

Reducing Carbon Emissions: Bottom-Up Approaches

EES 3310/5310

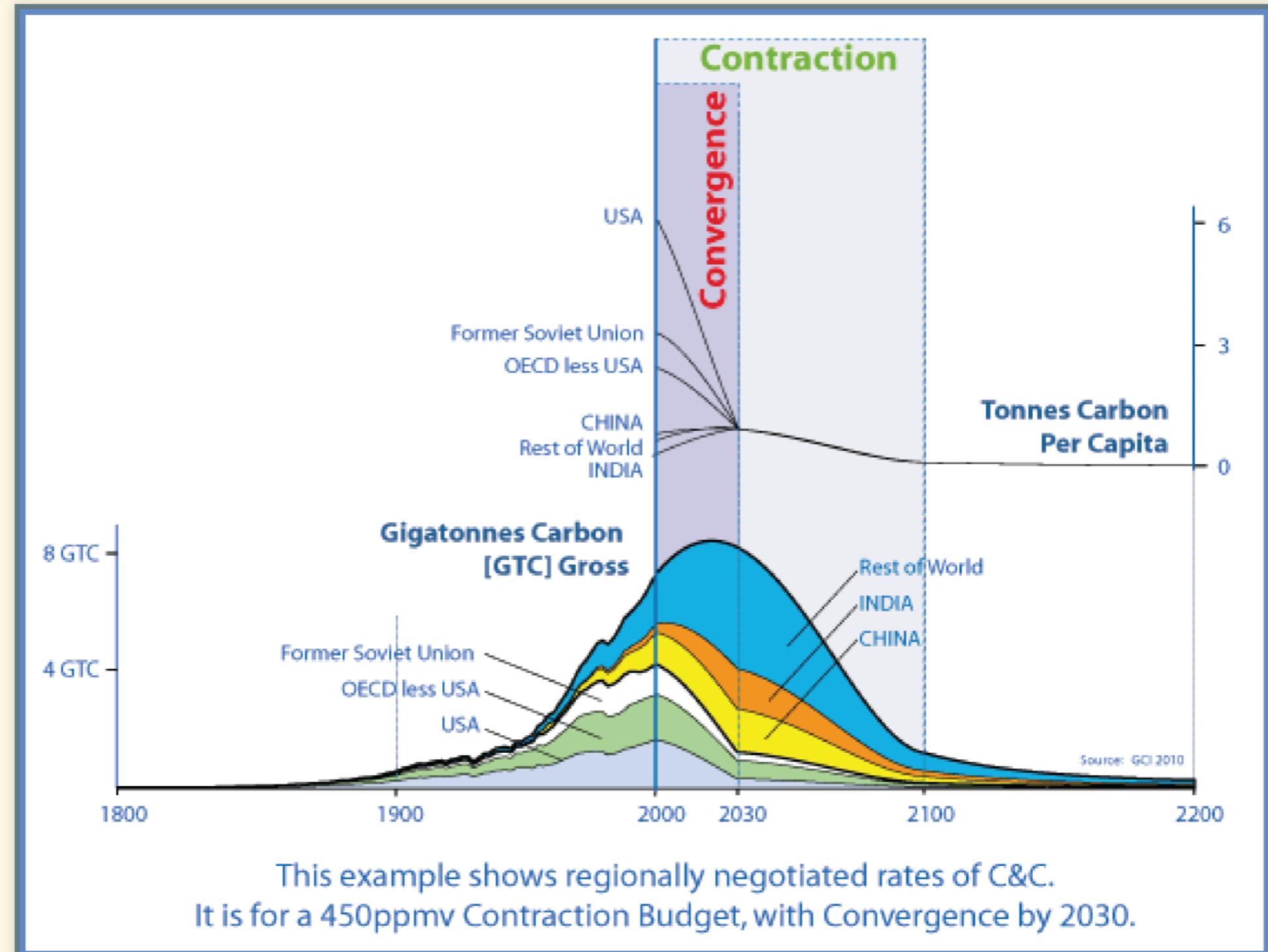
Global Climate Change

Jonathan Gilligan

Class #25: Monday, March 22 2021

Challenges of Decarbonizing

Scale of Problem: 450 ppm target



Pielke's Policy Criteria

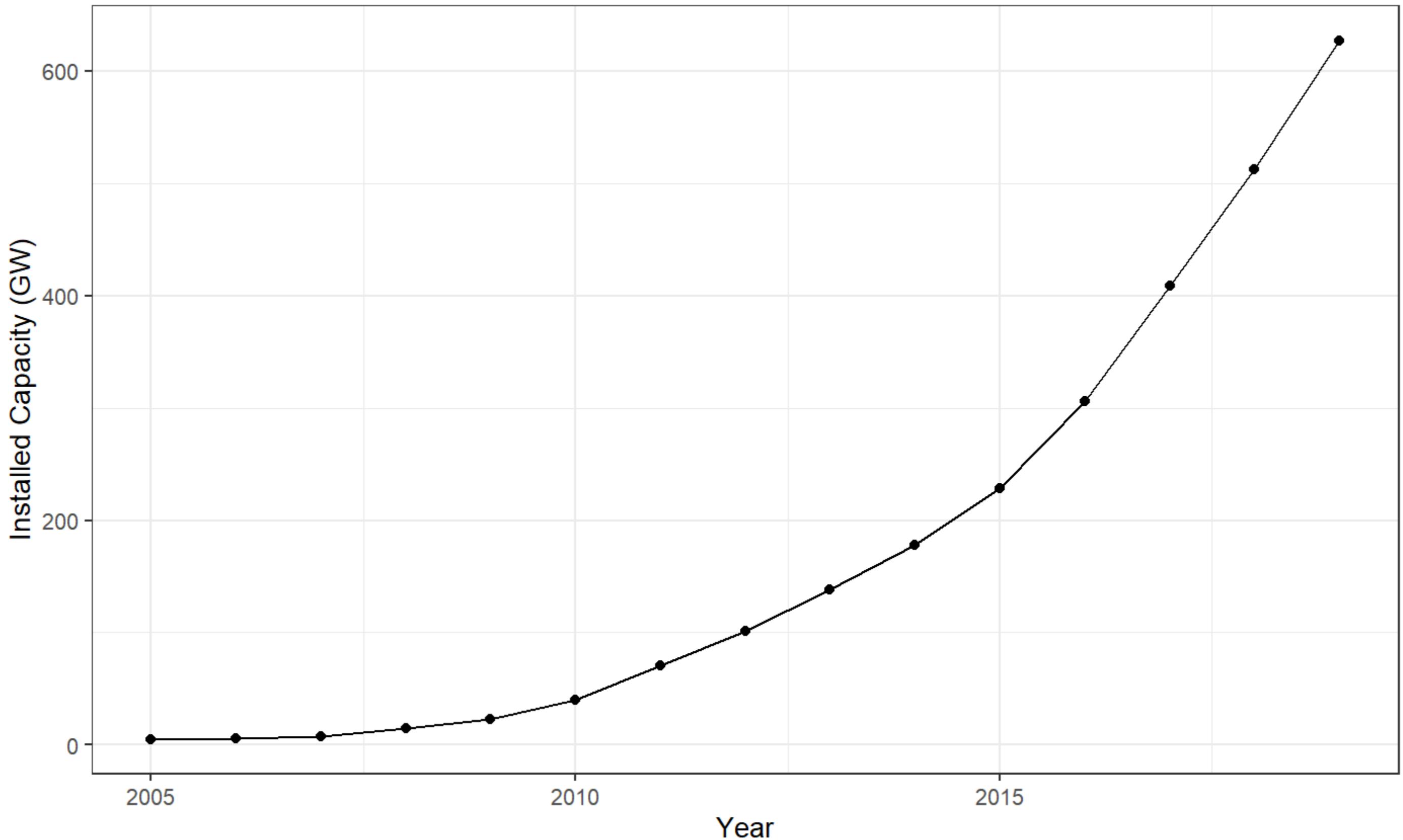
1. Policies should flow with public opinion
2. Public will not tolerate significant short-term costs, even for big long-term benefits
3. Policy must center on clean energy innovation

