Reducing Carbon Emissions: Bottom-Up Approaches

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #25: Wednesday, March 23 2022

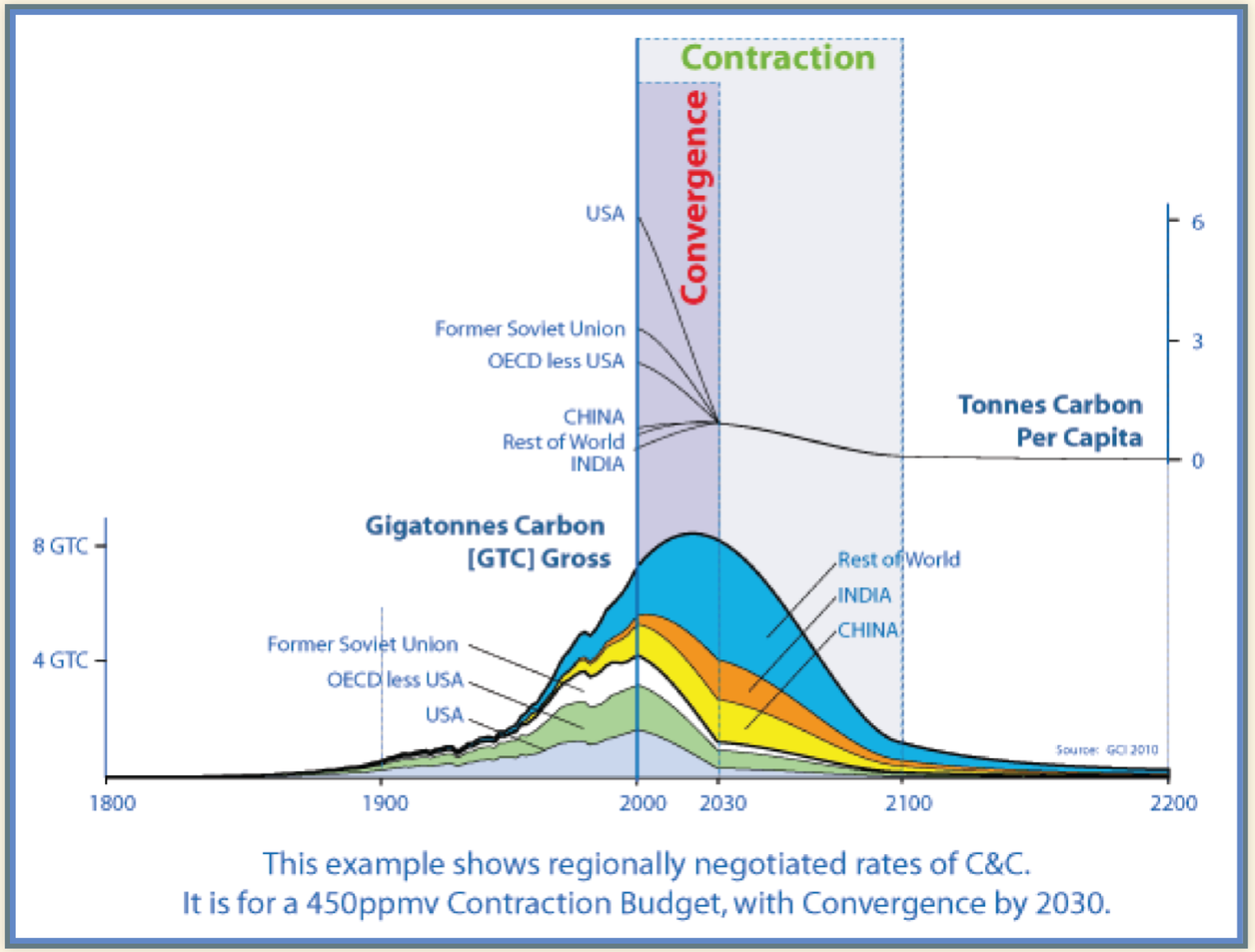
Announcements

Announcements

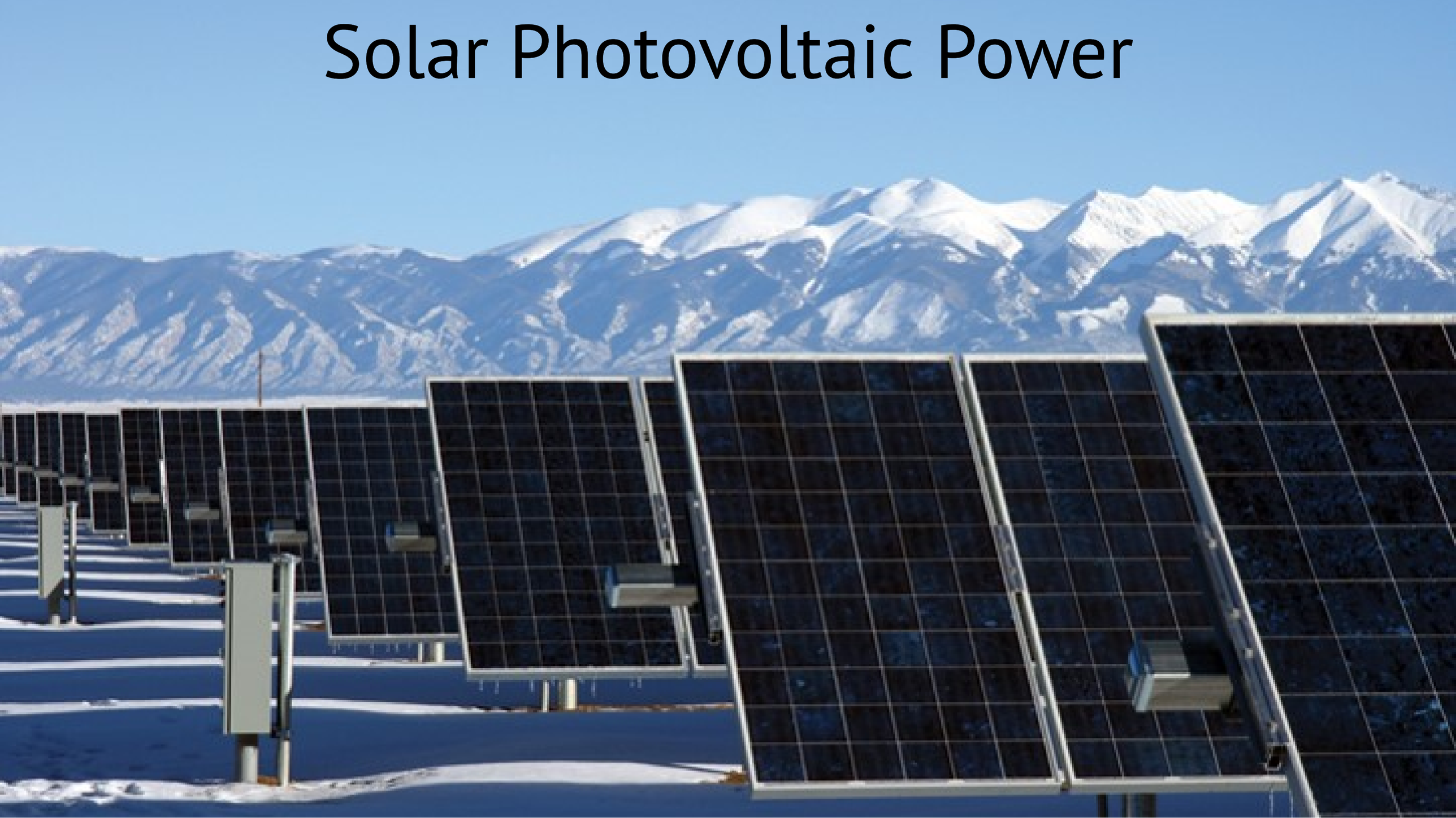
- I have to cancel class this Friday (March 25). I have posted an announcement on Brightspace with a link to a survey for scheduling a makeup class.

