Top-Down Decarbonization

EES 3310/5310

Global Climate Change

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Bottom-Up Implied Decarbonization

Kaya Identity

$$\color{firebrick}{F} = \color{darkgreen}{P} \times \color{blue}{g}\times \color{mediumorchid}{e} \times \color{crimson}{f}$$

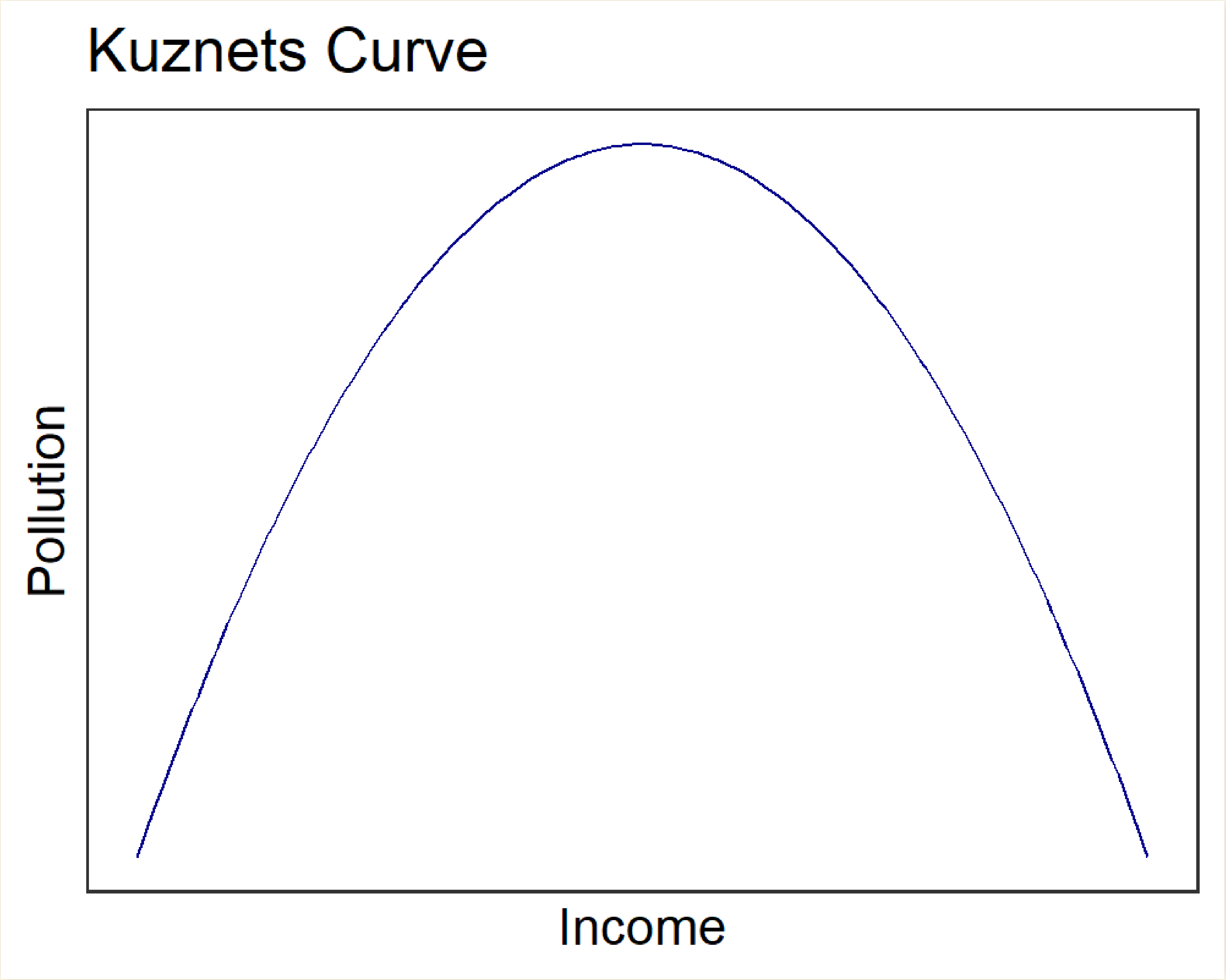
- $\color{firebrick}{F} =$ emissions (million metric tons (MMT) CO_2 per year)
- $\color{darkgreen}{P} =$ population (billions)
- $\color{blue}{g} =$ per-capita GDP ($1000 per person)
- $\color{mediumorchid}{e} =$ energy intensity of economy (quads / $ trillion)
  - Reducing *e* means increasing **energy efficiency**
- $\color{crimson}{f} =$ carbon intensity of energy supply (MMT CO_2 / quad)
  - Reducing *f* means **replacing fossil fuels** with cleaner energy