Solar Photovoltaic Power

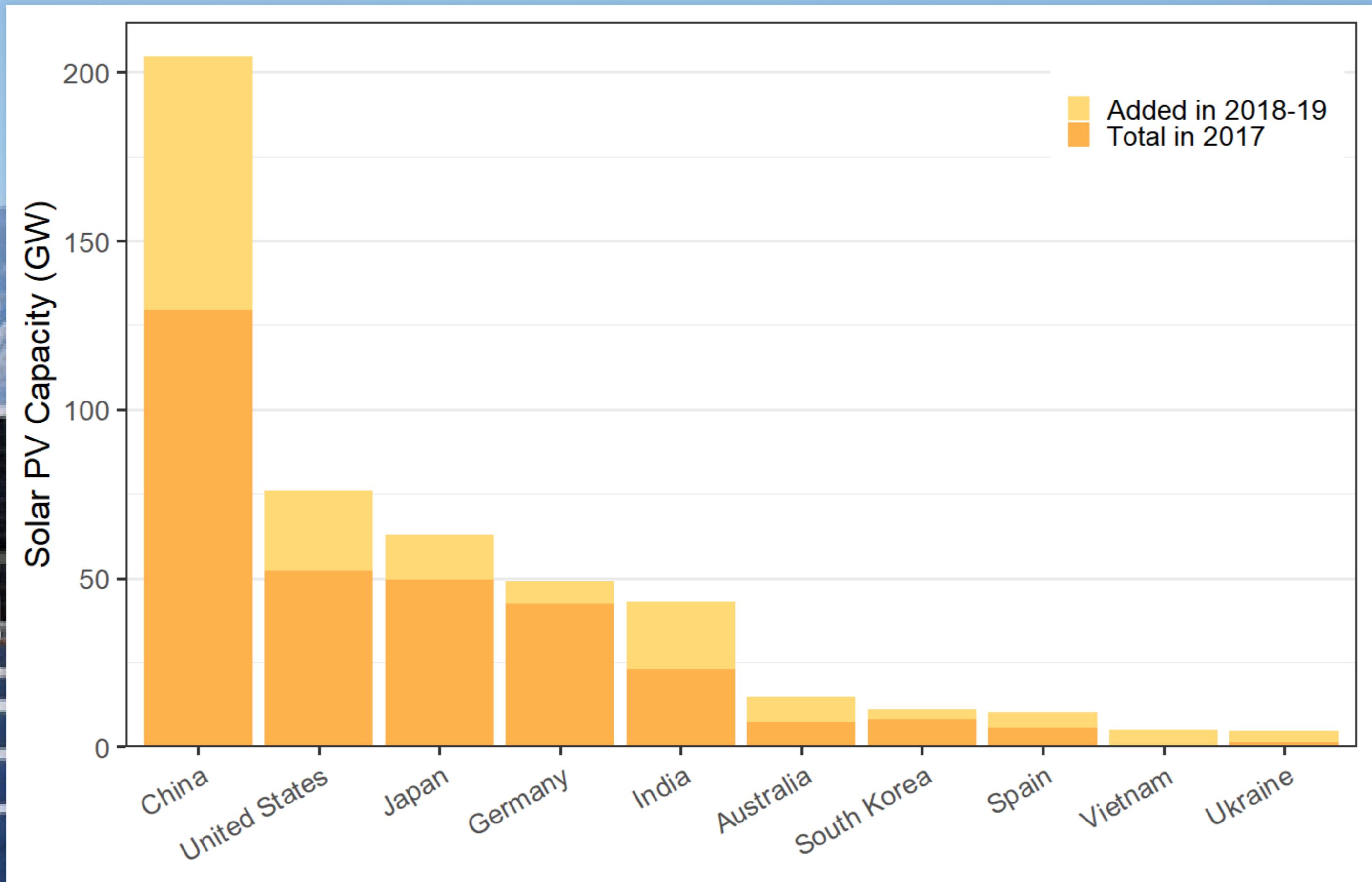


Solar Energy over Time

Installed Solar Photovoltaic Capacity



Top-10 Nations for Solar PV

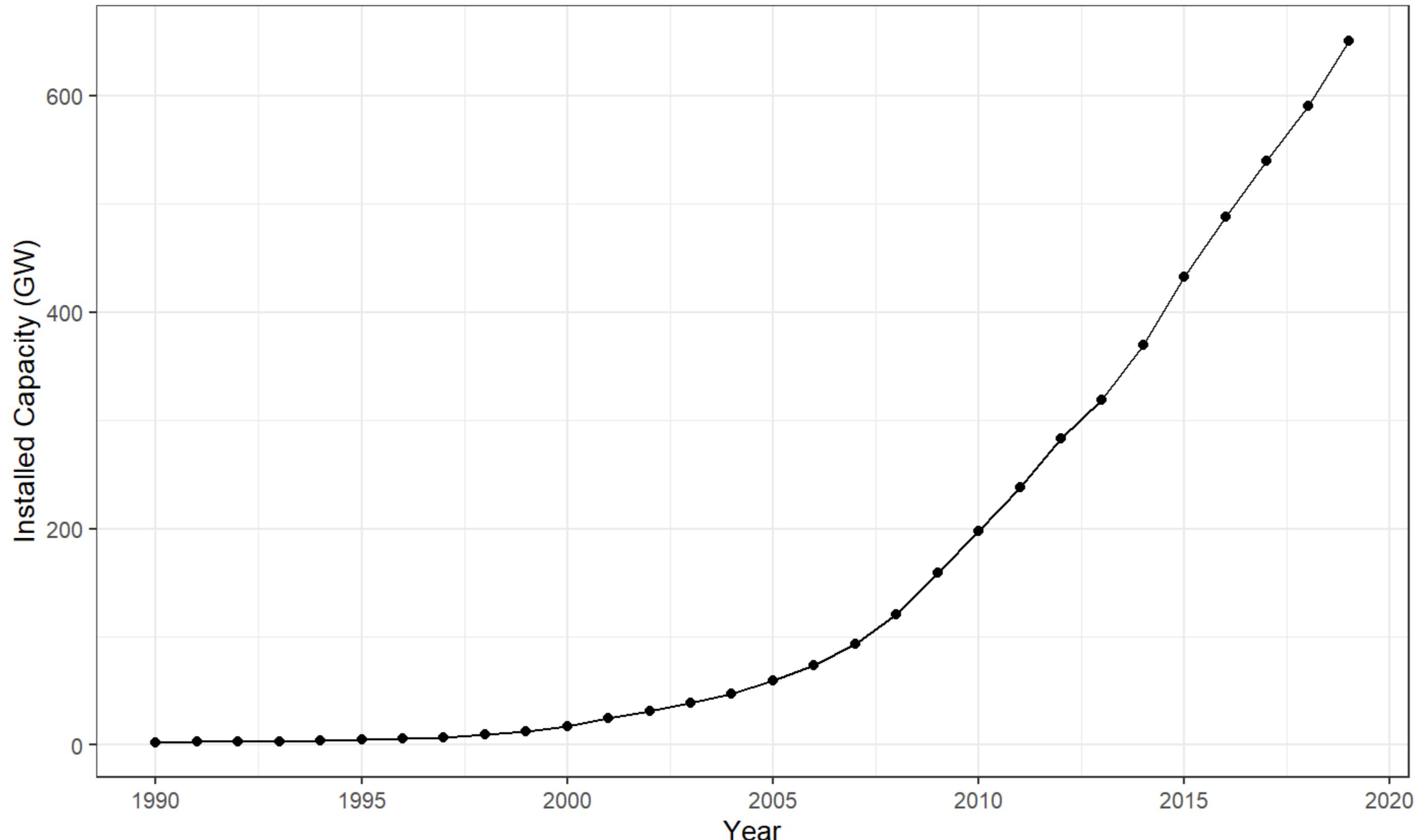


Wind Power

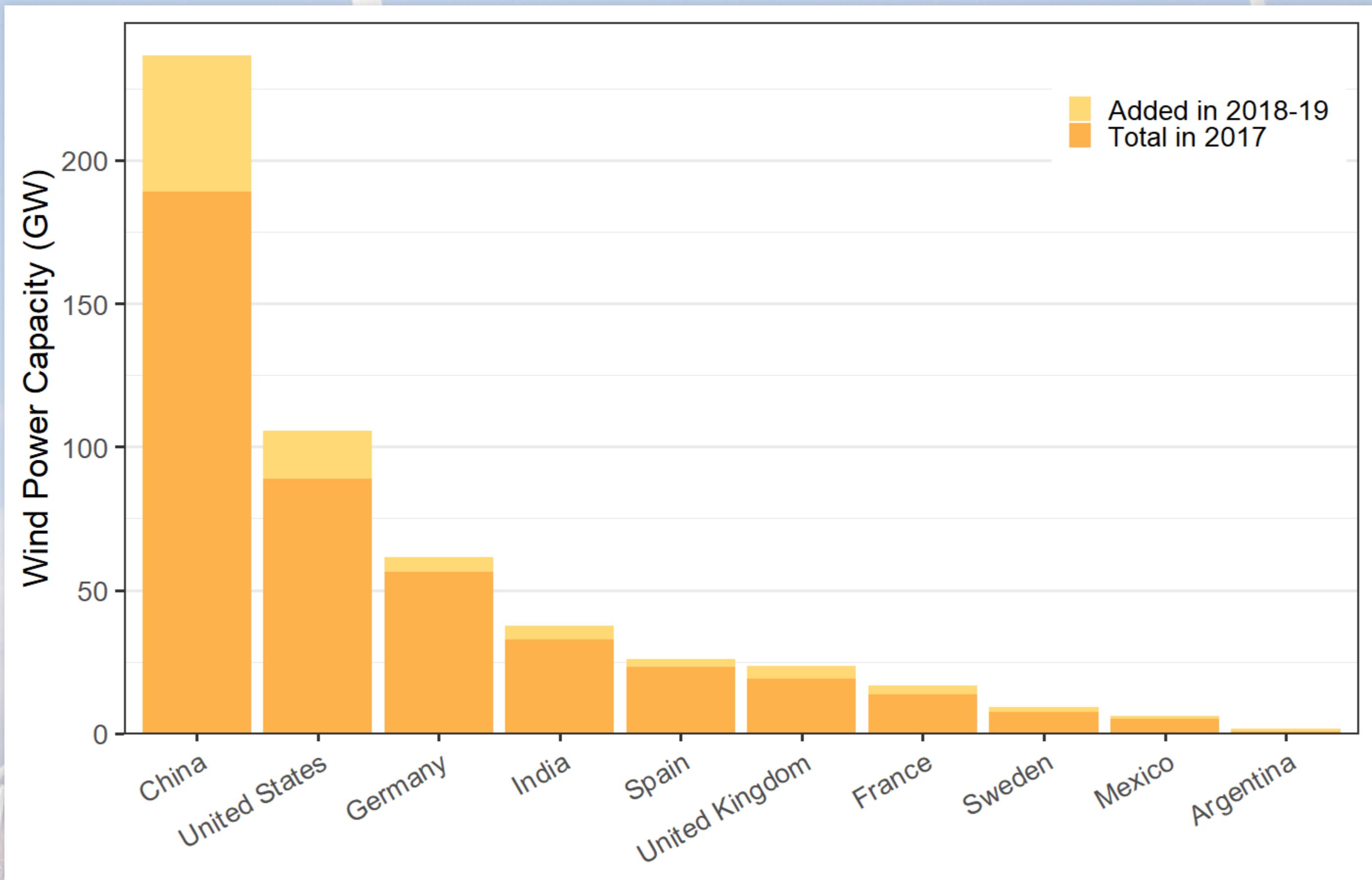


Wind Energy over Time

Installed Wind Capacity



Top-10 Nations for Wind