Challenges of Decarbonizing

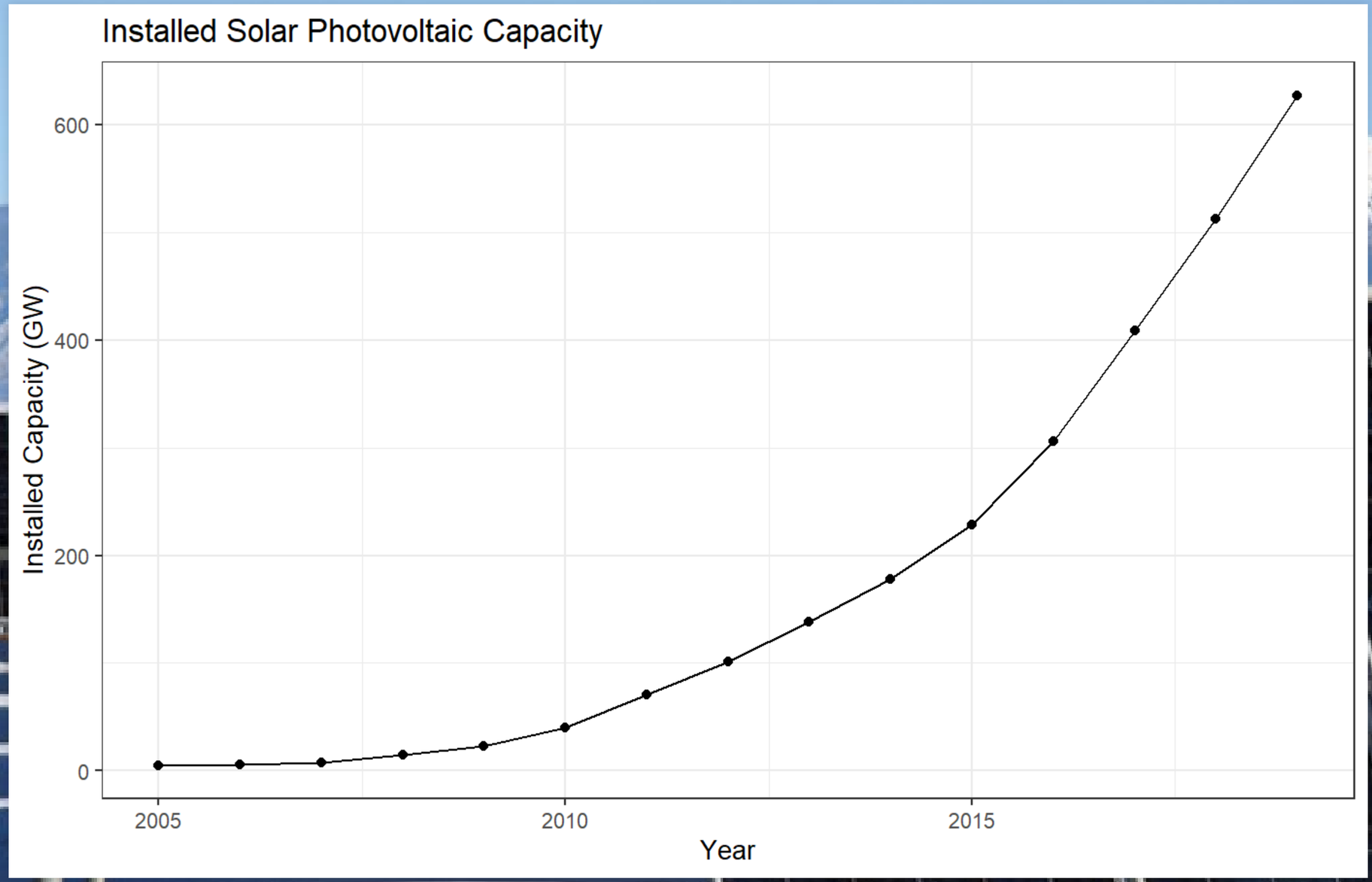
Scale of Problem: 450 ppm target



Solar Photovoltaic Power

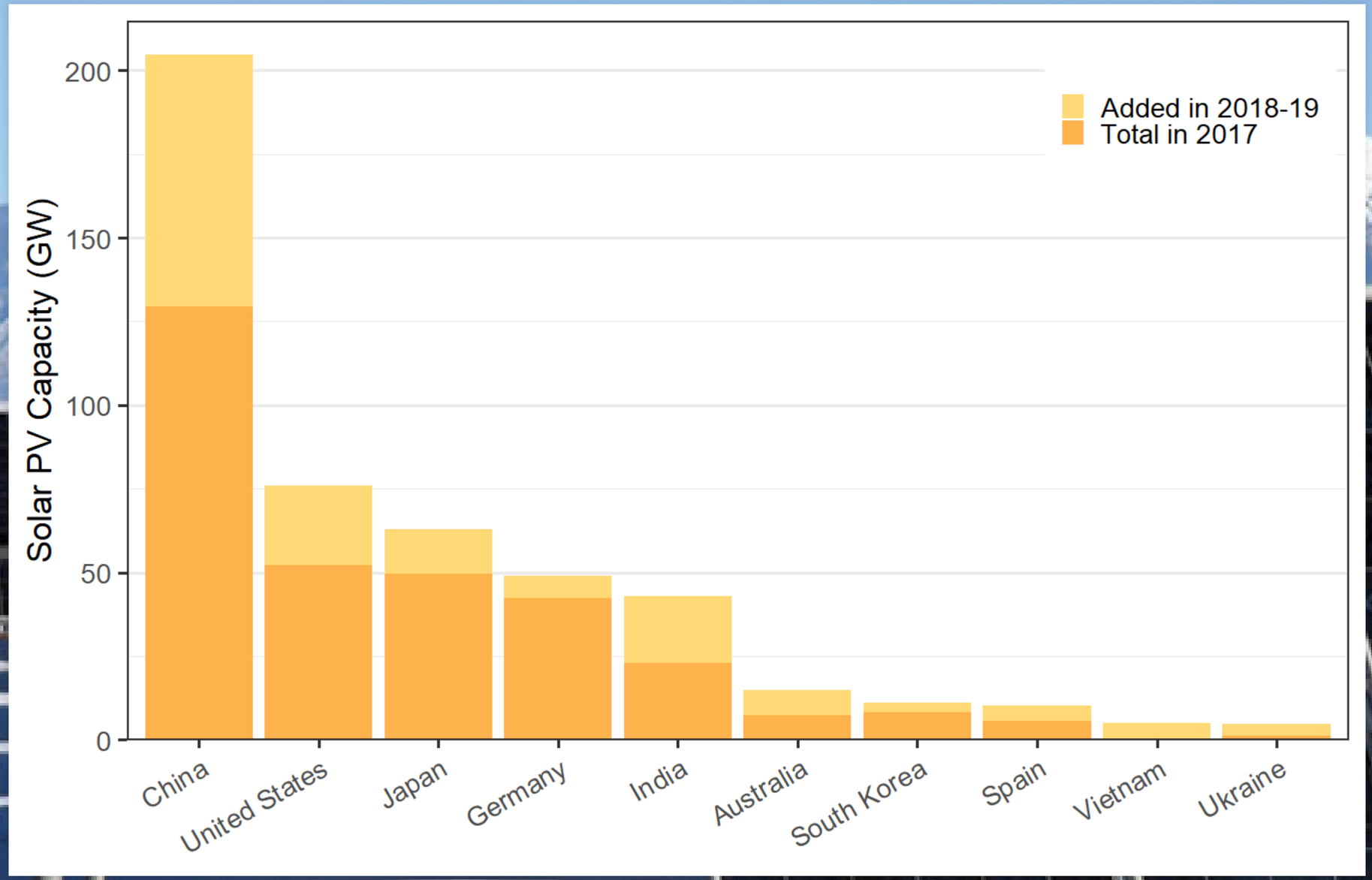


Solar Energy over Time



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

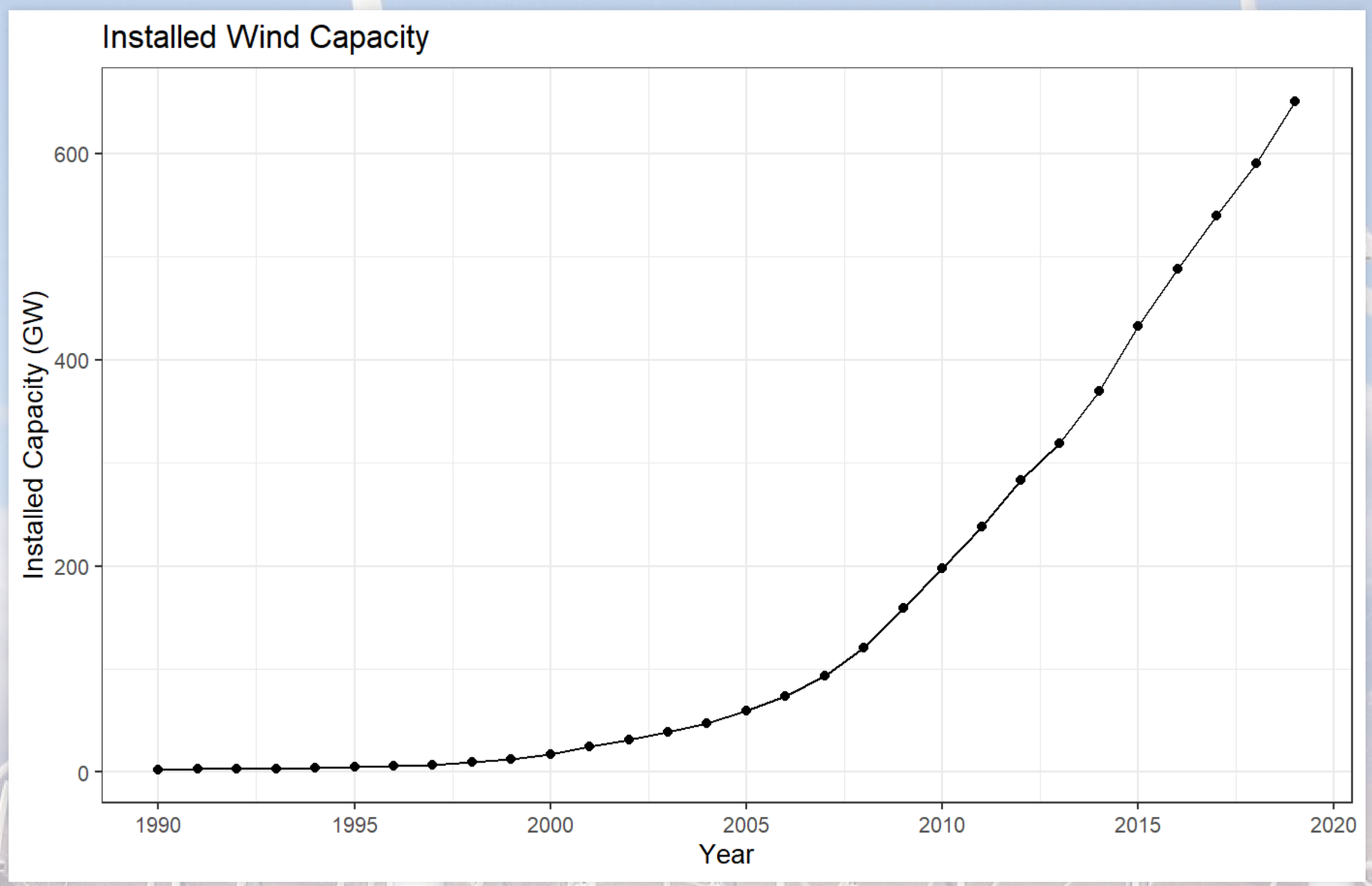
Top-10 Nations for Solar PV



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

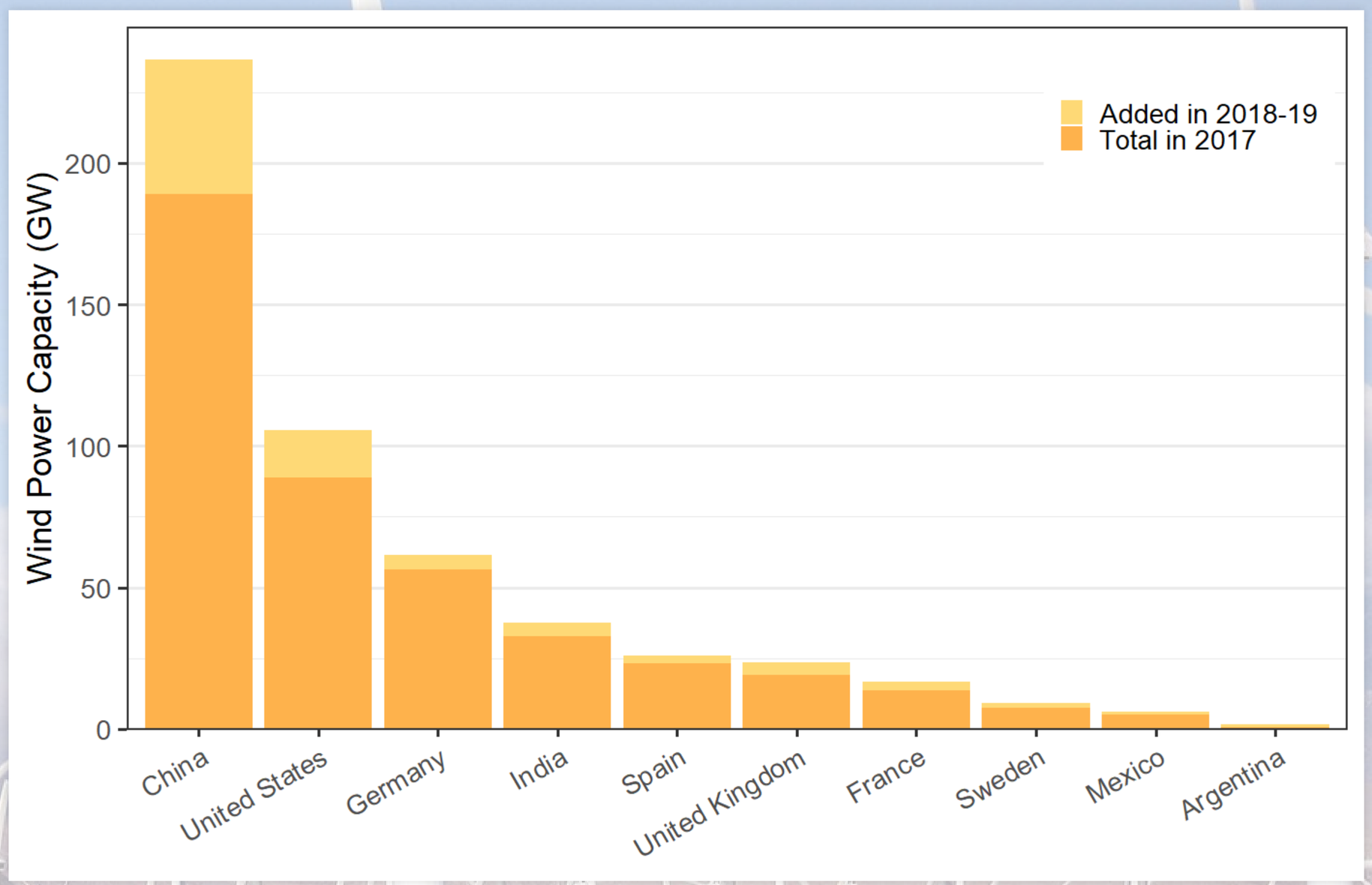
Wind Power

Wind Energy over Time