Grain of Salt

- Implied ef depends on prediction of $\text{GDP} = G = P \times g$.
- Predicting population and economic growth are very tricky and imprecise.
- So take any of these calculations with a grain of salt.
- But are they still useful, despite the uncertainties?

Kuznets curve

- This fits the US and European pattern for air pollution:
  - 19th–mid-20th centuries: growing
  - Since round 1970: decreasing
  - Different in different parts of the world
- Vanderbilt Professor Patrick Greiner:
  - Relationship between economic development and greenhouse gas emissions depends on:
    - History of colonialization
    - Women’s rights & political participation
    - etc.



How Can We Decarbonize?

Detailed Abatement Options

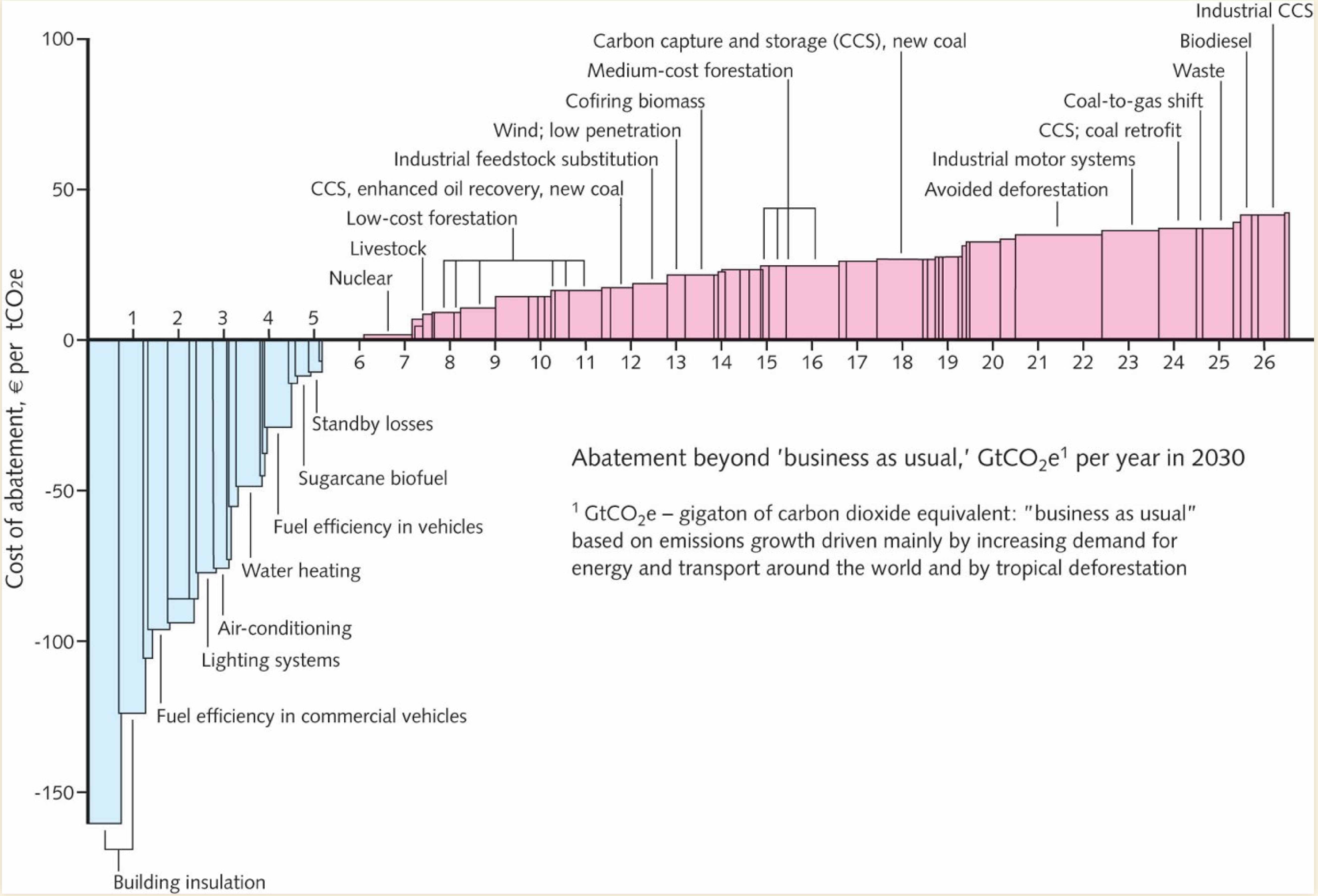
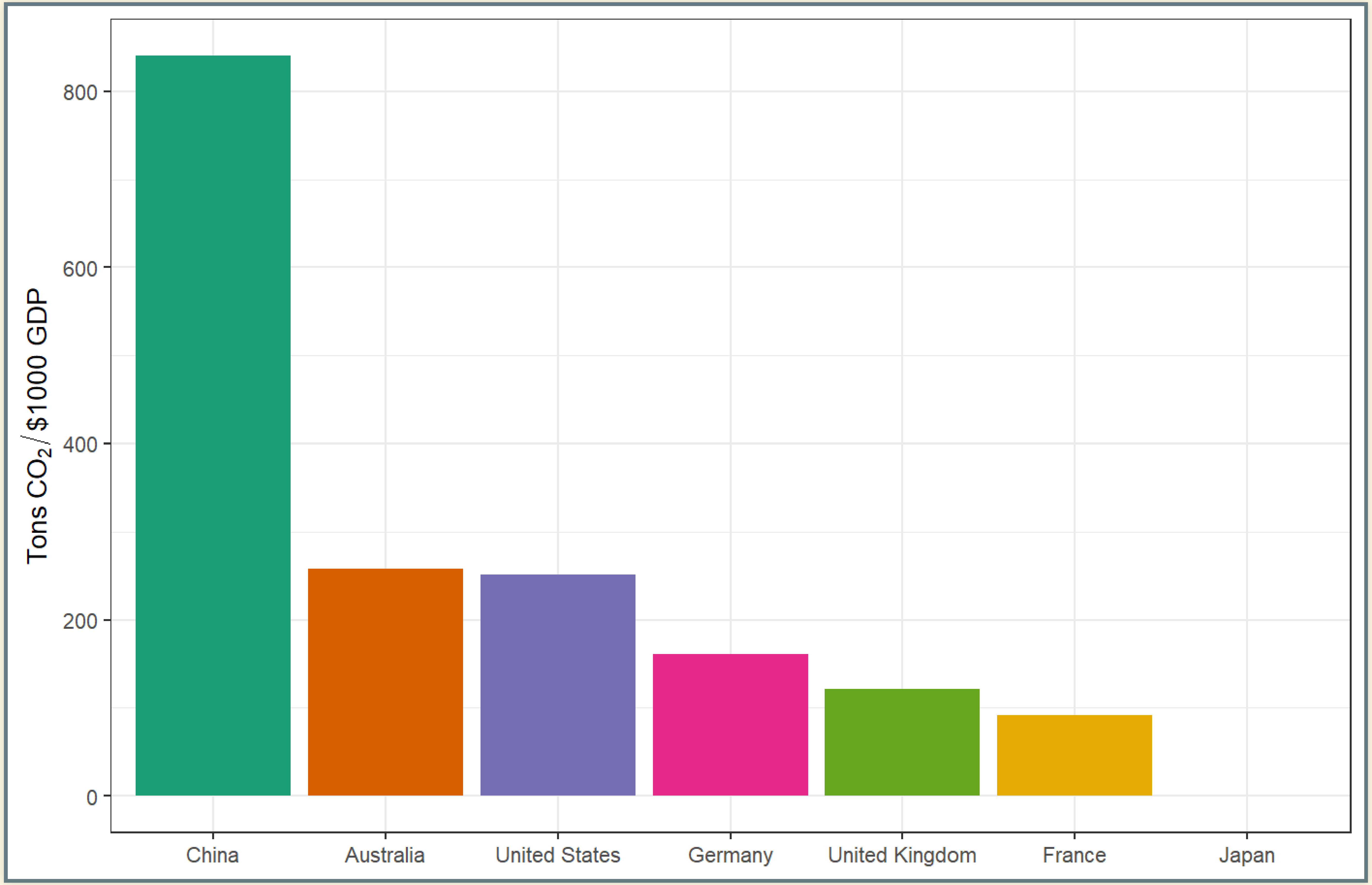
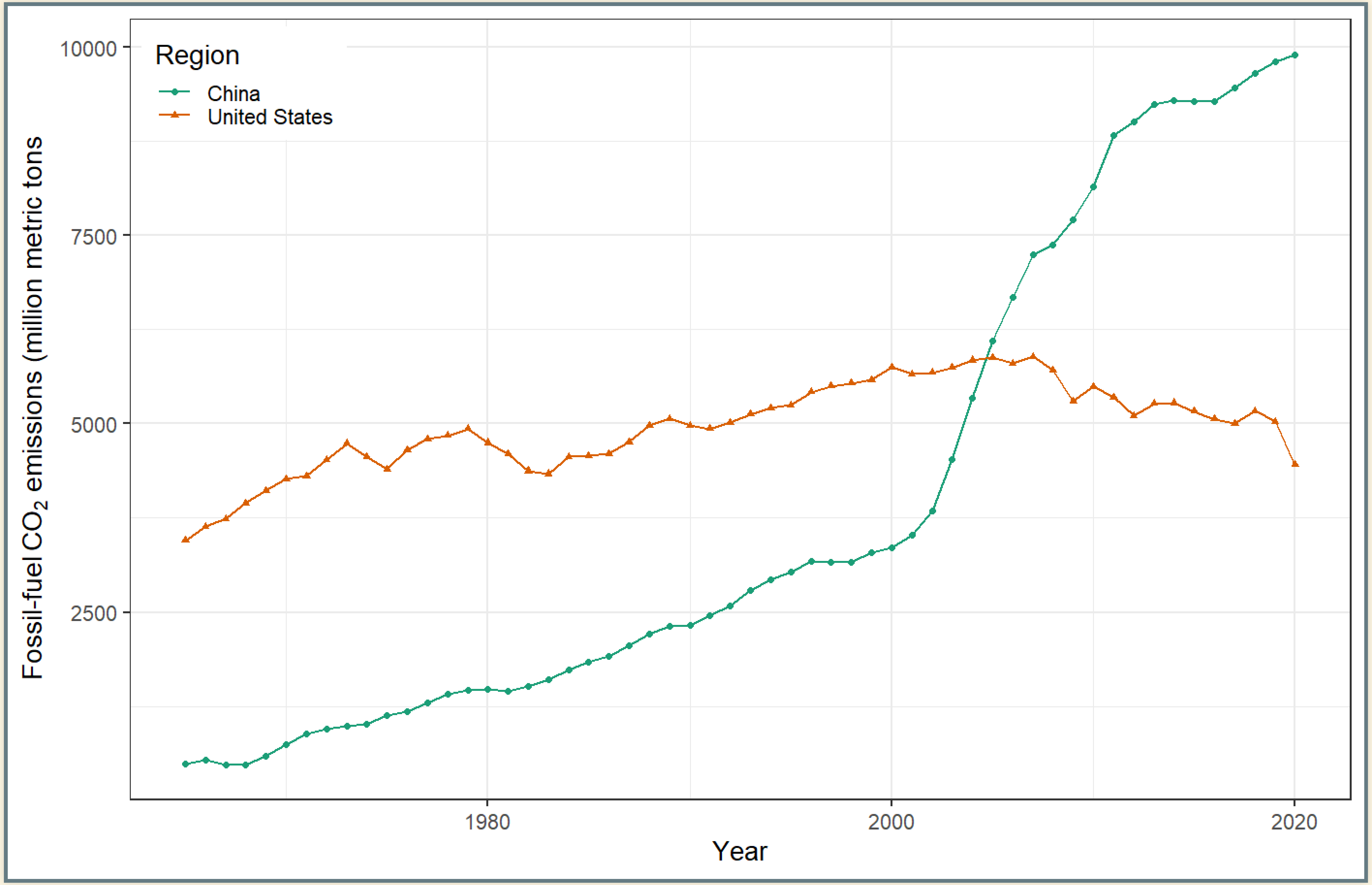