Prospects for Future Renewable Energy

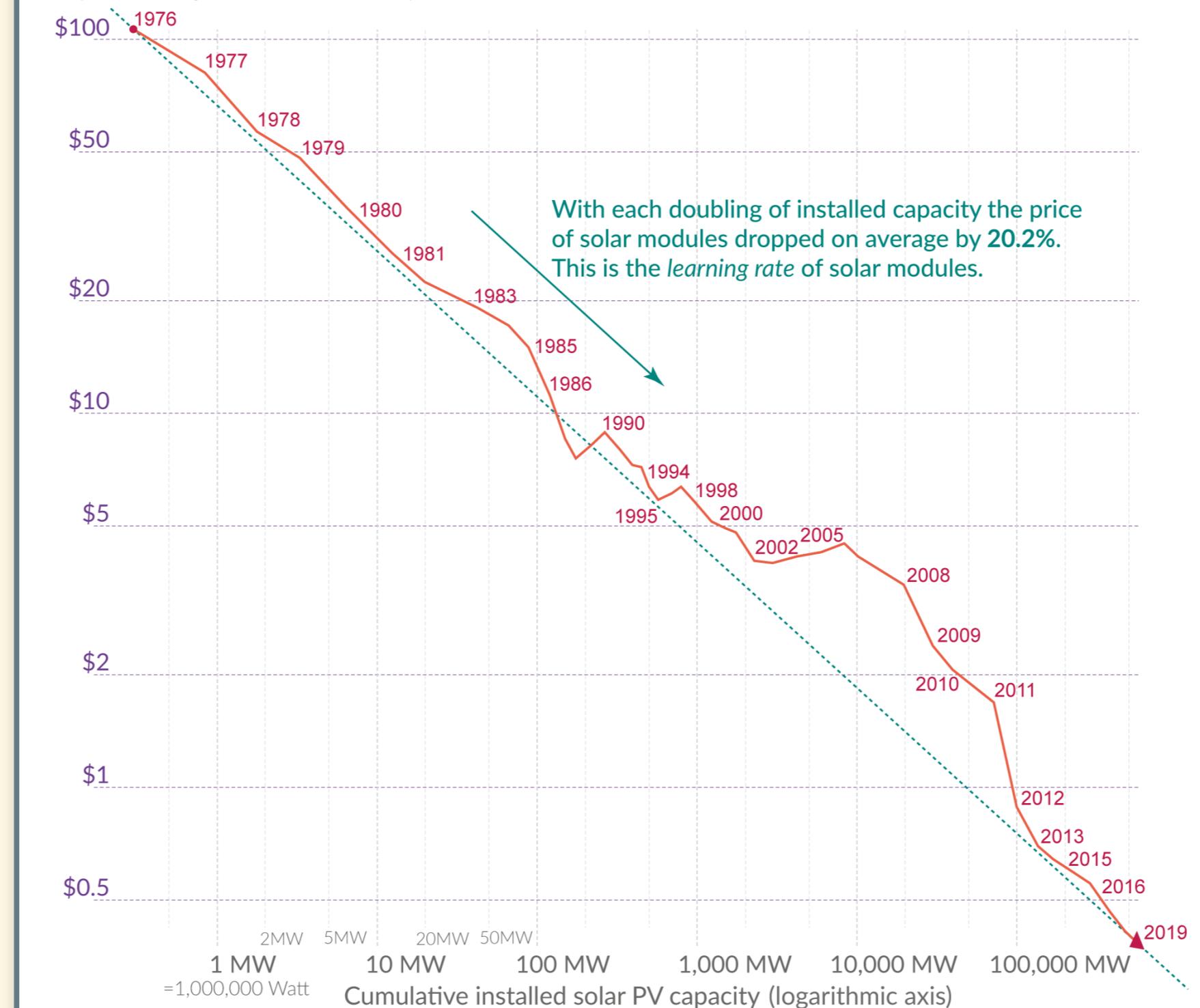
Solar PV

The price of solar modules declined by 99.6% since 1976

Our World
in Data

Price per Watt of solar photovoltaics (PV) modules (logarithmic axis)

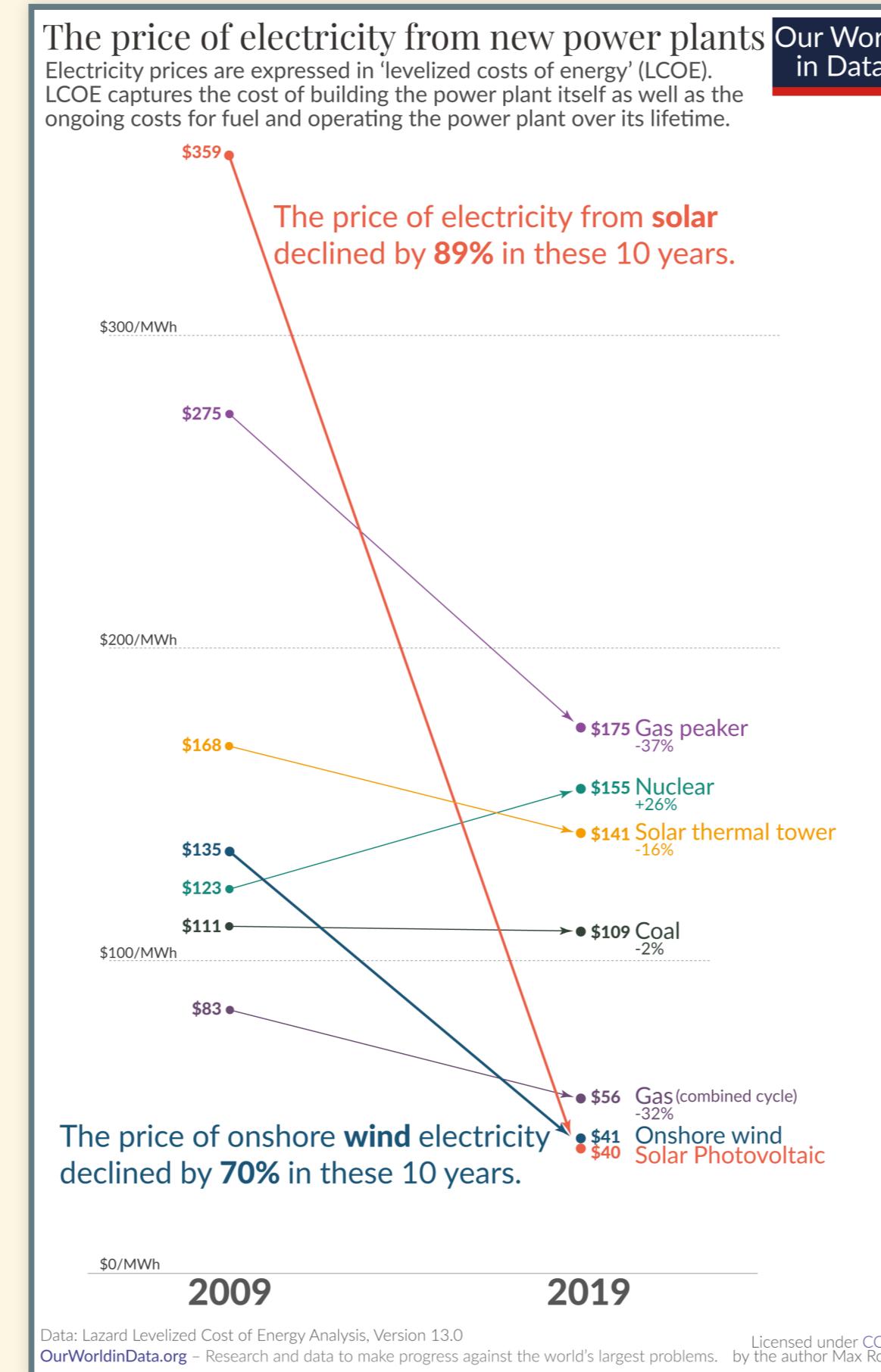
The prices are adjusted for inflation and presented in 2019 US-\$.