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

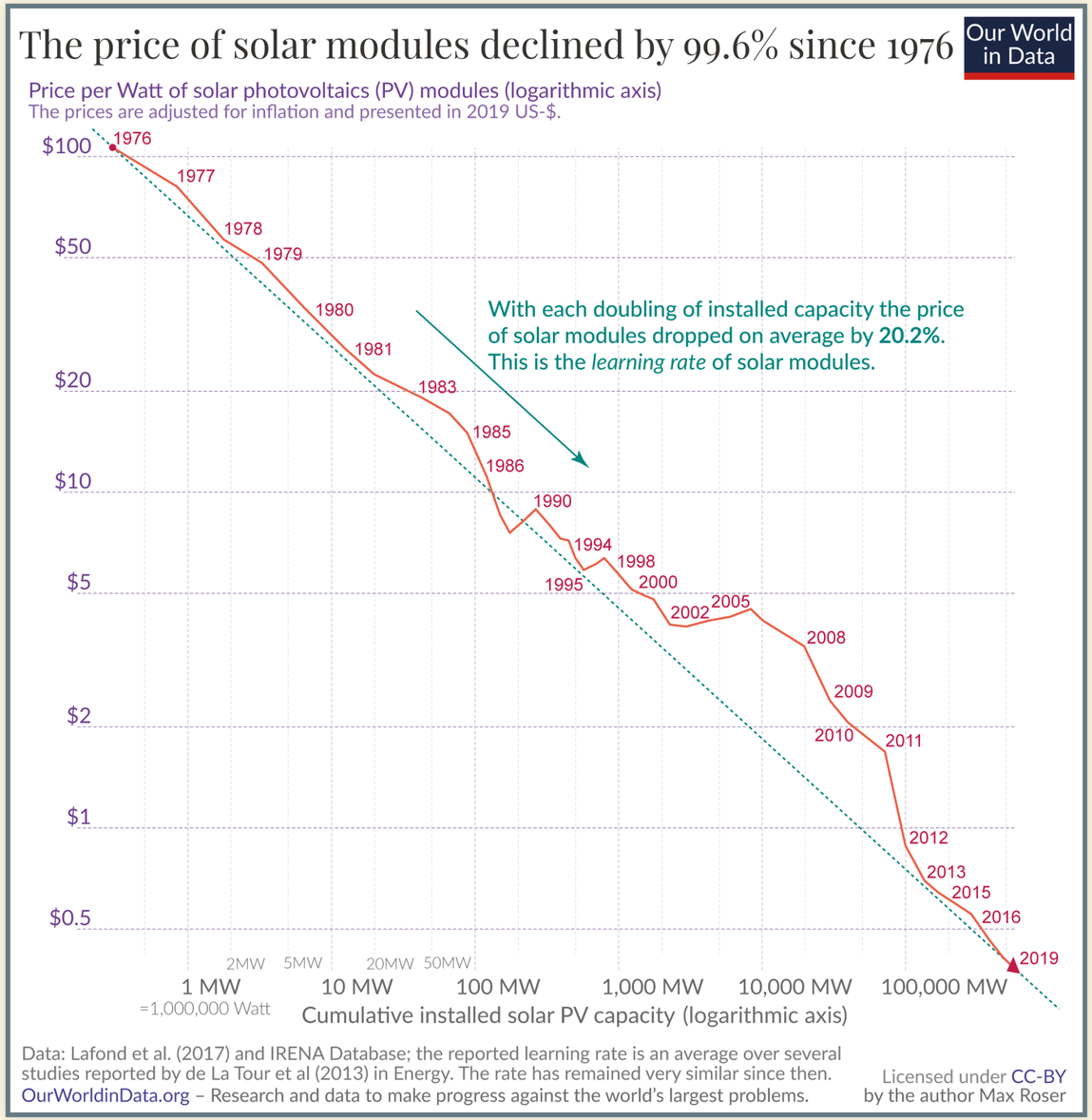
Top-10 Nations for Wind



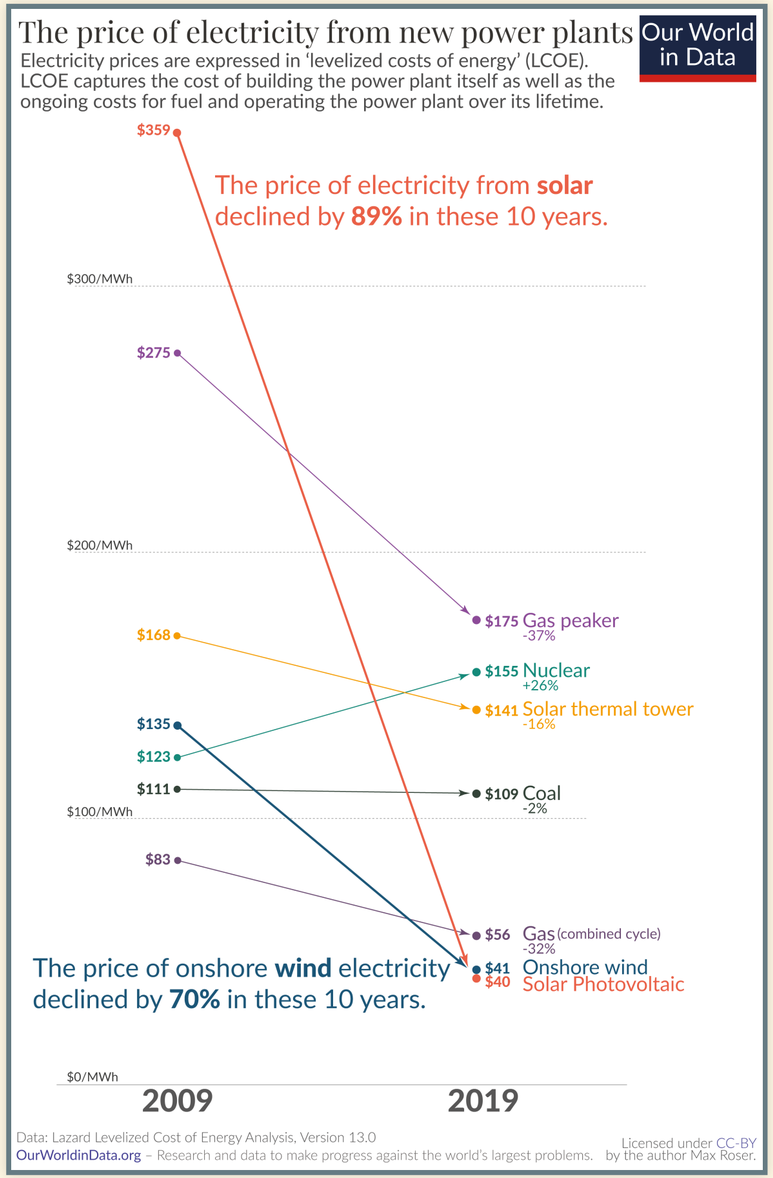
Renewable Energy Parity Network for the 21st Century, *Global Status Report 2020*, http://www.ren21.net/status-of-renewables/global-status-report/

Prospects for Future Renewable Energy

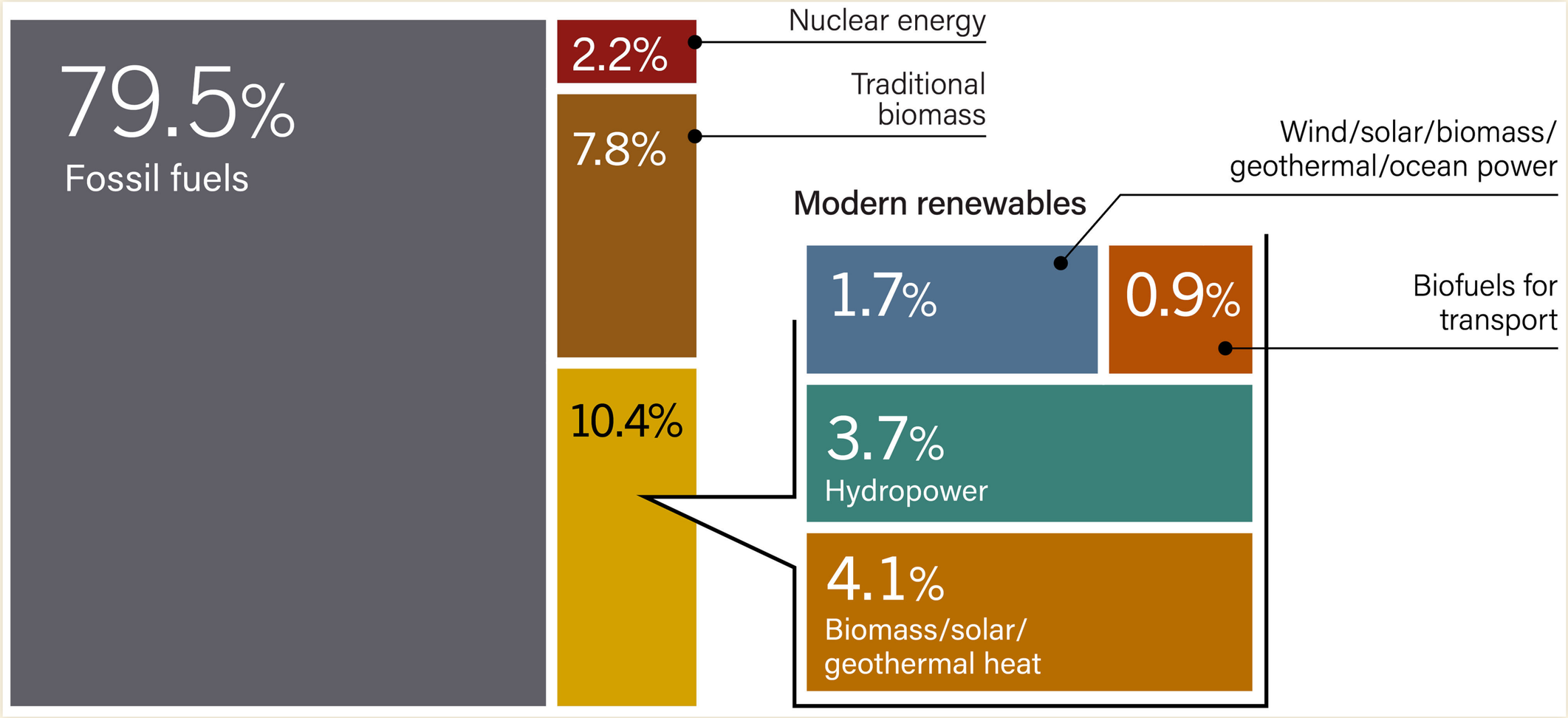
Solar PV


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-$.
$100
$50
$20
$10
$5
$2
$1
$0.5
1976
1977
1978
1979
1980
1981
1983
1985
1986
1990
1994
1998
2000
1995
2002
2005
2008
2009
2010
2011
2012
2013
2015
2016
2019
With each doubling of installed capacity the price of solar modules dropped on average by 20.2%. This is the learning rate of solar modules.
2MW
5MW
20MW
50MW
1 MW
=1,000,000 Watt
10 MW
100 MW
1,000 MW
10,000 MW
100,000 MW
Cumulative installed solar PV capacity (logarithmic axis)
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.
Licensed under CC-BY by the author Max Roser

