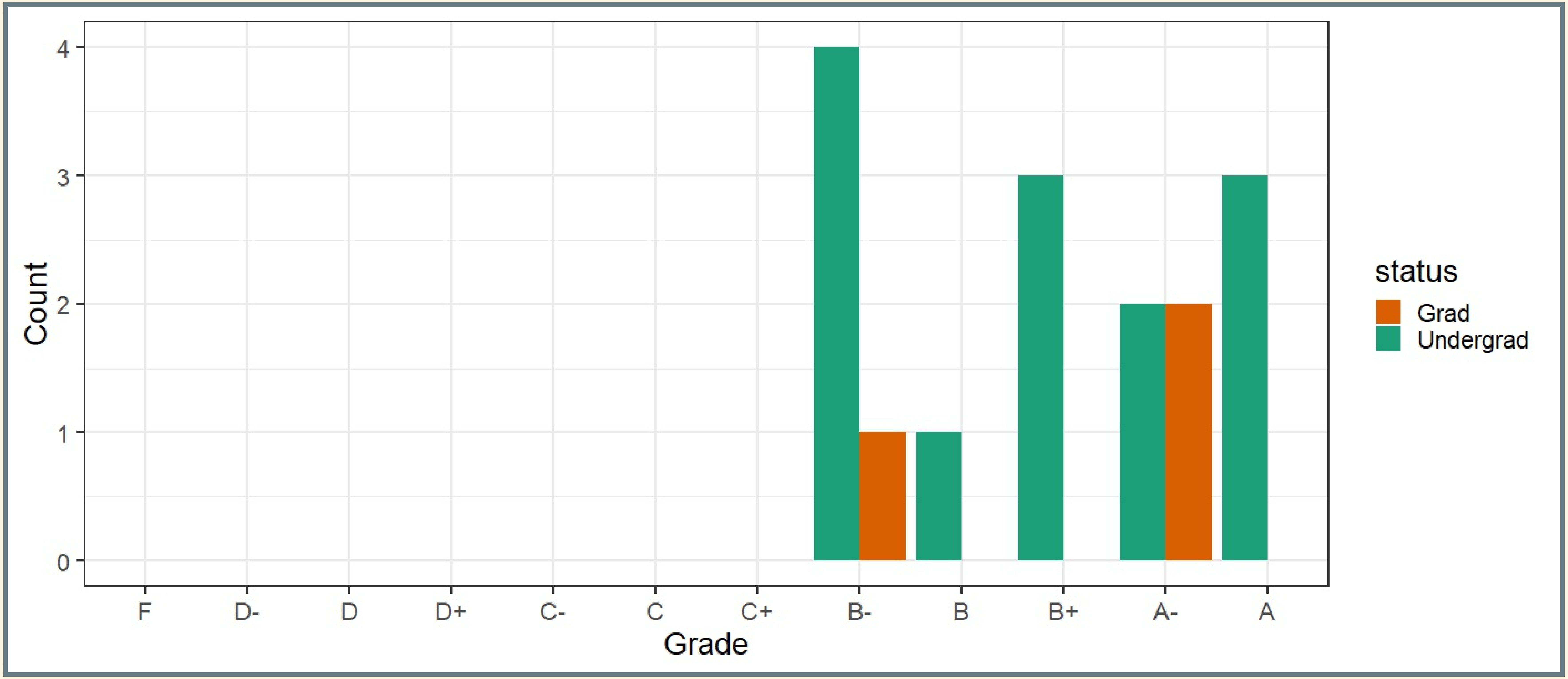
Class #24: Monday Oct. 15 2018

Midterm Exam

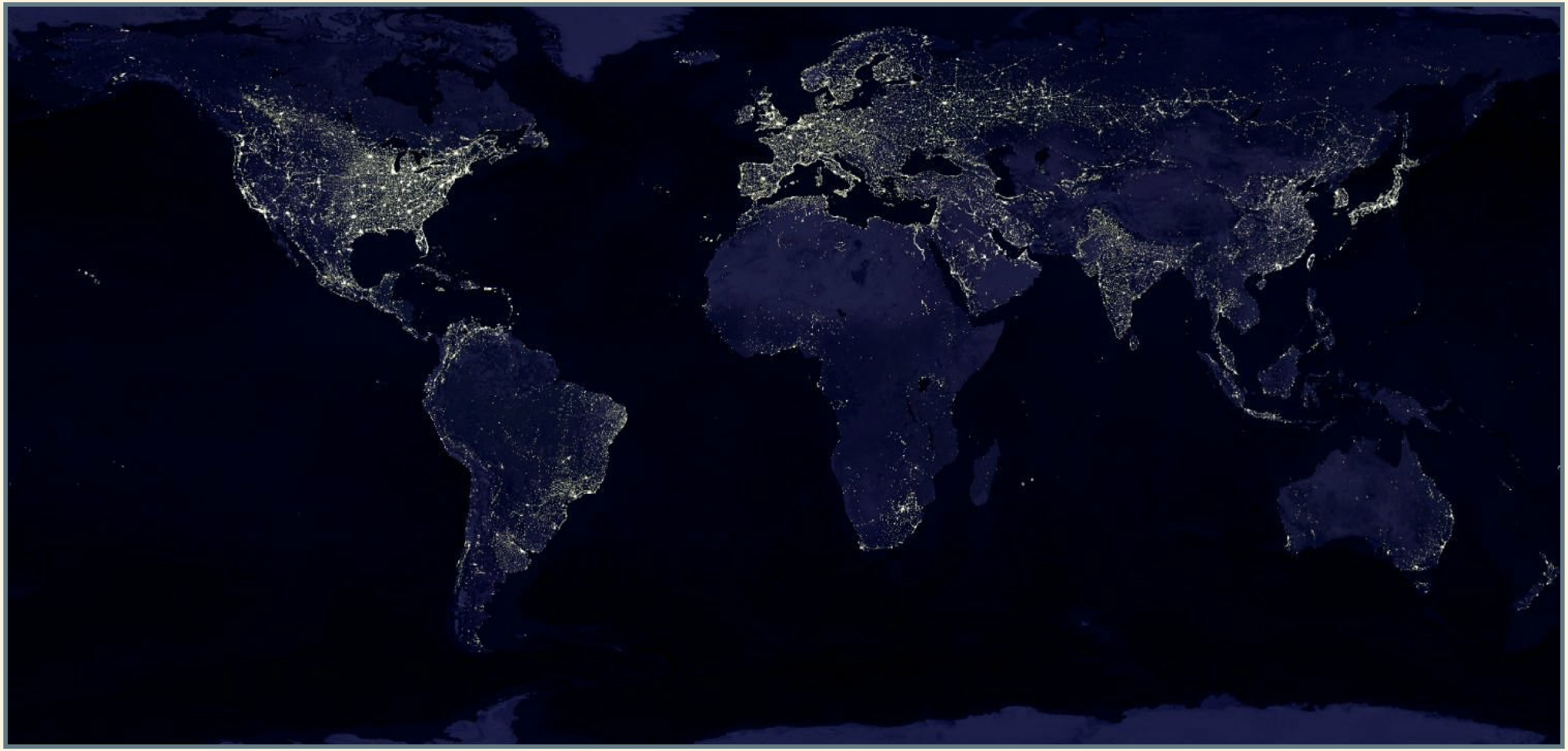


- Median = B+
- Average = 3.33

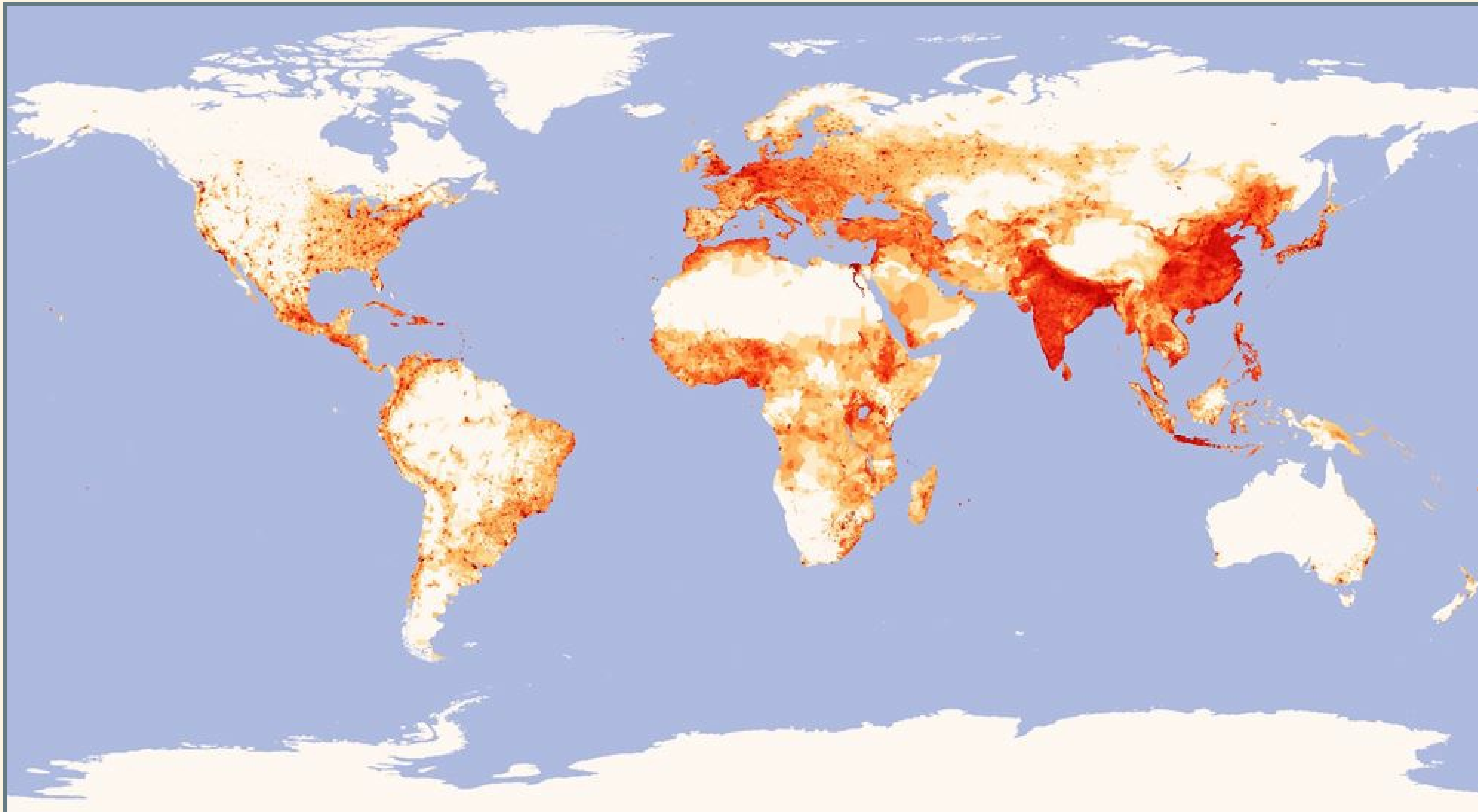
Decarbonizing Global Economy

- World needs lots more energy
  - National/industrial energy poverty:
    - Energy consumption for economic growth
  - Household energy poverty:
    - Energy consumption for quality of life

Energy



Population Density



Energy Poverty

Household Energy Poverty

- Roughly 1.2 billion people do not have acccess to electricity.
  - Down from 1.5 billion in 2008
- Benefits of providing even a little electricity:
  - Children study 30% more with just one light bulb in home.
  - Women have more say in household decisions
  - Allows economically productive activity in evening
- Role of refrigeration in preventing disease
- Electricity and gas reduce exposure to indoor air pollution
  - Indoor air pollution from cooking, lighting kills around 4.3 million/year
- Home solar typically provides light, but insufficient for refrigeration, cooking

Measuring Energy and Environmental Impact

Measuring Energy

- Heat:
  - BTU (British Thermal Unit) = quantity of heat
  - Quad = quadrillion BTU
  - Kilowatt Hour (kWh): measure of electricity
- Conversions:
  - 1 quad is about 300 billion kWh
  - 1 quad per year is about 11 billion watts
    - Typical large power plant (coal or nuclear) produces an average of around 750 million watts
    - 1 quad per year is about 15 big power plants
- Magnitudes
  - World uses about 600 quads per year of primary energy
  - U.S. uses about 100 quads per year of primary energy
    - 4% of population, 17% of energy consumption

Some Definitions:

- Primary vs. Secondary
  - Primary energy consumption = heat generated
  - Secondary energy consumption = useful energy consumed
    - Coal generation is about 33% efficient
    - Gas generation is about 45% efficient
    - A car engine is about 33% efficient
  - More efficient generation can produce more secondary energy with less primary energy.
- Nameplate vs. Average Power Output:
  - Nameplate = power when operating at 100% capacity
  - Duty factor = average fraction of maximum capacity achieved over a ye
  - Actual energy produced = nameplate power × duty factor × 1 year

Kaya Identity

Kaya Identity

$$F = P \times g \times e \times f$$

- $F =$ emissions (million tonnes carbon per year)
- $P =$ population (billions)
- $g =$ per-capita GDP ($1000 per person)
- $e =$ energy intensity of economy (quads / trillion dollars)
- $f =$ carbon intensity of energy supply (million tonnes carbon / quad)