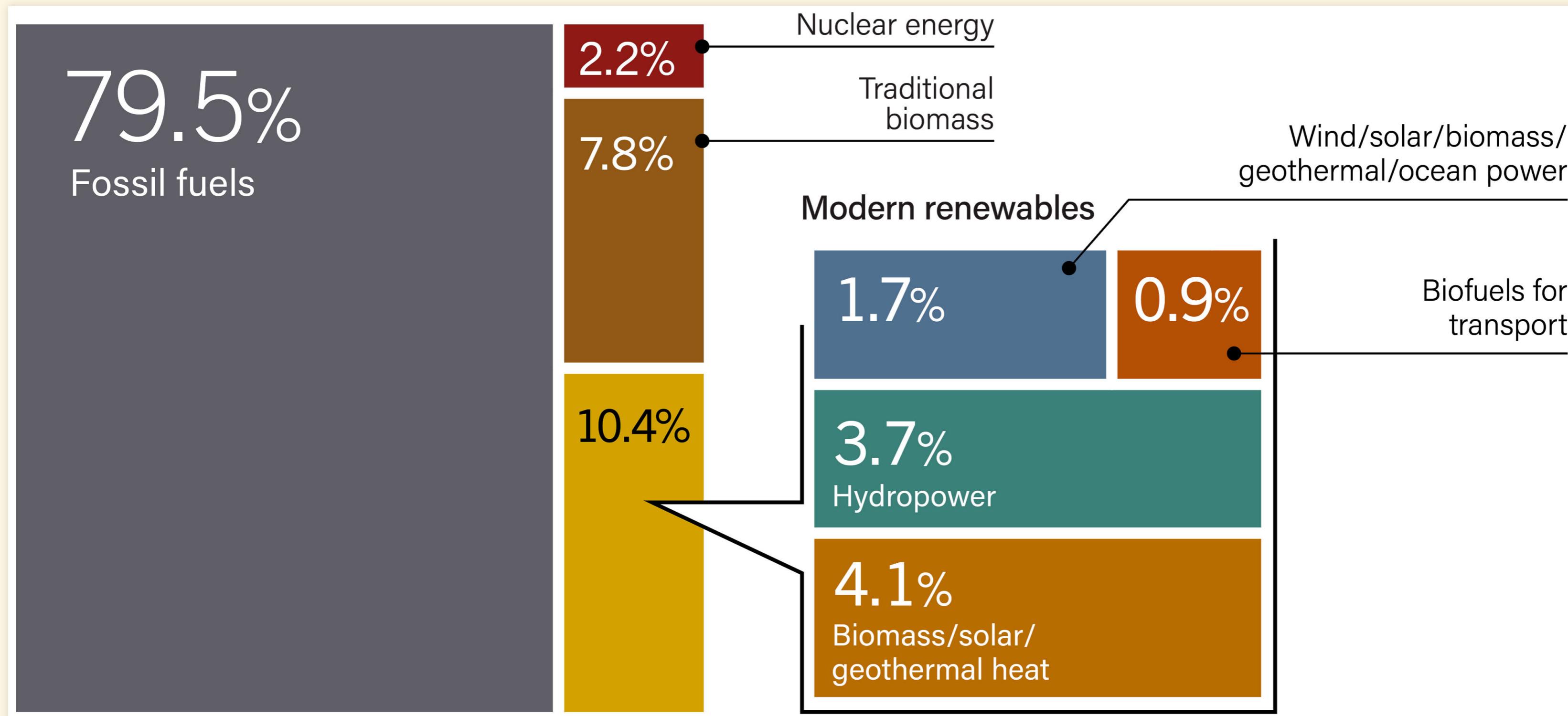
Data: Lafond et al. (2017) and IRENA Database; the reported learning rate is an average over several studies reported by de La Tour et al (2013) in Energy. The rate has remained very similar since then.
OurWorldInData.org – Research and data to make progress against the world's largest problems.