Image credit: McKinsey Global Institute

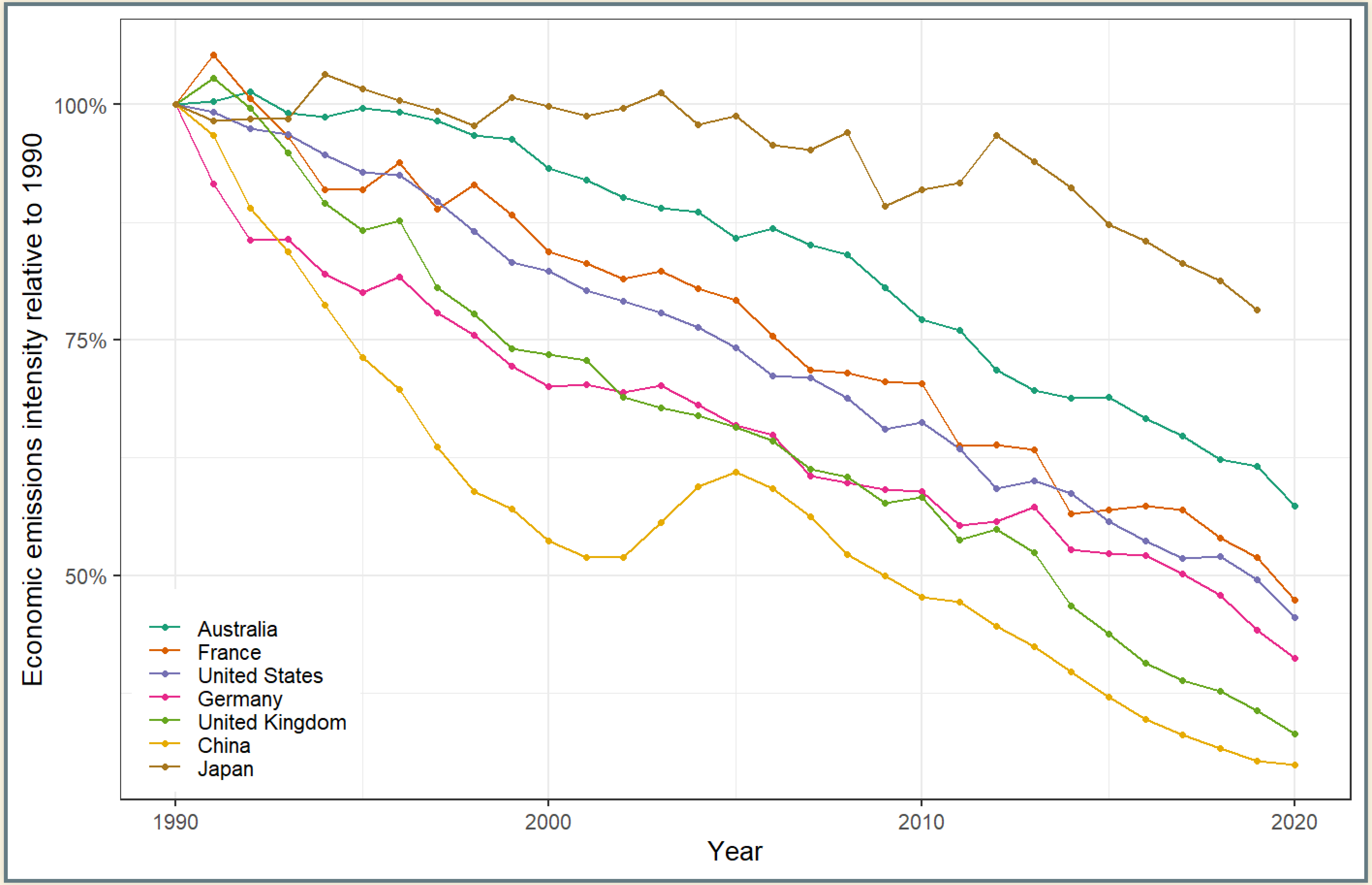
Economic Carbon Intensity in 2020



CO_2 Emissions 1965–2020



Relative improvement in carbon intensity 1990–2020



Top-Down Analysis

Top-Down Analysis

Bottom Up

- Treat each Kaya component (P, g, e, f) separately
- Predict future GDP ($G = P \times g$):
  - Extrapolate from historical trends to predict G in target year.
- Calculate *implied* reduction in e and f required to meet target emissions F in the target year, for the predicted GDP G.

Top Down

- Use macroeconomic model to predict energy demand ($E = P \times g \times e$) in target year.
  - Take account of interactions between population, economy, and technology.
- Calculate *implied* quantity of clean energy needed to meet target emissions F in the target year, while satisfying the predicted energy demand E.