Policy

- We can't directly control P
- We want g to grow
- Therefore, decrease e and f

Economic and Energy Trends

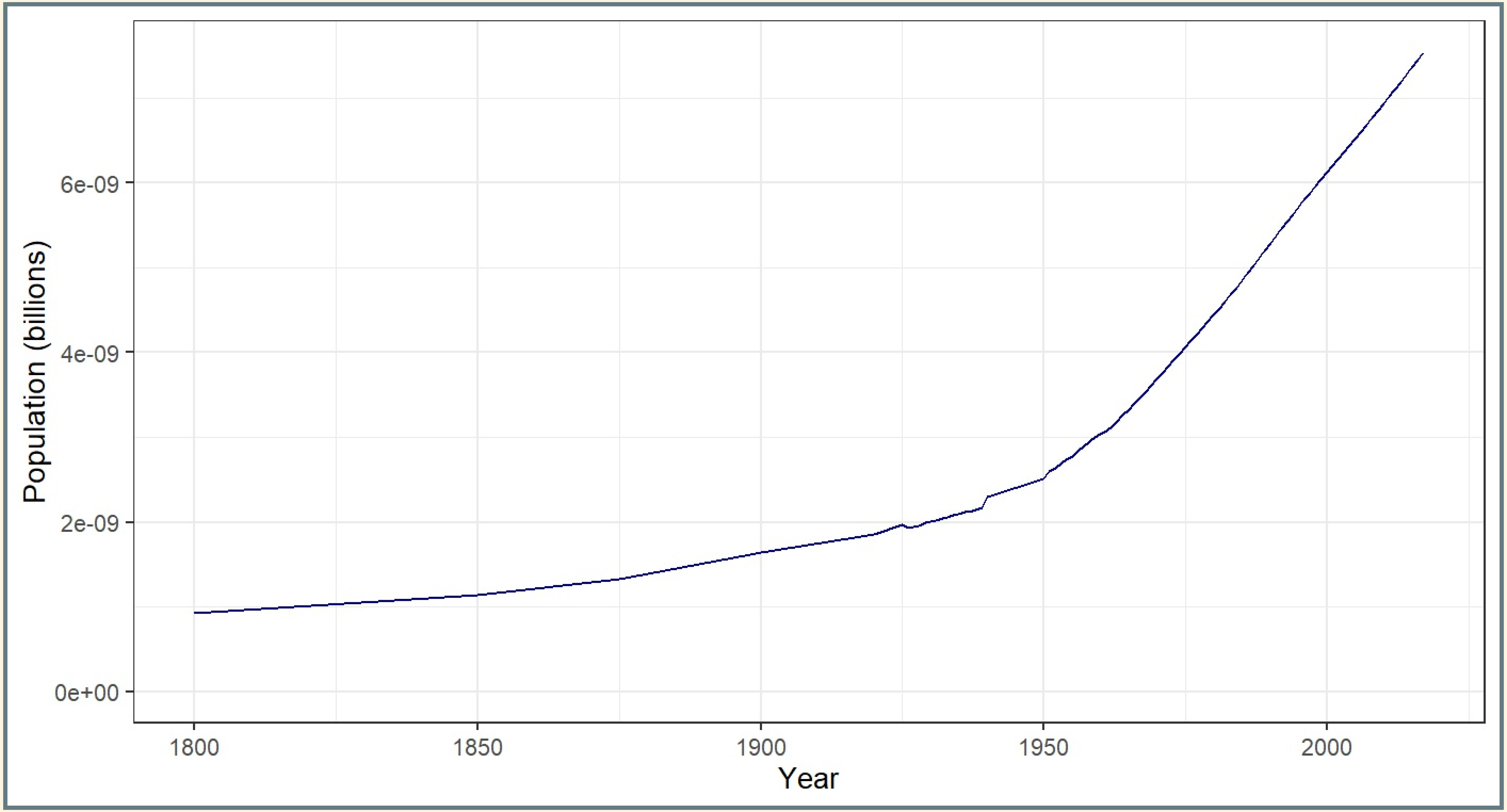
Interactive Tool

https://ees3310.jgilligan.org/decarbonization/

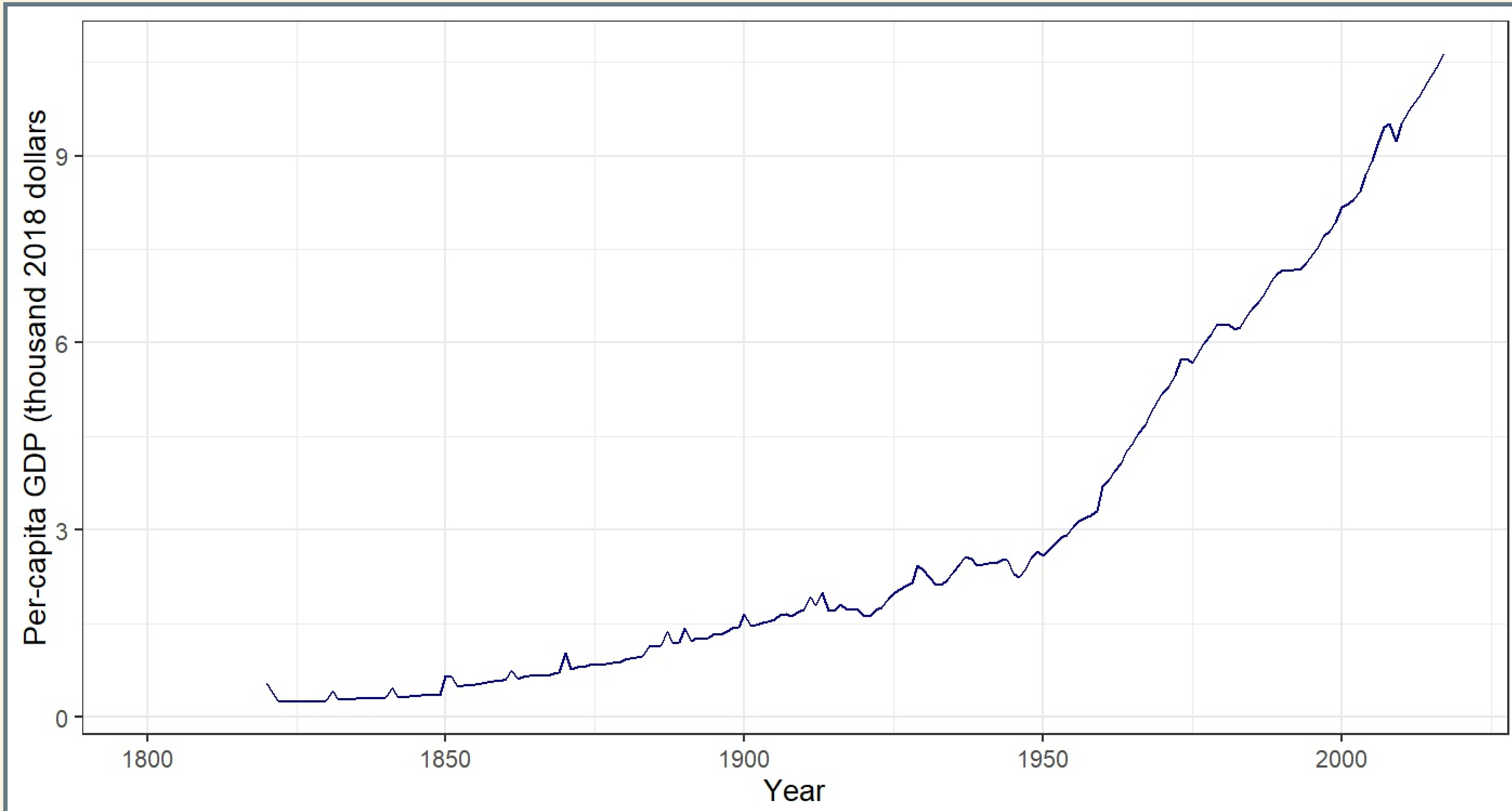
Kaya data and analysis for your own computer:
https://github.com/jonathan-g/kayadata

An experimental version of the interactive tool is available at https://github.com/jonathan-g/kayatool. You can install it on your own computer, but it may be a bit iffy when you run it.