Cost of Renewable Energy vs. Fossil Fuels

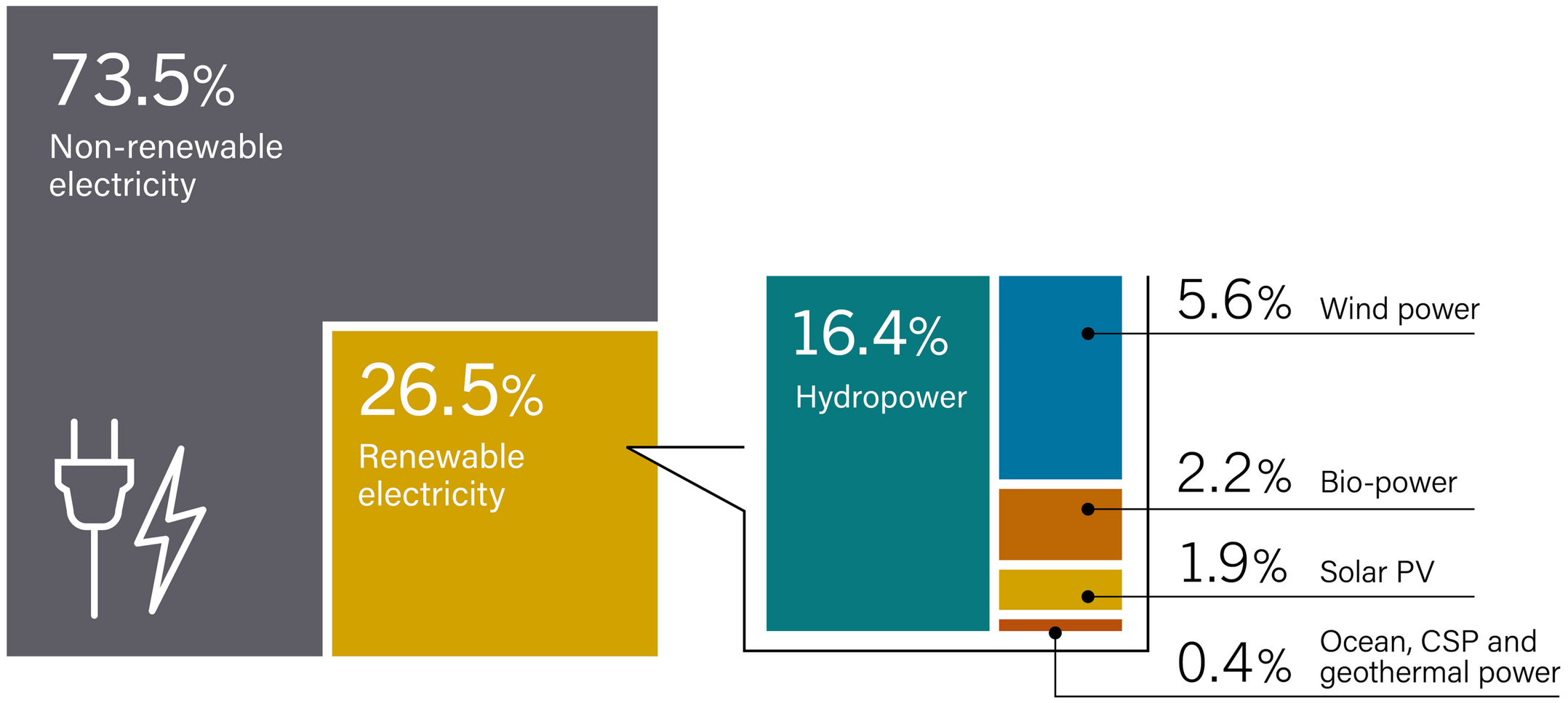


Current World Mix of Energy



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

World Electricity Generation



Renewable Energy Parity 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 $F(2005)$.
- 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)

Implied Decarbonization

- Specify emissions for 2050, compared to 2020
- Assume global GDP G grows at rate r ($5\% \rightarrow r = 0.05$)

$$\text{emissions: } F = Pgef = G \times ef$$

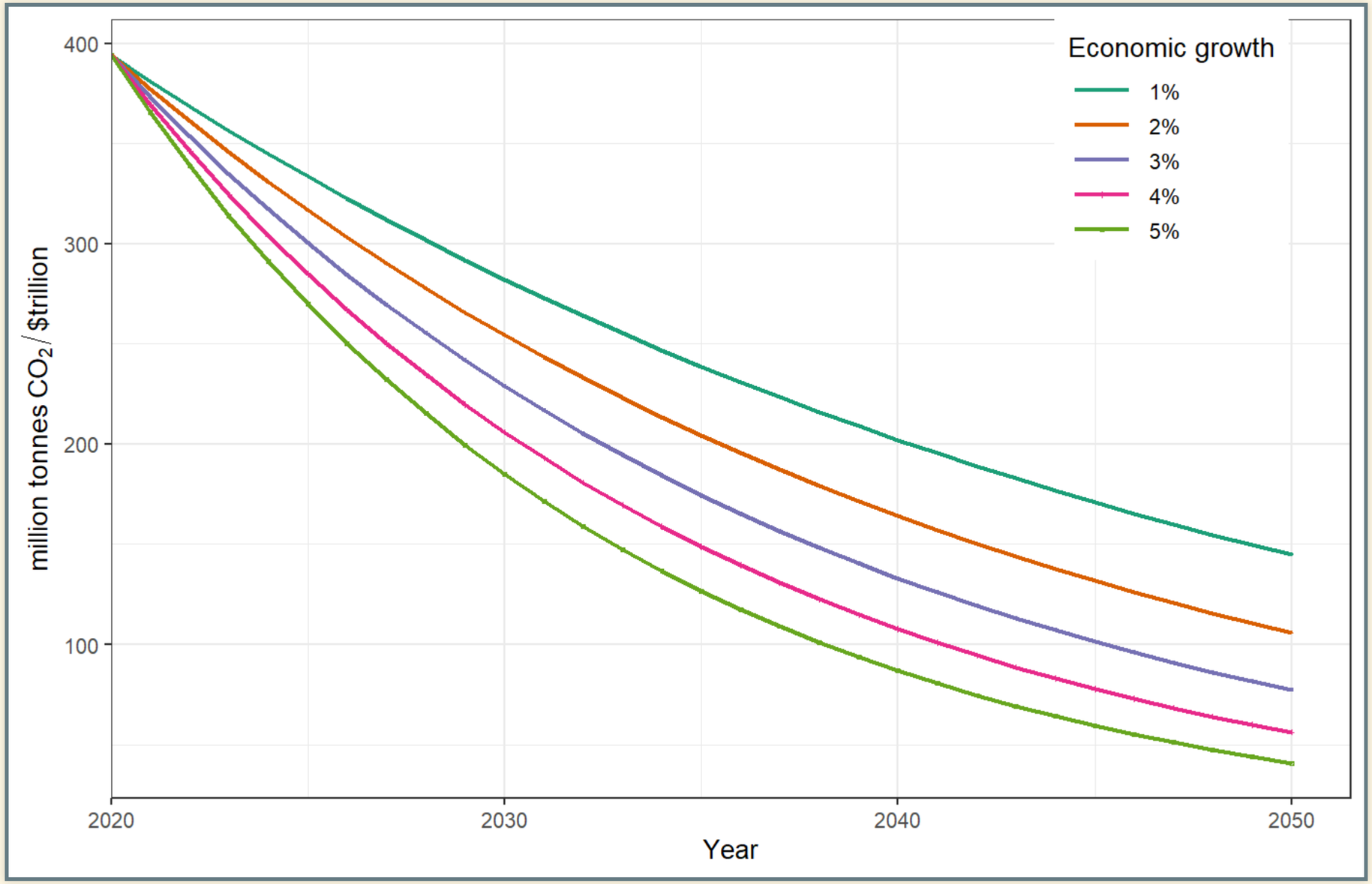
$$F(2050) = G(2050) \times ef(2050)$$

Growth:

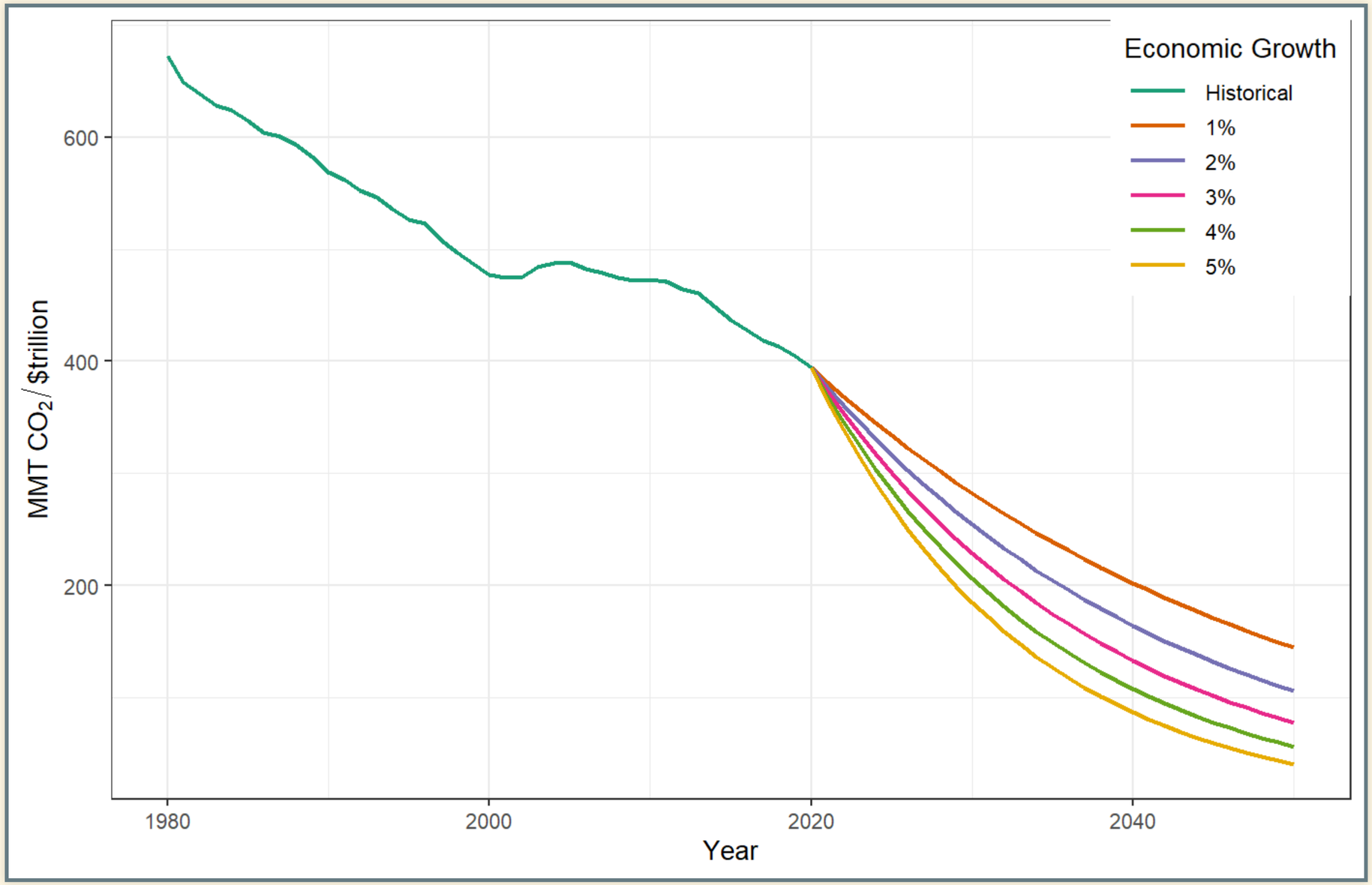
$$y(\text{5 years from now}) = y(\text{today}) \times \exp(r \times 5)$$
$$\approx y(\text{today}) \times (1 + r)^5$$

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

Reduce emissions 50% by 2050:



Actual and Implied Decarbonization



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 if 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).

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

https://ees3310.jgilligan.org/decarbonization

Bottom-Up Analysis

- GDP(2008) = $2.54 trllion
  - Emissions intensity *ef*(2008) = 222 tons per $1000
- Business as usual:
  - If growth follows historical trends
    - Population *P* grows at 0.31%,
    - per-capita GDP *g* grows at 2.44%,
    - GDP grows at 0.31% + 2.44% = 2.75%

$$
\begin{aligned}
GDP(2050) &= GDP(2008) \times \exp(0.0275 \times (2050 - 2008)) \\
&= \$2.54 \text{ trillion} \times \exp(0.0275 \times 42) \\
&= \$8.05 \text{ trillion}
\end{aligned}
$$

Bottom-Up Analysis

- F(2008) = 562 million tons CO_2.
- F(1990) = 600 million tons CO_2.
- Goal: Emissions in 2050 are 80% less than in 1990:
  - $F(2050) = 0.20\ F(1990) = 0.20 \times 600\ \text{MMT} = 120\ \text{MMT}$
  - Implied growth rate of F:

$$\begin{aligned} r_F &= \ln(F(2050)/F(2008))/42\ \text{years} \\ &= \ln(120/562)/42 \\ &= -3.67\%. \end{aligned}$$

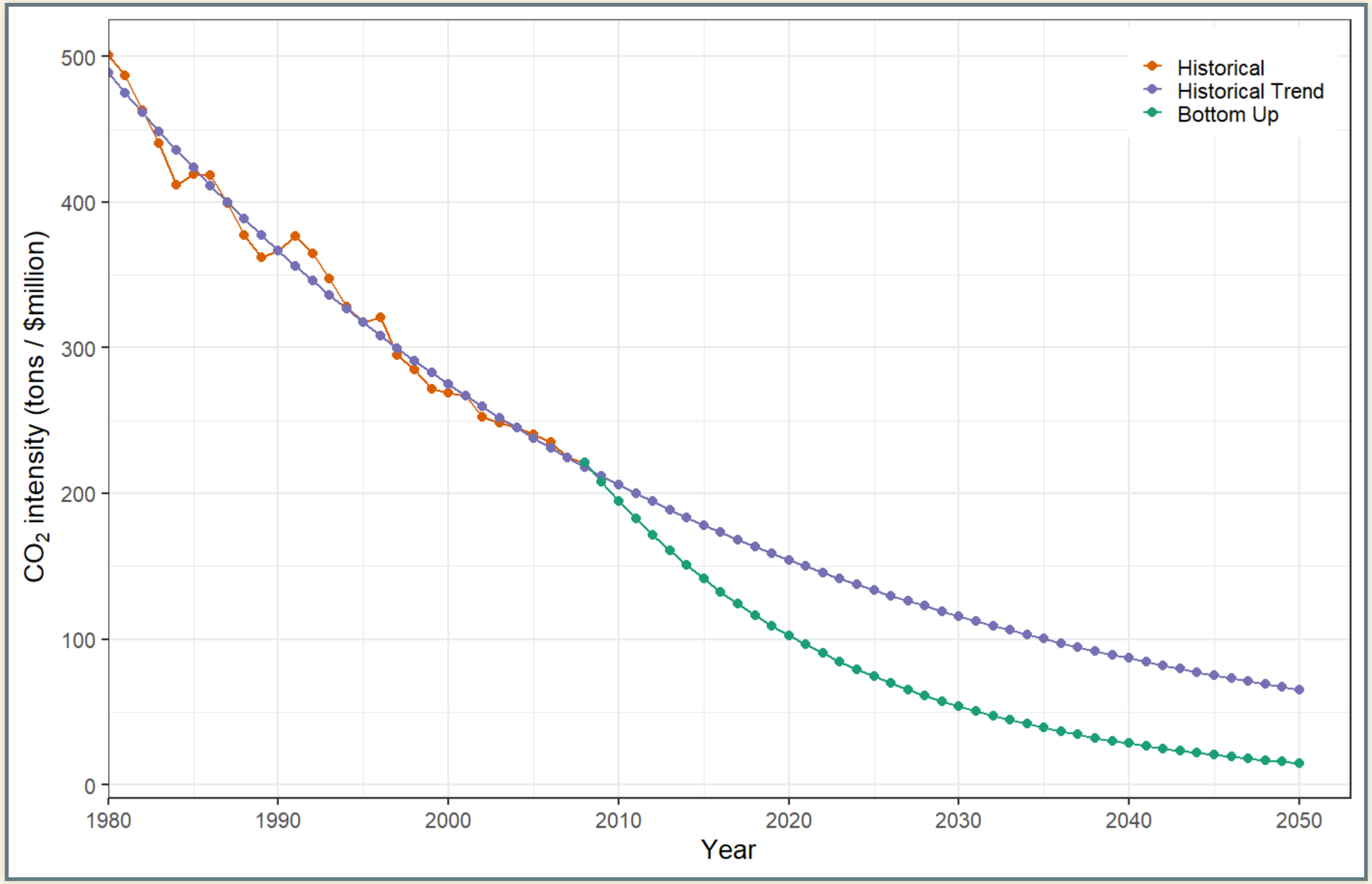
Implied decarbonization rates:

- GDP ($P \times g$) grows at 2.75%
- Implied growth rate of F: $r_F = -3.67\%$.
- Implied growth rate of ef (carbon intensity of the economy):
  - $F = Pgef$, so
  - $r_F = r_{Pg} + r_{ef} = r_G + r_{ef}$

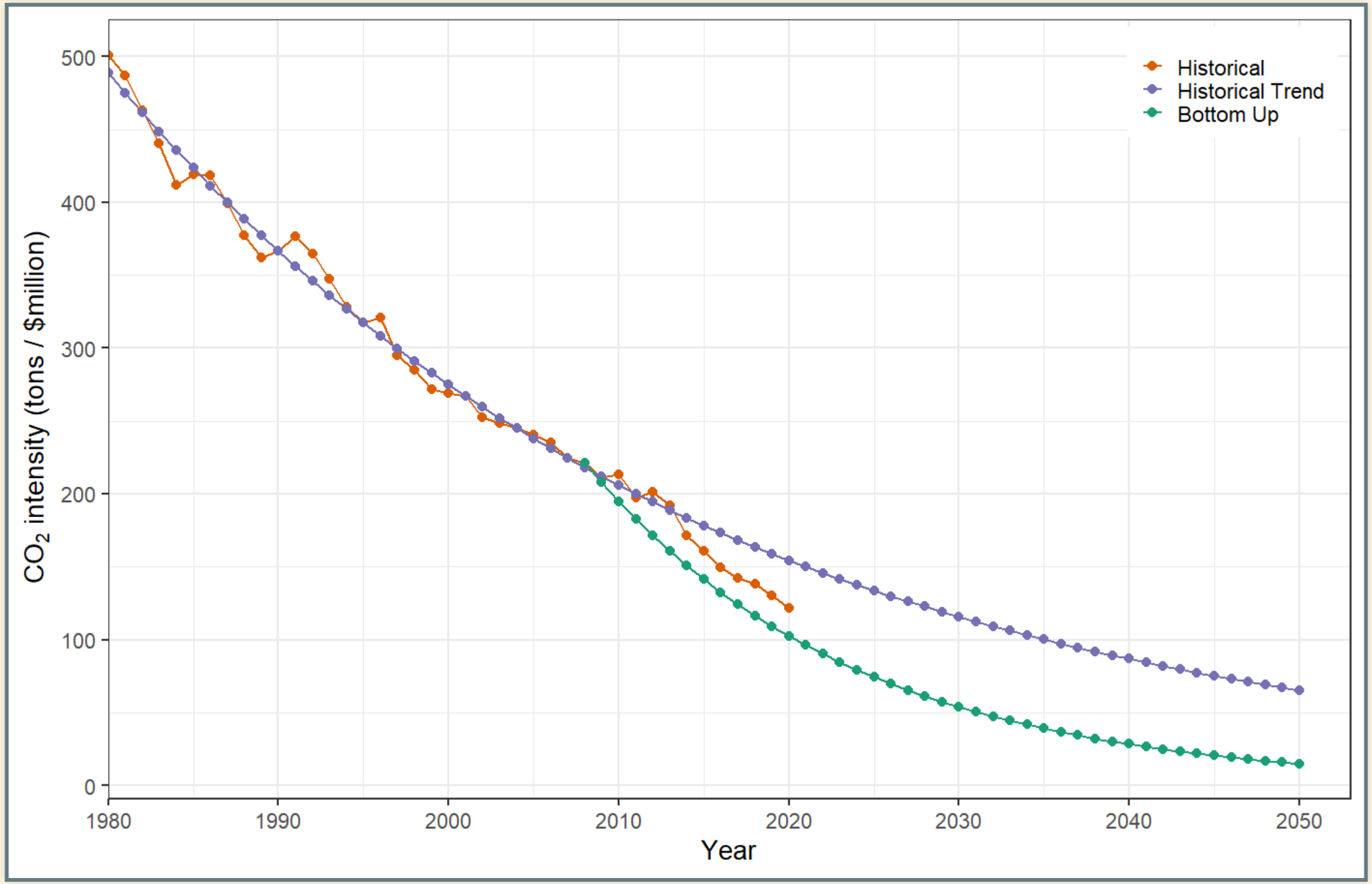
$$\begin{aligned} r_{ef} &= r_F - r_G \\ &= -3.67\% - 2.75\% \\ &= -6.42\% \end{aligned}$$

- The implied $r_{ef} = -6.42\%$
- The historical $r_{ef} = -2.88\%$
- To meet the goal, the UK would have to decarbonize 2.2 times faster than it did for the previous several decades.
- However, since 2010, decarbonization has accelerated!