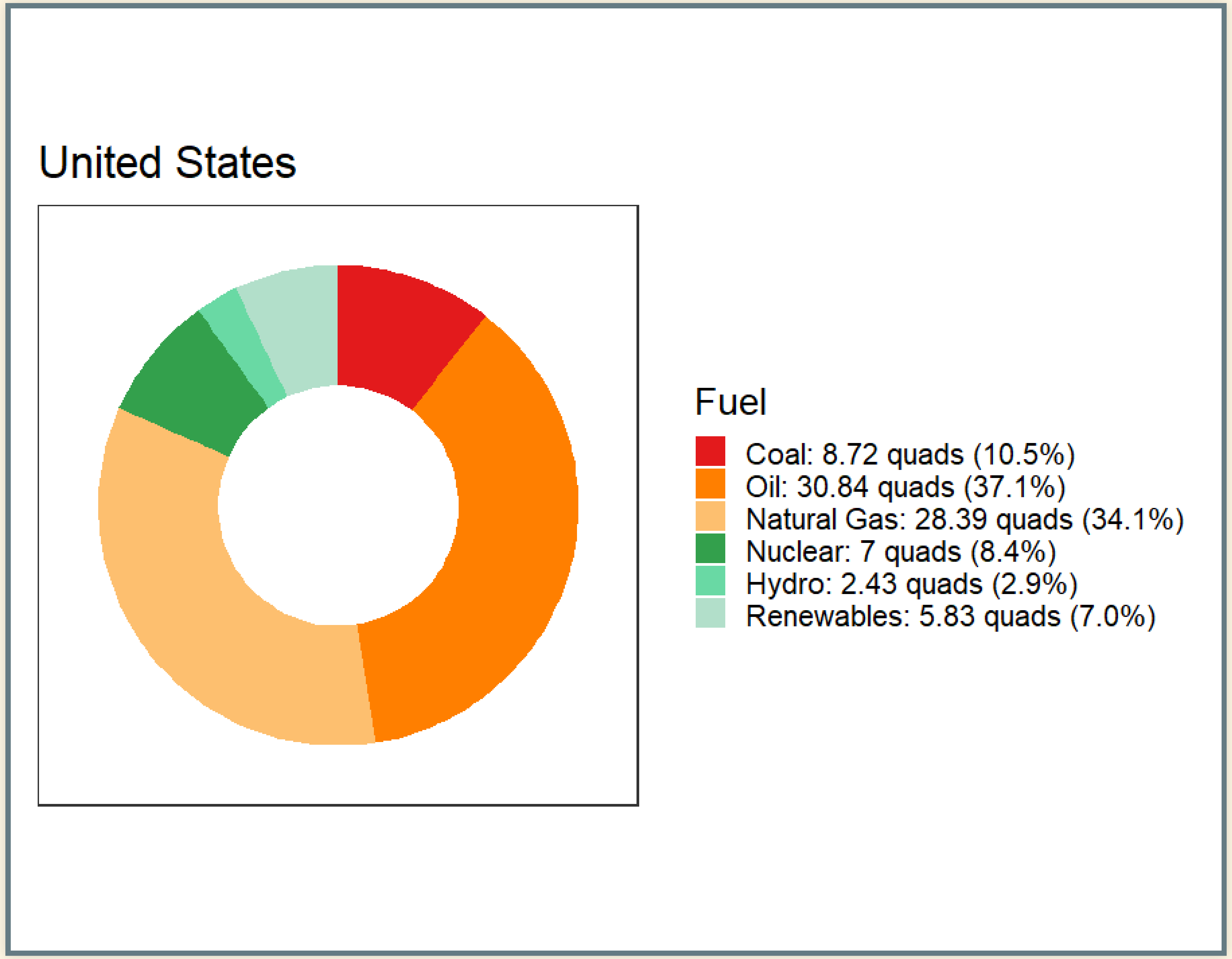
Cut emissions 80% by 2050

- Can the US cut emissions 50% below 2019 between 2020 and 2050?
  - $F(2020) = 4457~\text{MMT}$
  - $F(2050) = 1006~\text{MMT}$
  - Could we do this in 30 years?
    - We would have to cut *ef* by 7.3% per year.
    - Historically, since 1990, *ef* has dropped 2.5% per year.

Projected Energy Use in 2050

- Energy Information Administration top-down projection for energy demand in United States in 2050:
  - Total 2050 Primary Energy Use = 95.8 Quads
  - Assume P, g, and e are fixed.
  - Manage emissions by reducing f
    - Switch from fossil fuels to clean energy

Energy Mix in 2020



Fuel	**Quads**	**%**
Coal	8.7	10
Oil	30.8	37
Natural Gas	28.4	34
Nuclear	7.0	8
Hydro	2.4	3
Renewables	5.8	7
Total	83.2	100

Emissions Factors

Fuel	**MMT CO_2 per Quad**
Coal	94
Oil	70
Natural Gas	53
Nuclear	0
Hydro	0
Renewables	0

Projected Business as Usual Emissions in 2050

Fuel	**%**	**Quads**	**MMT/Quad**	**MMT CO_2**
Coal	10	10.0	94	948
Oil	37	35.5	70	2485
Natural Gas	34	32.7	53	1735
Nuclear	8	8.1	0	0
Hydro	3	2.8	0	0
Renewables	7	6.7	0	0
Total	100	95.8	NA	5167