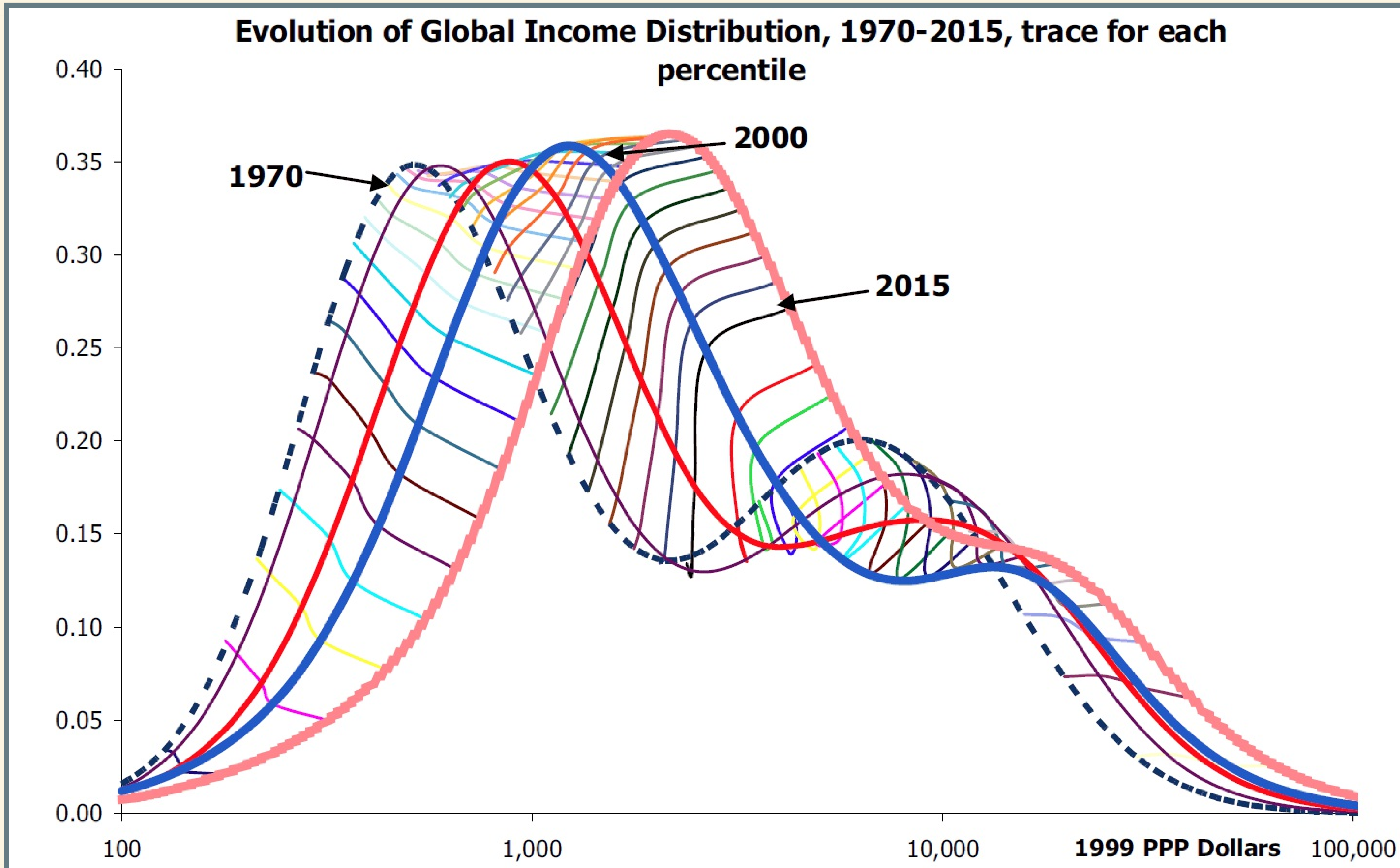
Global Population (*P*)



Global Economy (per-capita GDP g)