Implied decarbonization for UK



Progress since 2008



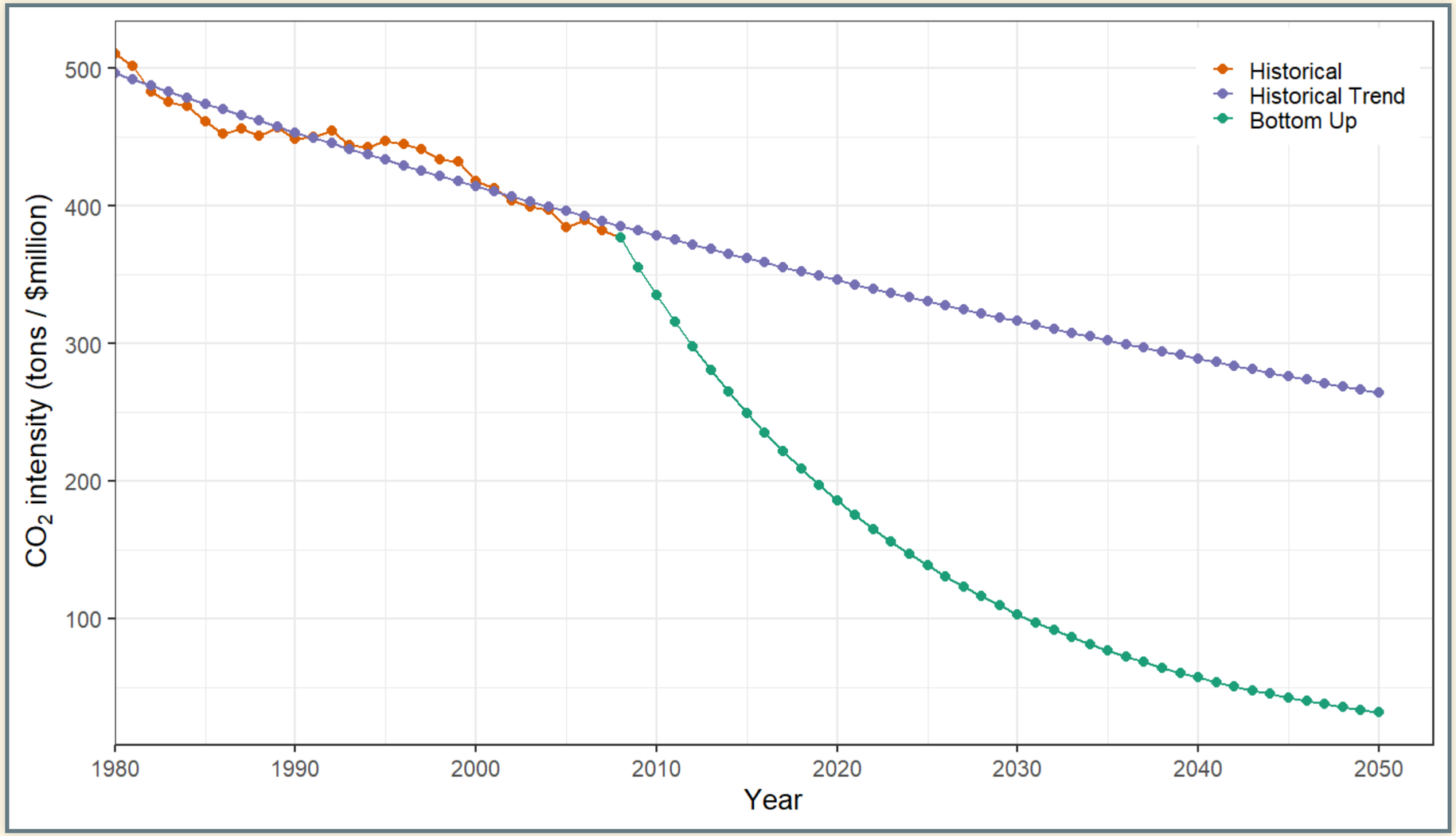
Implied Decarbonization for Australia

Australia's Emissions Trading Scheme

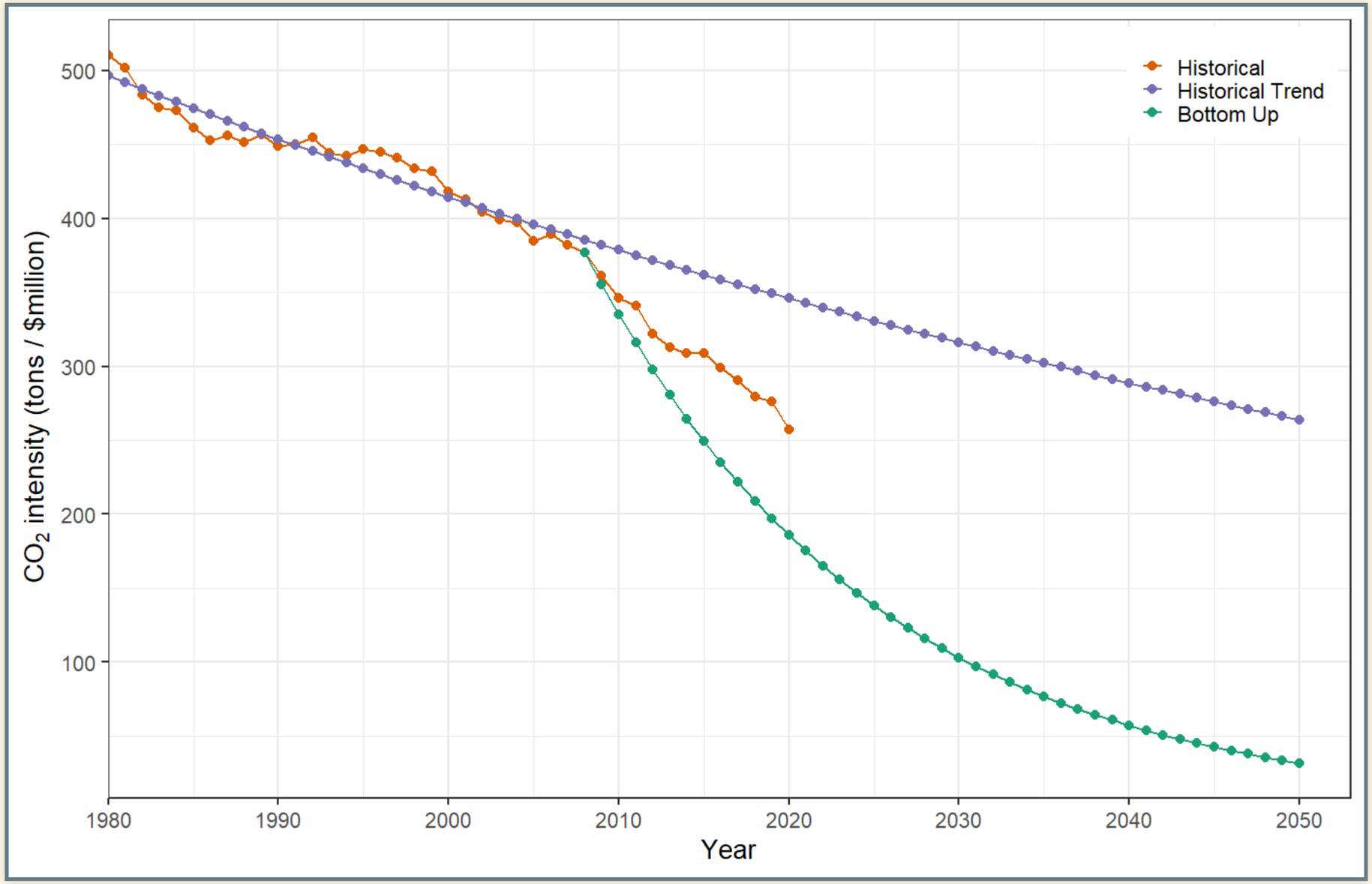
- PM Kevin Rudd calls for cutting emissions 60% below 2000 levels by 2050
- $F(2050) = 0.40\ F(2000) = 0.40 \times 355\ \text{MMT} = 142\ \text{MMT}$

Implied Decarbonization for Australia

- Historical decarbonization rate: $r_{ef} = -0.90\%$
- Implied decarbonization rate: $r_{ef} = -5.90\%$

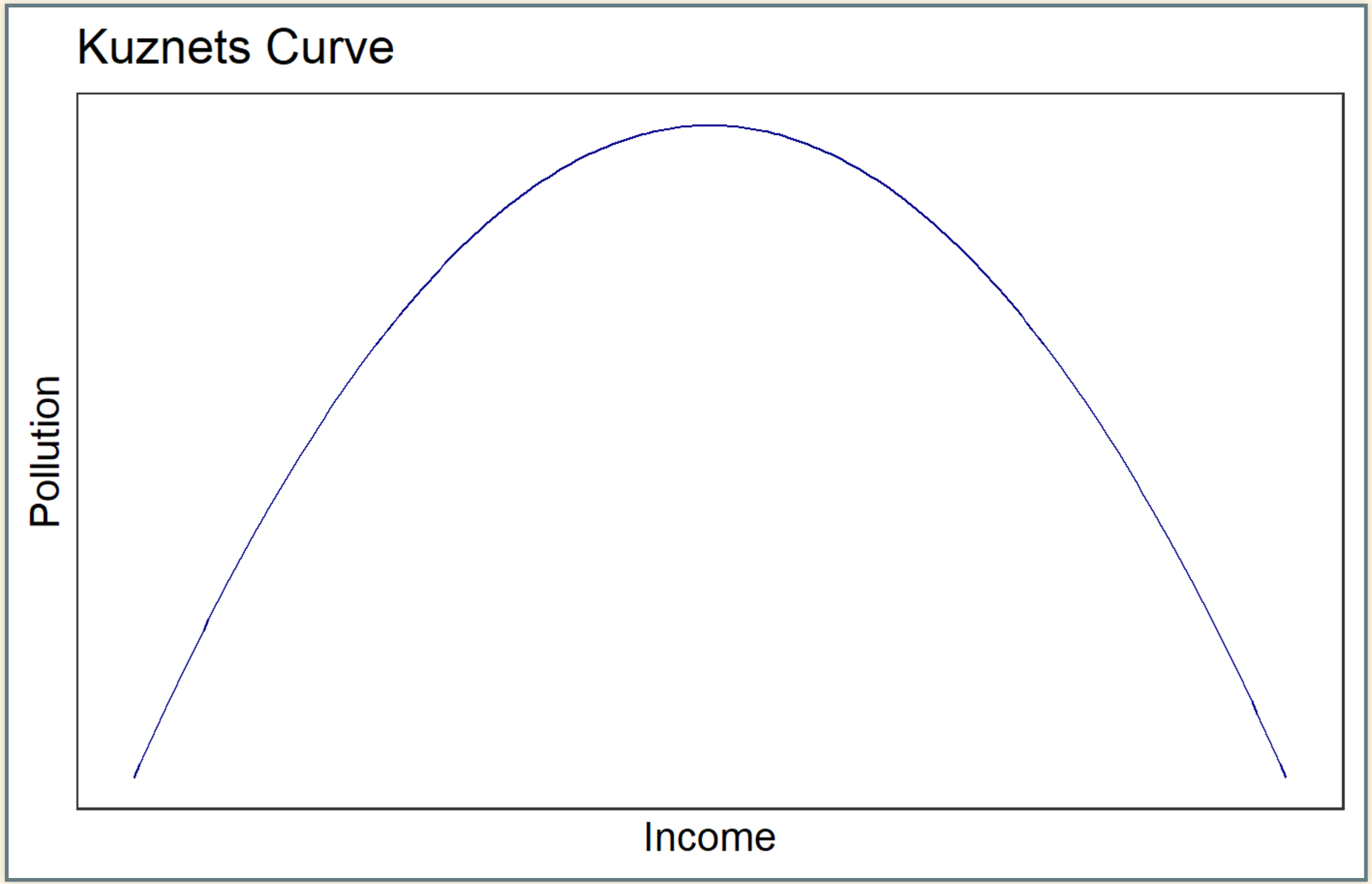


Progress since 2008



Other Considerations

Kuznets curve



Concluding Remarks

- 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?