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Cost of Renewable Energy vs. Fossil Fuels

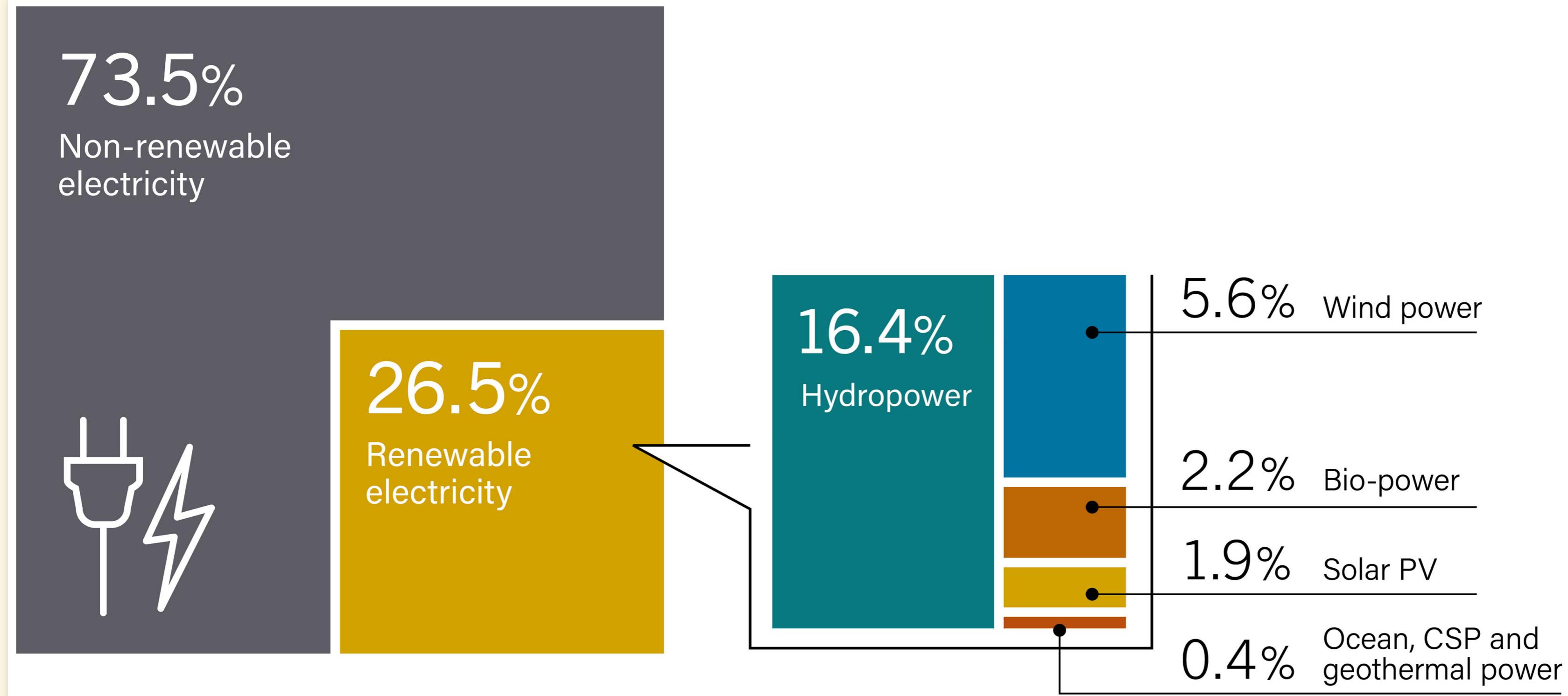


Current World Mix of Energy



Renewable Energy Policy Network for the 21st Century, *Global Status Report 2020*, <http://www.ren21.net/status-of-renewables/global-status-report/>

World Electricity Generation



Renewable Energy Policy Network for the 21st Century, *Global Status Report 2020*, <http://www.ren21.net/status-of-renewables/global-status-report/>

Decarbonizing the World

Implied Decarbonization:

- Goal:
 - Reduce emissions to some percentage below a reference year, by a target year
 - Example: Reduce emissions so $F(2050)$ is 80% less than $F(1990)$.
- Bottom-up procedure:
 - Treat each Kaya identity factor separately: P, g, e, f .
 - e.g., **extrapolate each factor**, based on historical rate of change
 - Combine P and g to get G (GDP in target year)
- Top-down procedure:
 - Begin with integrated model of total GDP growth
 - e.g., **macroeconomic model** that considers interactions between P, g, e , and f .
 - F = total CO_2 emissions
 - $G = Pg$ is Gross Domestic Product: Size of the economy
 - ef = carbon intensity of the economy
 - If ef rapidly gets smaller, then we can have economic growth while reducing emissions.

Implied Decarbonization (Bottom Up)

- We know F and G at the start.
- We know the goal for F at the target date
- We predict what P and g will be at the target date
- Kaya Identity:

$$\begin{aligned} F &= P \times g \times e \times f \\ &= G \times ef \\ F/G &= ef \end{aligned}$$

- Change in F/G implies change in ef : decarbonization.
 - $\Delta(F/G) = \Delta(ef)$
- Achieve decarbonization by some mix of energy efficiency (reduce e) and adoption of clean energy (reduce f).

Implied Decarbonization (Top Down)

- We know F and E at the start.
- We know the goal for F at the target date
- We predict what energy consumption E will be at the target date
- Kaya Identity:

$$F = E \times f$$
$$F/E = f$$

- Change if F/E implies change in f : decarbonization.
 - $\Delta(F/E) = \Delta(f)$
- Achieve decarbonization by adopting clean energy (reduce f).

Worked Example: UK

UK Climate Change Act (2008)

- Reduce greenhouse gas emissions so F in 2050 is 80% lower than in 1990:

$$F(2050) = 0.20 F(1990)$$

- How hard will it be to achieve this goal?