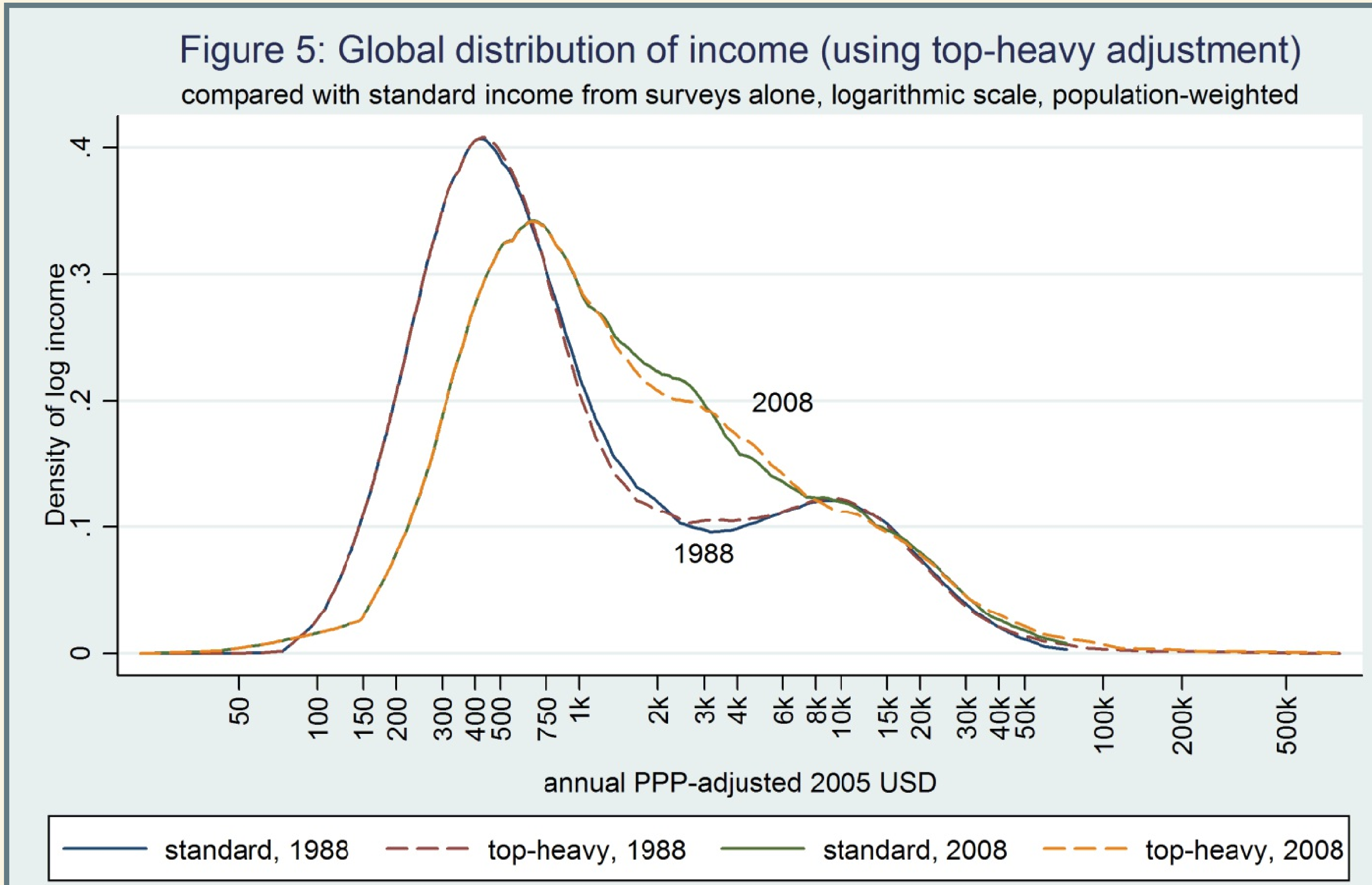


Global Income Distribution



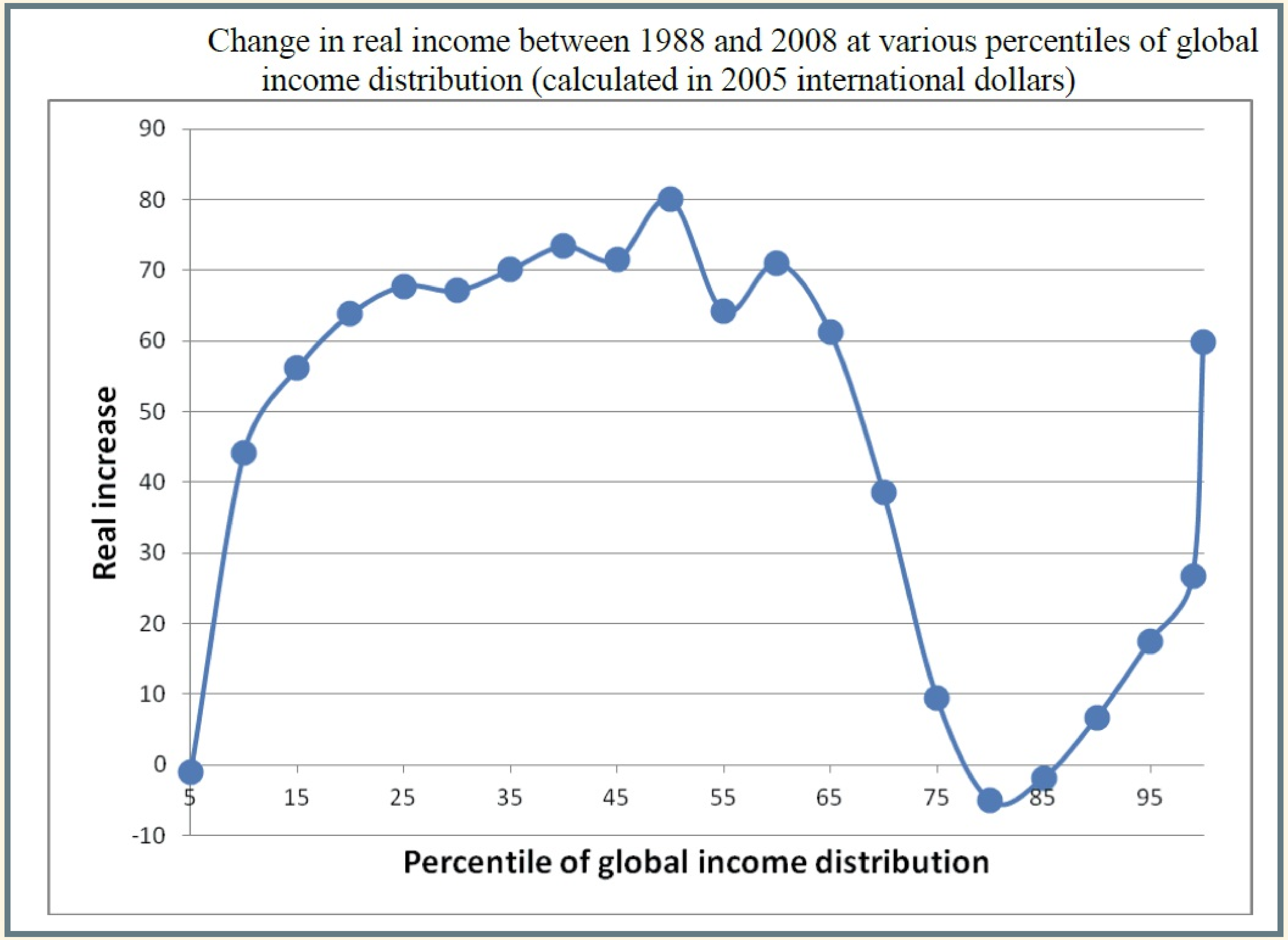
- Big drop in “desperate poverty”
- Growth of global middle-class