Top-down emissions-reduction

Fuel	**%**	**Quads**	**MMT/Quad**	**MMT CO_2**
Coal	10	10.0	94	948
Oil	37	35.5	70	2485
Natural Gas	34	32.7	53	1735
Nuclear	8	8.1	0	0
Hydro	3	2.8	0	0
Renewables	7	6.7	0	0
Total	100	95.8	NA	5167

- Projected emissions for 2050 = 5167 MMT
  - If f doesn't change.
- Emissions goal for 2050 = 1006 MMT
- Must cut by (5167 – 1006) = 4161 MMT
- Start with coal:
  - Cut 948 MMT (10.0 quads)
  - 3213 MMT left
- Next, cut gas:
  - Cut 1735 MMT (32.7 quads)
  - 1479 MMT left
- Finally, cut oil:
  - Cut 1479 MMT (21.1 quads)
- Total energy cuts = 10.0 + 32.7 + 21.1 = 63.8 quads.

Clean Energy Sources

- 11,000 megawatts (MW) for one year = 1 quad
  - (See Climate Fix, p. 97)
- **Nuclear Power Plant**:
  - 1000 MW × 75% capacity factor = **750 MW average**
  - 1 quad per year = 11,000 MW / (750 MW per nuclear plant) = **14.7 nuclear plants**
- **Solar Photovoltaic**:
  - 30 MW × 30% capacity factor = **9 MW average**
  - **1 quad = 1,200 photovoltaic solar farms**
- **Wind Turbine**:
  - 6 MW × 42% capacity factor = **3 MW average**
  - **1 quad = 4,400 wind turbines**

Meeting Policy Goal

- Cut CO_2 by 4161 MMT
  - 948 MMT from coal (10.0 quad)
  - 1735 MMT from gas (32.7 quad)
  - 1479 MMT from oil (21.1 quad)
- Total clean energy needed: quads per year

- 64 quads × 15 nuclear plants/quad =
  940 nuclear power plants in 30 years
  (31 per year)
- 64 quads × 1,200 photovoltaic solar farms/quad =
  77,000 photovoltaic solar farms in 30 years
  (3,000 per year, or 50 per week)
- 64 quads × 4,400 wind plants/quad =
  281,000 wind turbines in 30 years
  (9,000 per year, or 30 per day)

Pielke’s Bottom Line

- Unfeasible to build so much clean energy so quickly
- Expense of building so much clean energy would defeat economic goals
- This is why we don’t have the technology to decarbonize as quickly as politicians and activists have been promising.

But …

- Renewable energy is getting cheaper very quickly
- It may soon be profitable to shut down existing fossil-fuel power plants and replace them with renewables.

Review

Bottom-Up Analysis

- Start with individual Kaya-identity variables:
  - *P*, *g*, *e*, *f*
  - Figure out historical rates of change for each
- Gross Domestic Product: $G = P \times g$
  - Rate of change of G: $r_G = r_P + r_g$
  - Rate of change of a product is the sum of the rates of change of the factors.
  - Use rate of change of *G* to extrapolate *G* in the future

Bottom-Up Analysis

- Start with individual Kaya-identity variables
- Start with the policy goal: change in F.
  - Figure out implied rate of change of emissions r_F.
- Compare to the expected rate of change of GDP r_G.
- Calculate the implied rate of decarbonizing the economy, r_{ef}:

  $$r_{ef} = r_F - r_G$$
- Compare implied r_{ef} to the historical trend in *ef* to assess the difficulty of meeting the policy goals.

Top-Down Analysis

- Start with macroeconomic estimate of future energy demand *E*
- Use mix of energy sources and emissions factors to calculate future emissions (*F*) if the mix of energy sources does not change.
- Your policy has a a goal for *F*
- Calculate difference between projected future *F* and policy goal for *F*.
- Calculate how many **quads of fossil-fuel energy** you would have to replace with clean energy to meet the policy goal.
  - Start with cutting coal, then cut natural gas, and finally cut oil
  - Why?
- Figure out how many power plants of different kinds you would have to build to supply the necessary clean energy.