Bottom-Up Analysis

- Begin by figuring historical rates of change for P , g , e , and f .
- Estimate historical growth rate for $P \times g$.
- Calculate implied rate of change for $e \times f$.
- Compare implied rate of change for ef to historical rate of change.
- Use on-line web application to calculate rates of change. <https://ees3310.jgilligan.org/decarbonization/>
 - R package `kayadata`: `install.packages("kayadata")`

Bottom-Up Analysis

Decarbonization Explorer

Country/Region

Target year

Emissions reduction (%)

Reference year for emissions reduction

Calculate trends starting in

Trends Calculations Implied Decarbonization Energy Mix Historical

Variable

P

The screenshot shows a user interface for a 'Decarbonization Explorer'. On the left, there are five input fields: 'Country/Region' (dropdown), 'Target year' (text input '2050'), 'Emissions reduction (%)' (text input '80'), 'Reference year for emissions reduction' (text input '1990'), and 'Calculate trends starting in' (text input '1980'). Above these fields are five tabs: 'Trends' (selected), 'Calculations', 'Implied Decarbonization', 'Energy Mix', and 'Historical'. To the right of the tabs is a dropdown menu labeled 'Variable' with the letter 'P' selected.

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

Bottom-Up Analysis

- $GDP(2008) = \$2.54$ trillion
 - Emissions intensity $ef(2008) = 221$ tons per \$1000
- Business as usual:
 - If growth follows historical trends
 - Population P grows at 0.31%,
 - per-capita GDP g grows at 2.41%,
 - GDP grows at $0.31\% + 2.41\% = 2.72\%$

$$\begin{aligned} GDP(2050) &= GDP(2008) \times \exp(0.0272 \times (2050 - 2008)) \\ &= \$2.54 \text{ trillion} \times \exp(0.0272 \times 42) \\ &= \$7.95 \text{ trillion} \end{aligned}$$

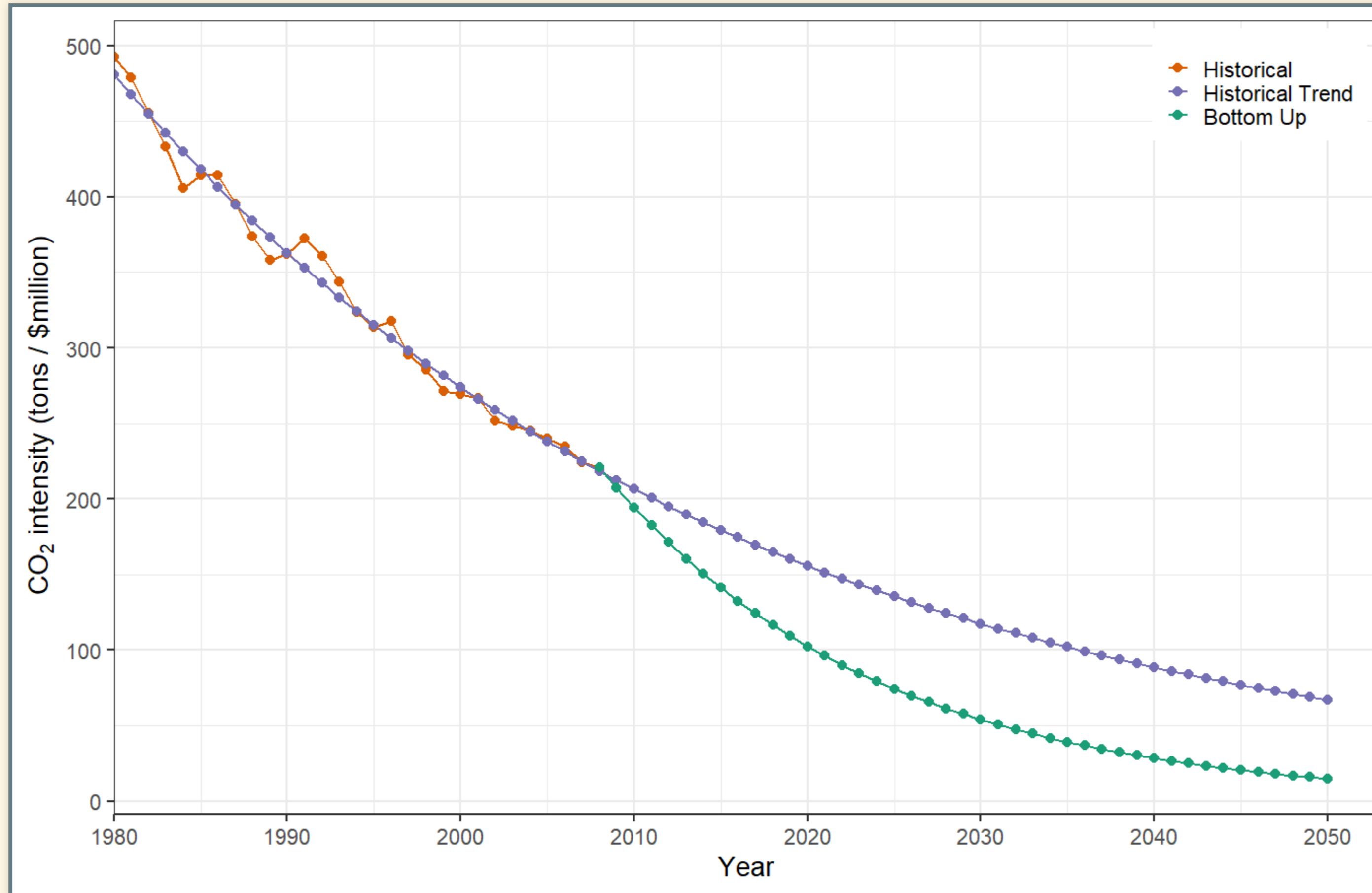
Bottom-Up Analysis

- $F(2008) = 561$ million tons CO₂.
- $F(1990) = 595$ million tons CO₂.
- Goal: Emissions in 2050 are 80% less than in 1990:
 - $F(2050) = 0.20 F(1990) = 0.20 \times 595 \text{ MMT} = 119 \text{ MMT}$
 - Implied growth rate of F :
$$r_F = \ln(F(2050)/F(2008))/42 \text{ years}$$
$$= \ln(119/561)/42$$
$$= -3.69\%.$$