Global Income Distribution



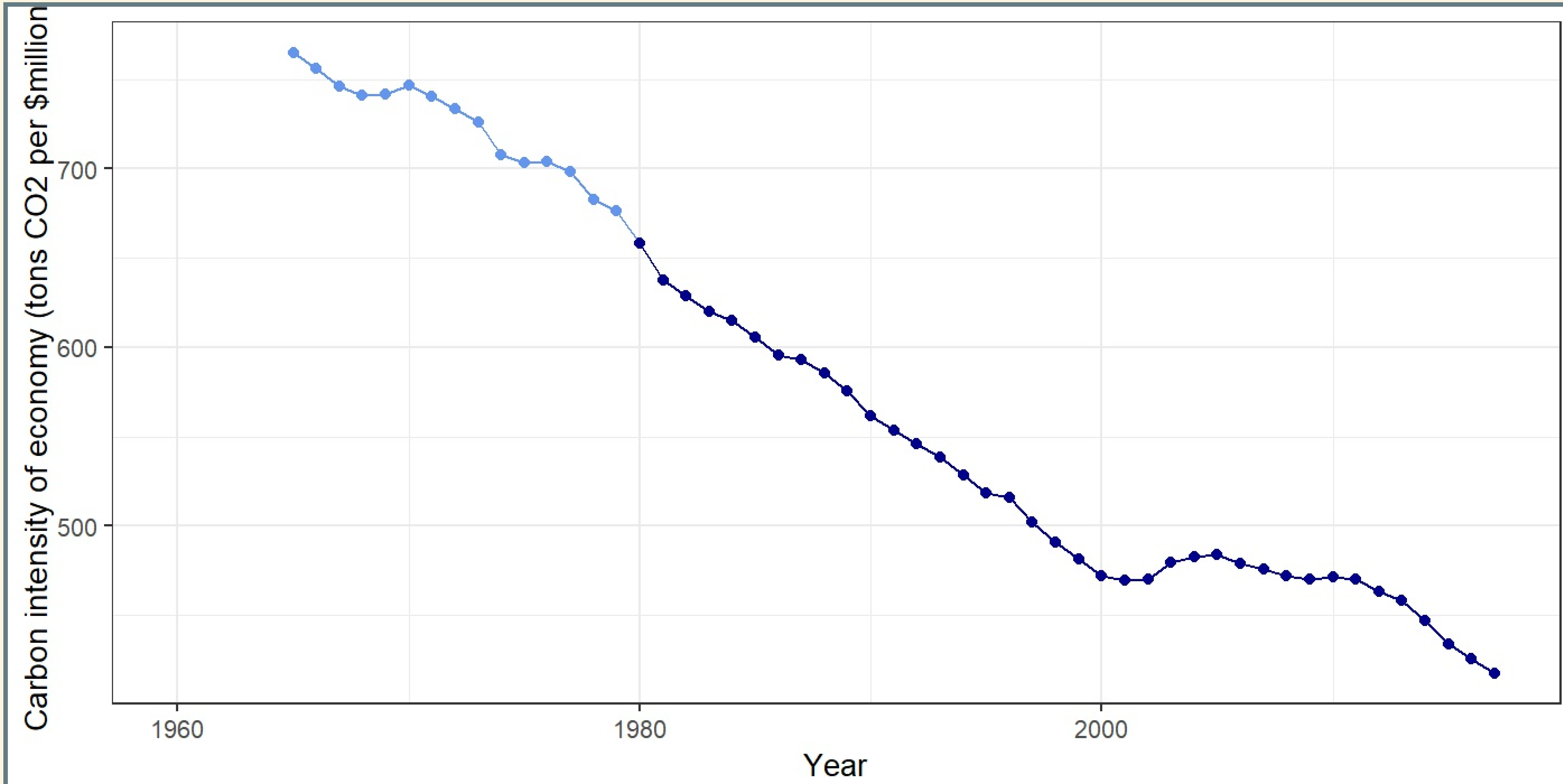
- Rightward movement of lower end: Big drop in poverty
- Growing lump in middle: Rise of global middle-class

Global Income Growth over Time

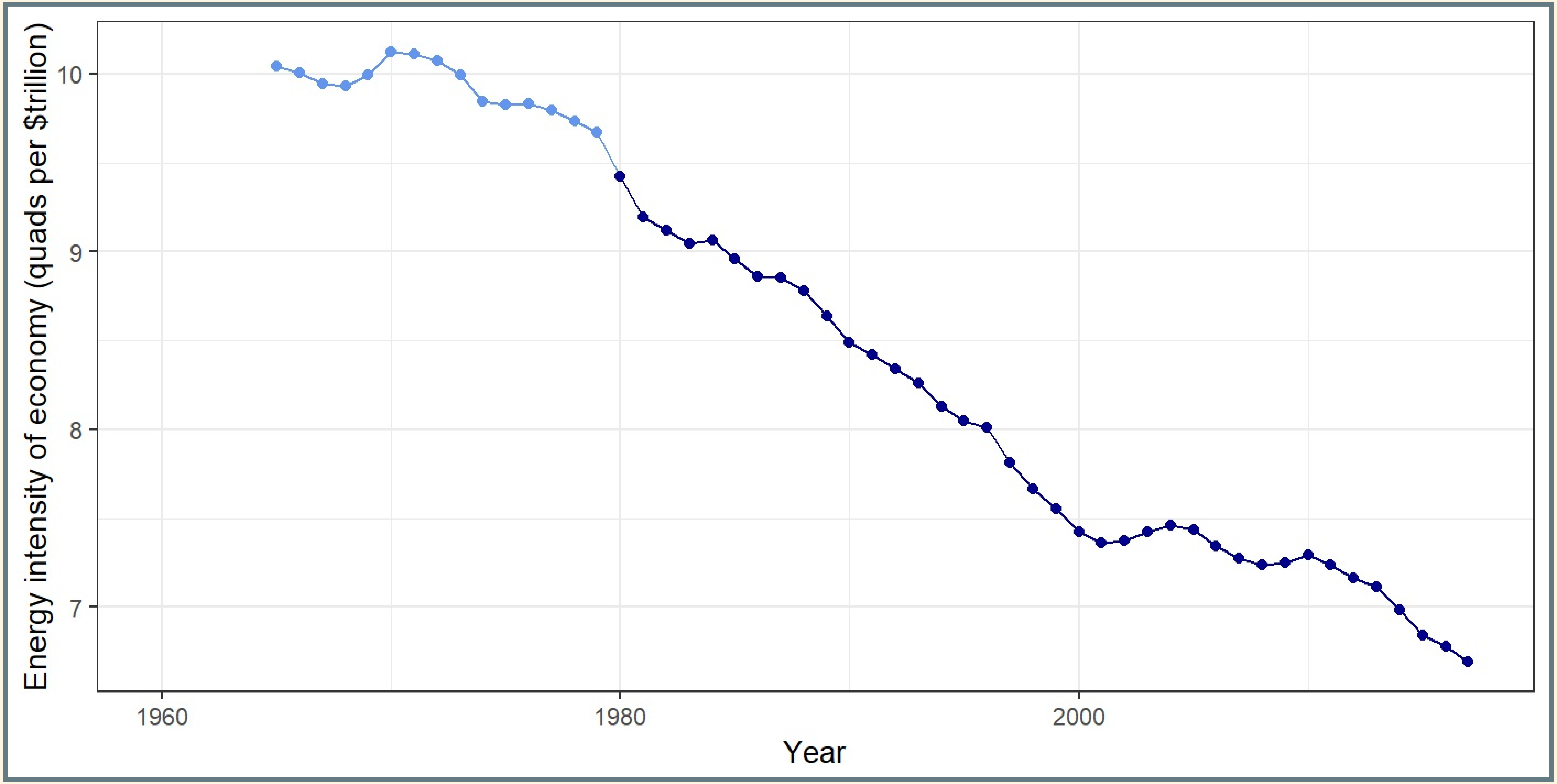


- Biggest gains for 10th–65th percentile (poor and middle class)
- Losses for 80th–85th percentile (middle class of rich nations)
- Big gains for richest 5% (> $75,000 US)

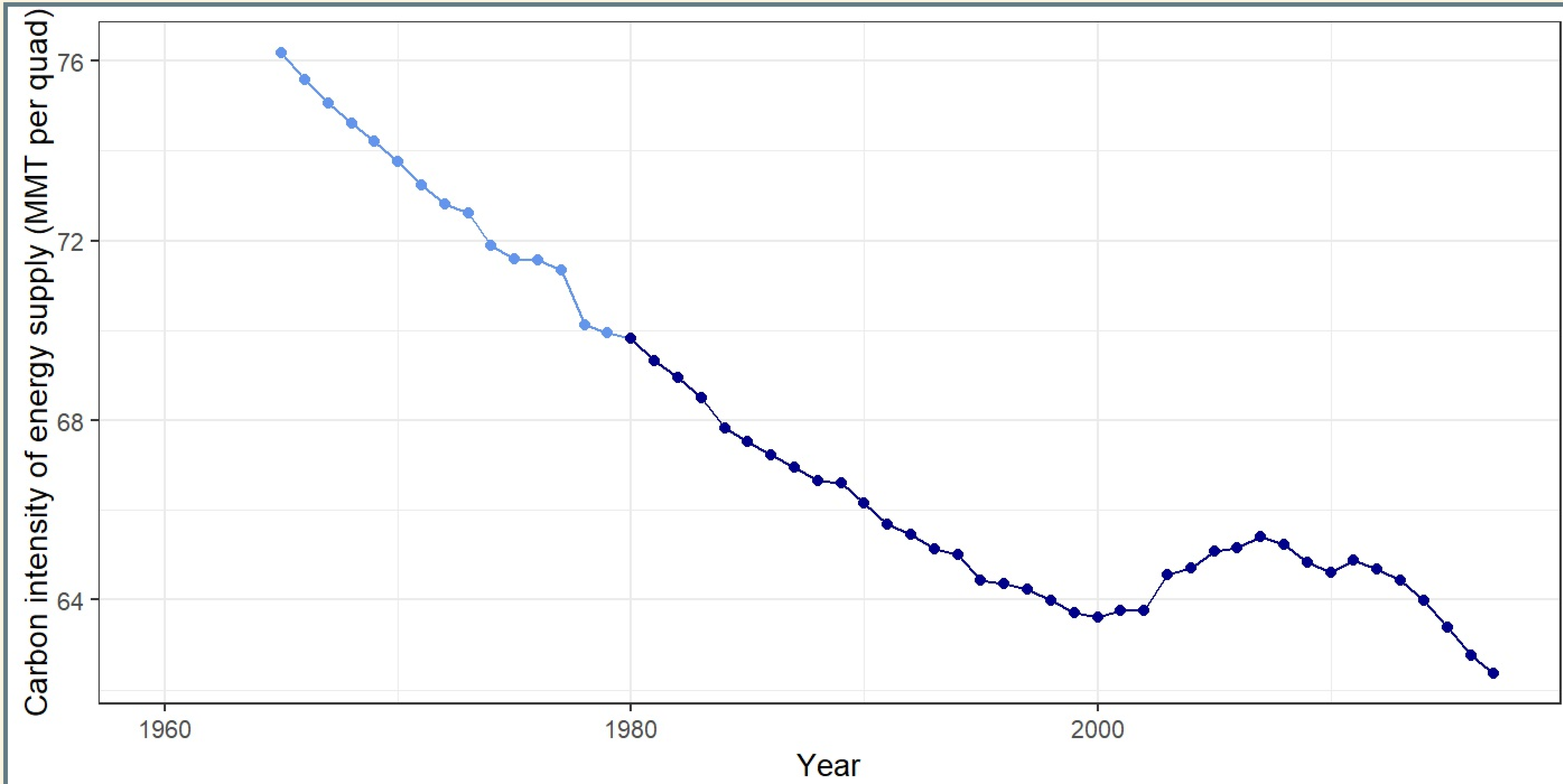
Emissions Intensity of Global Economy (*ef*)



Energy Intensity of Global Economy (e)



Carbon Intensity of Global Energy Supply (f)



Implied Decarbonization

- Specify emissions for 2050, compared to 2010
- Assume global GDP grows at rate r
  (5% $\longrightarrow$ $r = 0.05$)

$$\begin{aligned} \text{emissions: } F &= P g e f = \text{GDP} \times e f \\ F(2050) &= \text{GDP}(2050) \times e f(2050) \end{aligned}$$

Growth:

$$\begin{aligned} y(\text{5 years from now}) &= y(\text{today}) \times \exp(r \times 5) \\ &\approx y(\text{today}) \times (1 + r)^5 \end{aligned}$$

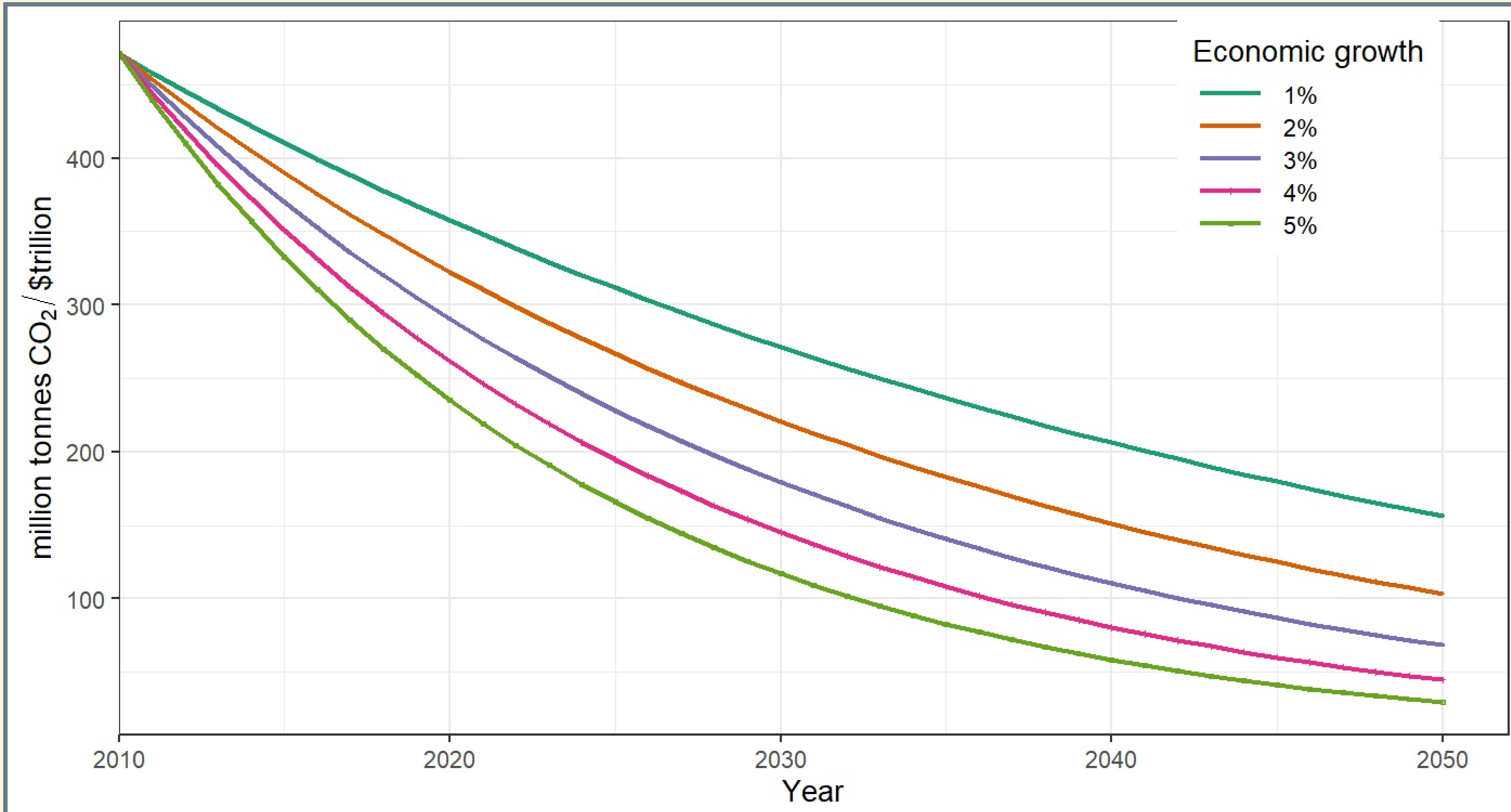
- exp = exponential function (e^x).
- Call it “exp” to avoid confusing e in Kaya formula with e, base of natural logarithm.