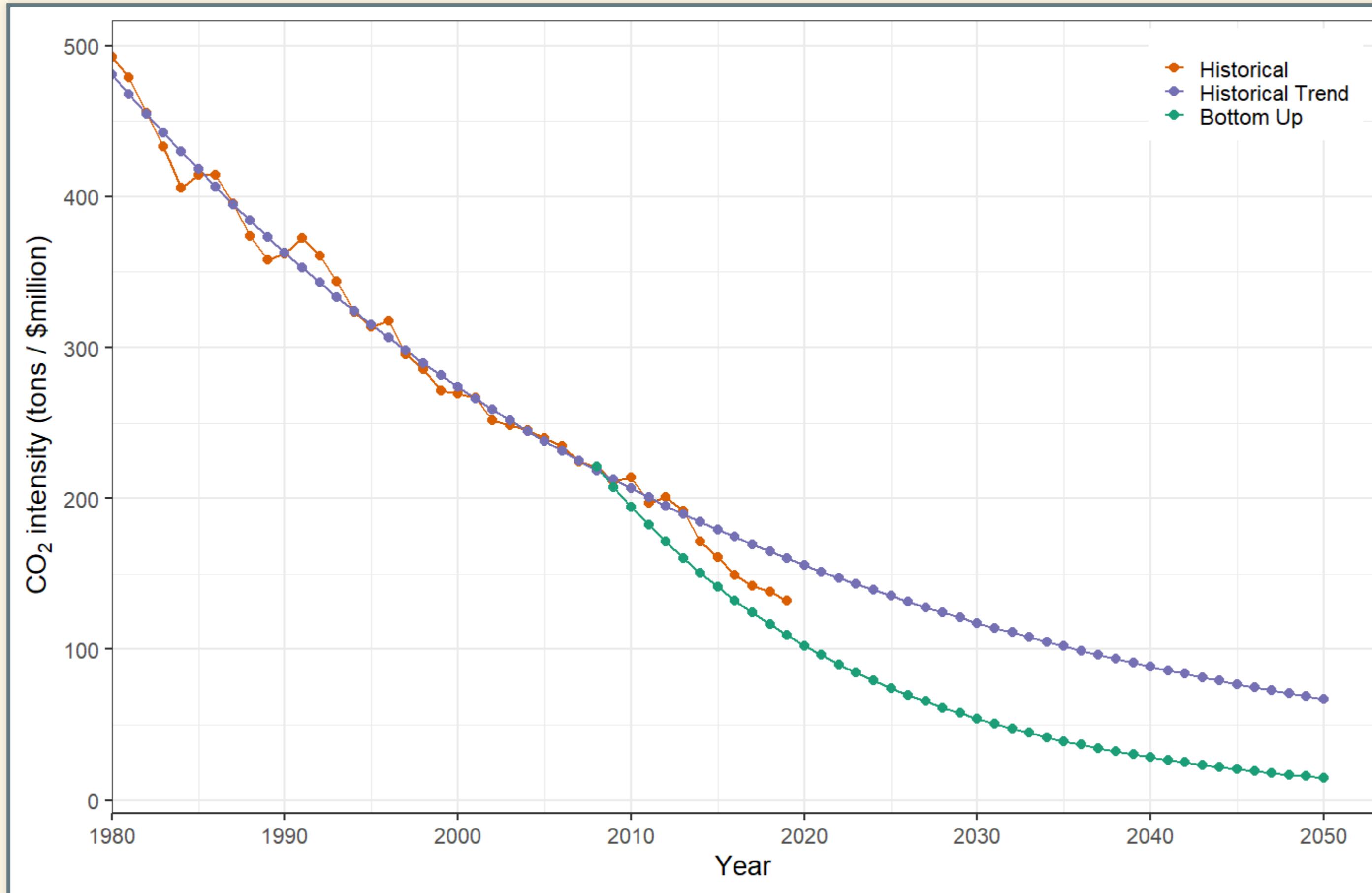
Implied decarbonization rates:

- GDP ($P \times g$) grows at 2.72%
- Implied growth rate of F : $r_F = -3.69\%$.
- Implied growth rate of ef (carbon intensity of the economy):
 - $F = Pgef$, so
 - $r_F = r_{Pg} + r_{ef} = r_G + r_{ef}$
- The implied $r_{ef} = -6.41\%$
- The historical $r_{ef} = -2.82\%$
- To meet the goal, the UK would have to decarbonize 2.3 times faster than it did for the previous several decades.
- However, since 2010, decarbonization has accelerated!