Implied Decarbonization

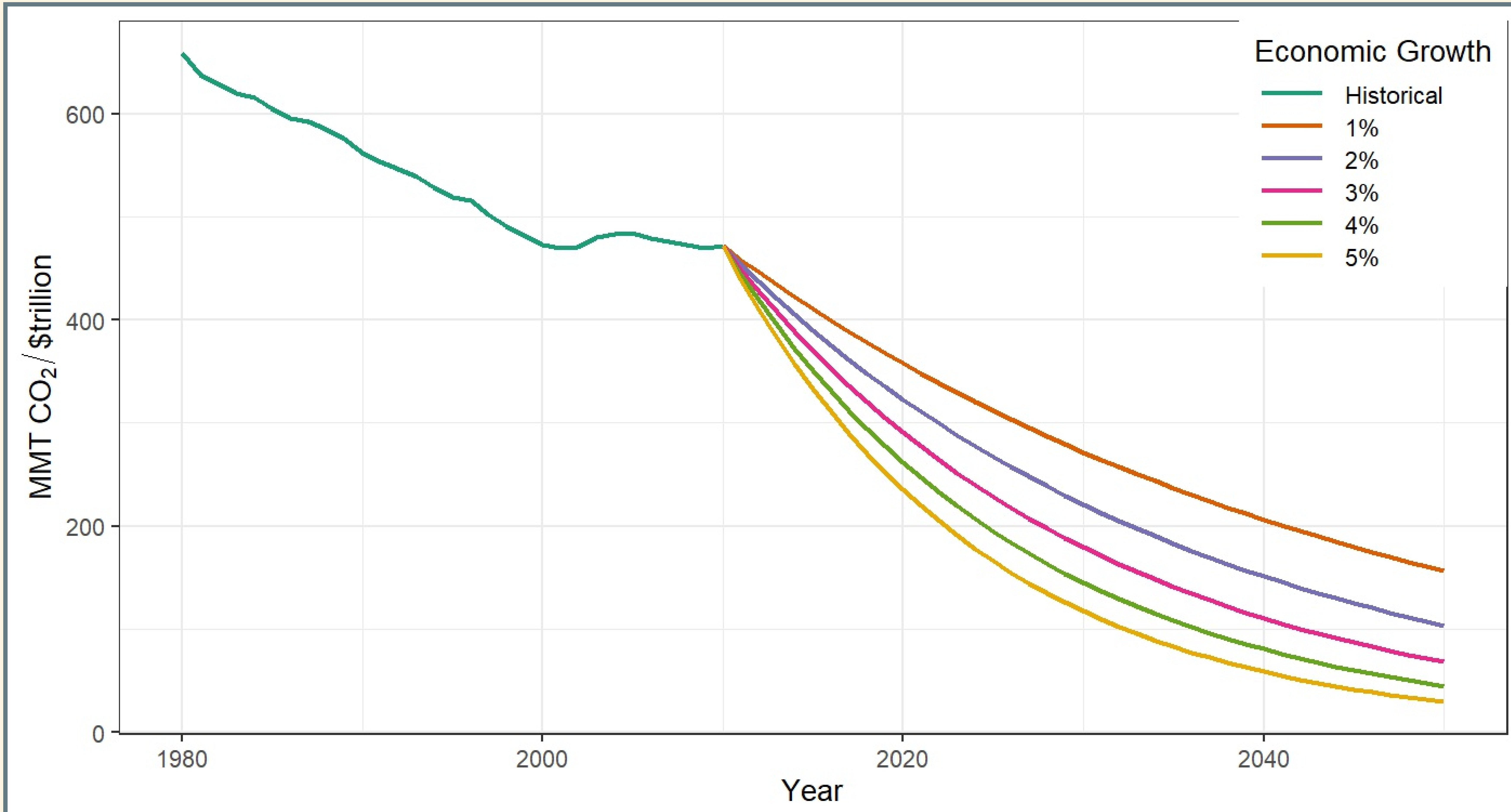
- Specify emissions for 2050, compared to 2010
- Assume global GDP grows at rate r ($5\% \longrightarrow r = 0.05$)

$$
\begin{aligned}
\text{emissions: } F &= Pgef = \text{GDP} \times ef \\
F(2050) &= \text{GDP}(2050) \times ef(2050) \\
\text{GDP}(2050) &= \text{GDP}(2010) \times \exp(r \times (2050 - 2010)) \\
ef(2050) &= \frac{F(2050)}{\text{GDP}(2050)} \\
&= \frac{F(2050)}{\text{GDP}(2010) \times \exp(r \times 40)} \approx \frac{F(2050)}{\text{GDP}(2010) \times (1 + r)^{40}}
\end{aligned}
$$

50% reduction by 2050:



Actual and Implied Decarbonization



Pielke's Policy Criteria

1. Policies should flow with public opinion
2. Public will not tolerate significant short-term costs, even for big long-term benefits
3. Policy must center on clean energy innovation