Implied decarbonization for UK



Progress since 2008



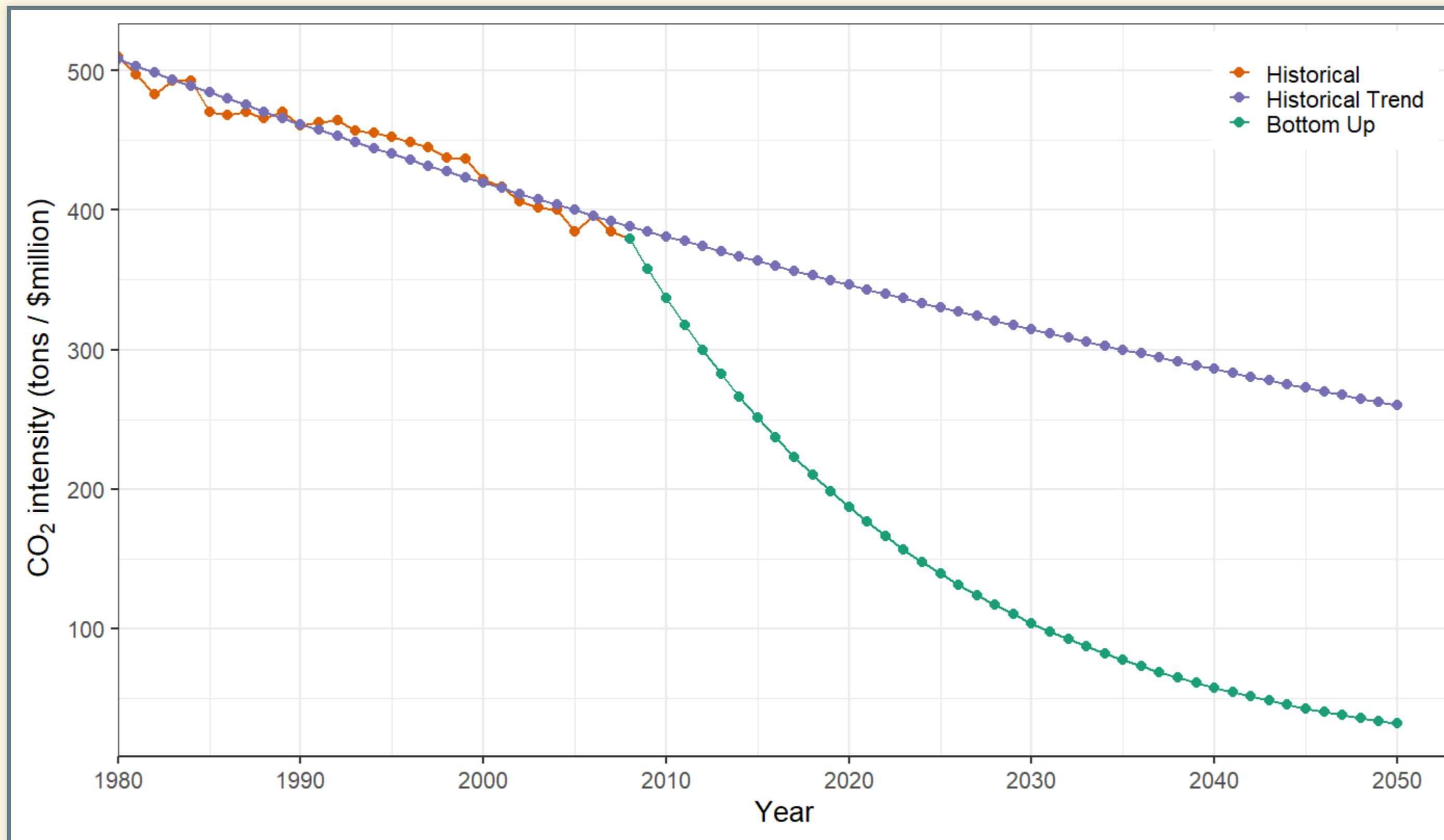
Implied Decarbonization for Australia

Australia's Emissions Trading Scheme

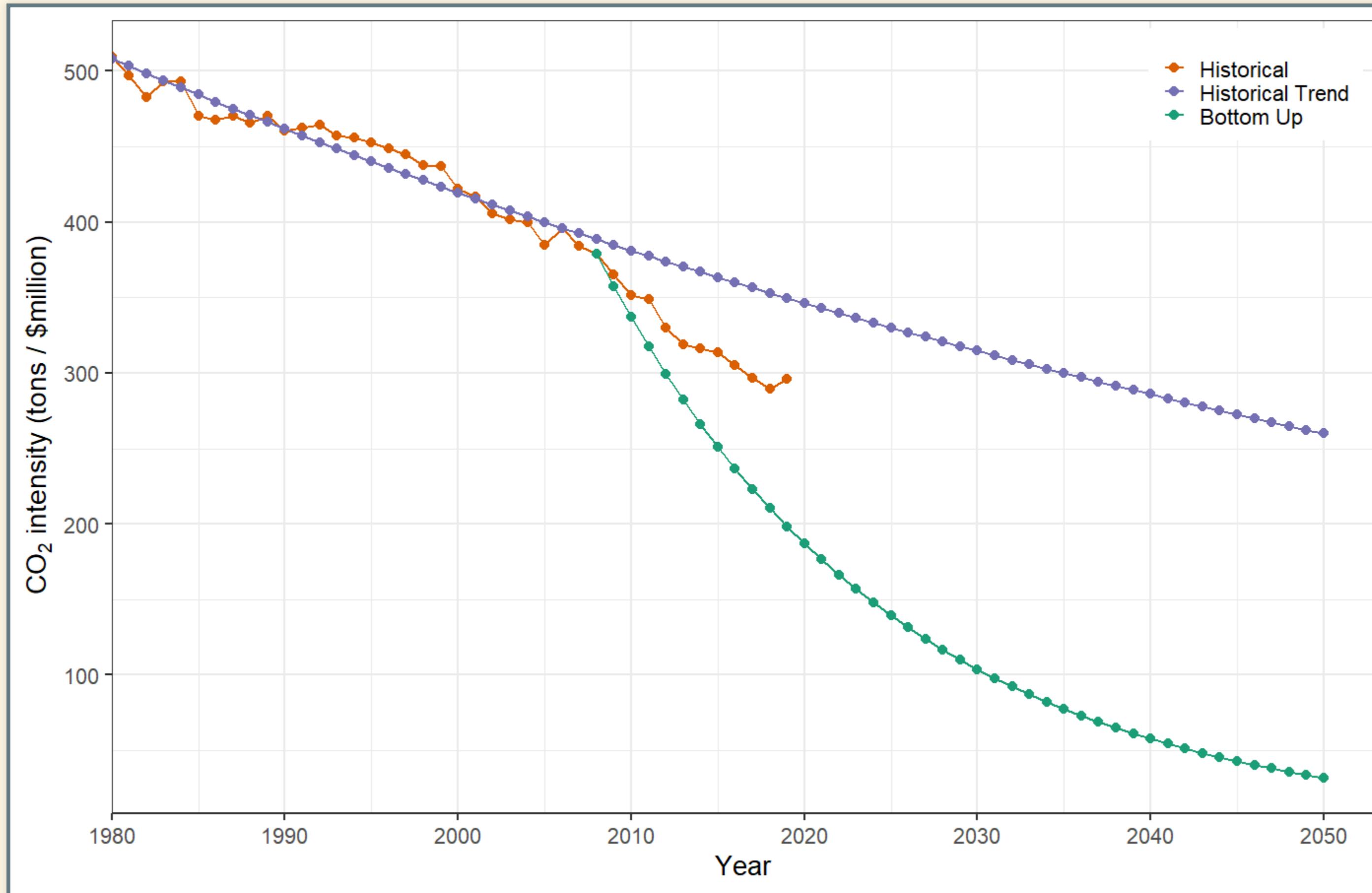
- PM Kevin Rudd calls for cutting emissions 60% below 2000 levels by 2050
- $F(2050) = 0.40 F(2000) = 0.40 \times 358 \text{ MMT} = 143 \text{ MMT}$

Implied Decarbonization for Australia

- Historical decarbonization rate: $r_{ef} = -0.96\%$
- Implied decarbonization rate: $r_{ef} = -5.89\%$

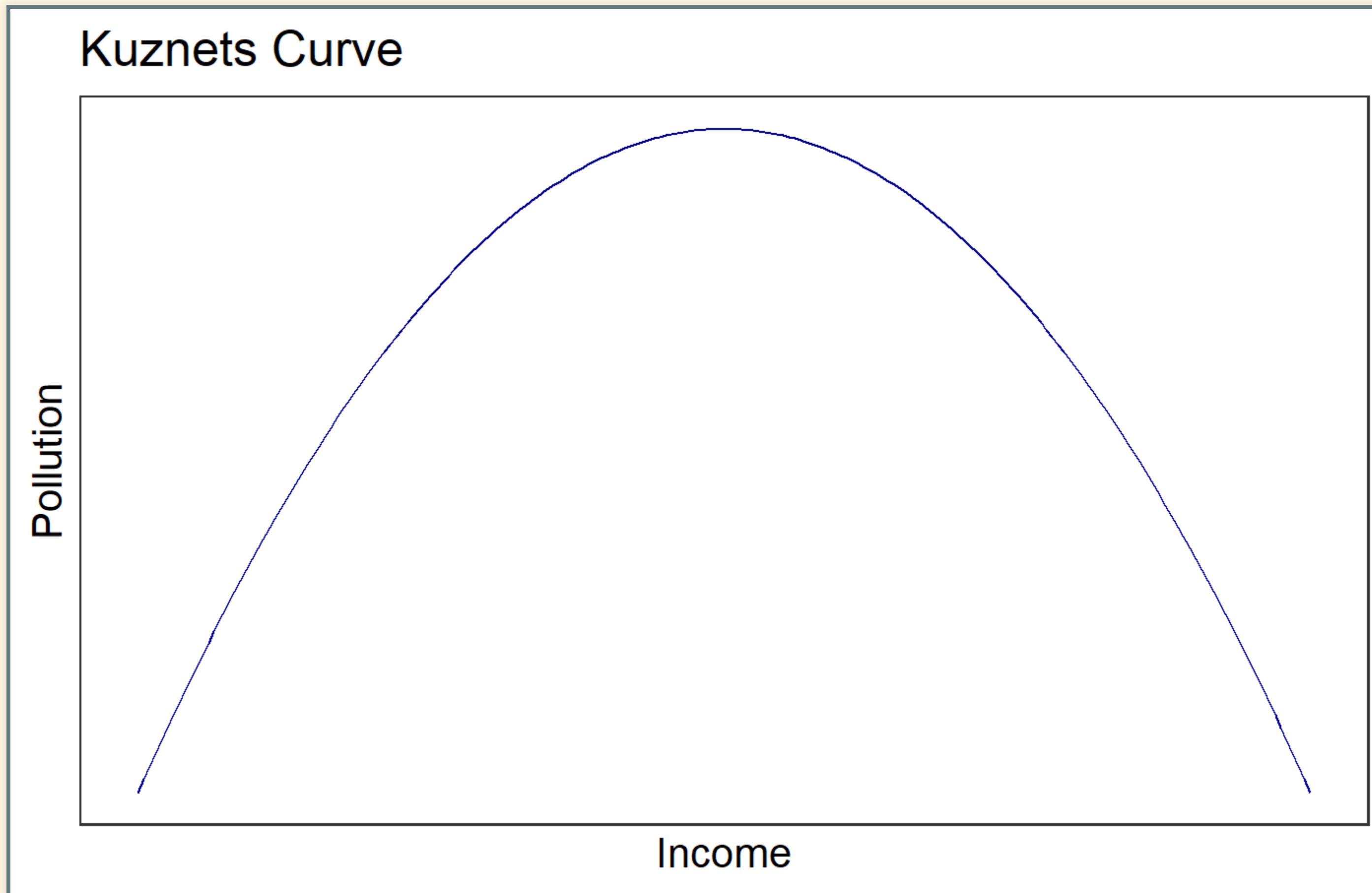


Progress since 2008



Other Considerations

Kuznets curve



Concluding Remarks

- Implied ef depends on prediction of $GDP = G = P \times g$.
- 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?