Reducing Carbon Emissions: Bottom-Up Approaches

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #26: Wednesday March 18 2020

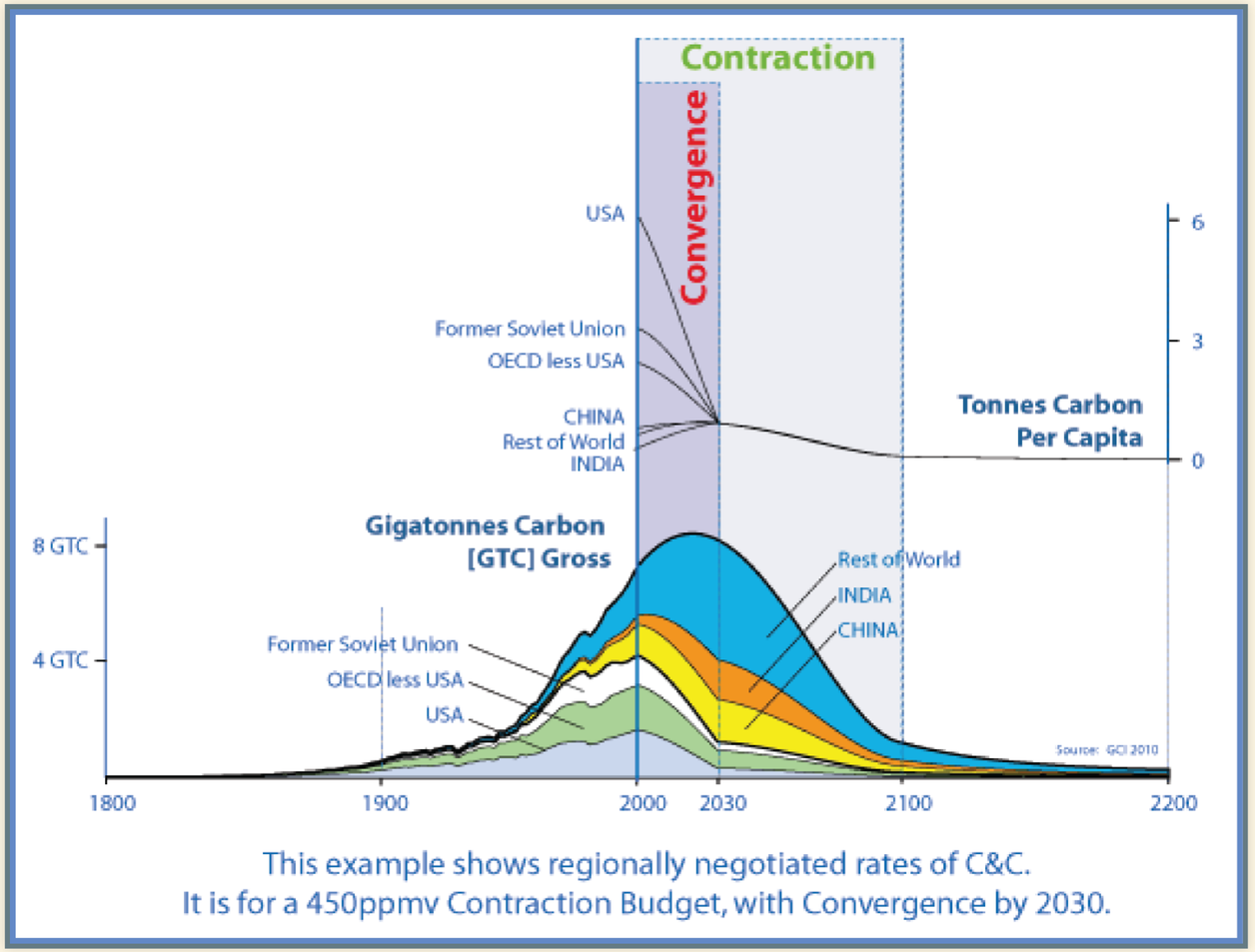
Announcements

Announcements

- Revised lab project assignment posted
  - Choices:
    1. Record and upload a video presentation
       - 5–10 minutes per person
    2. Write a “press release” describing your project to the general public.
       - 1–2 pages, double-spaced
  - Both choices are due March 30
  - Details posted on Piazza and class web site.
- Labs for the rest of the semester:
  - Use Kaya Identity to analyze decarbonization policies.
  - Zoom lab session on Monday
  - Revised assignment will be posted later this week for you to read.

Challenges of Decarbonizing

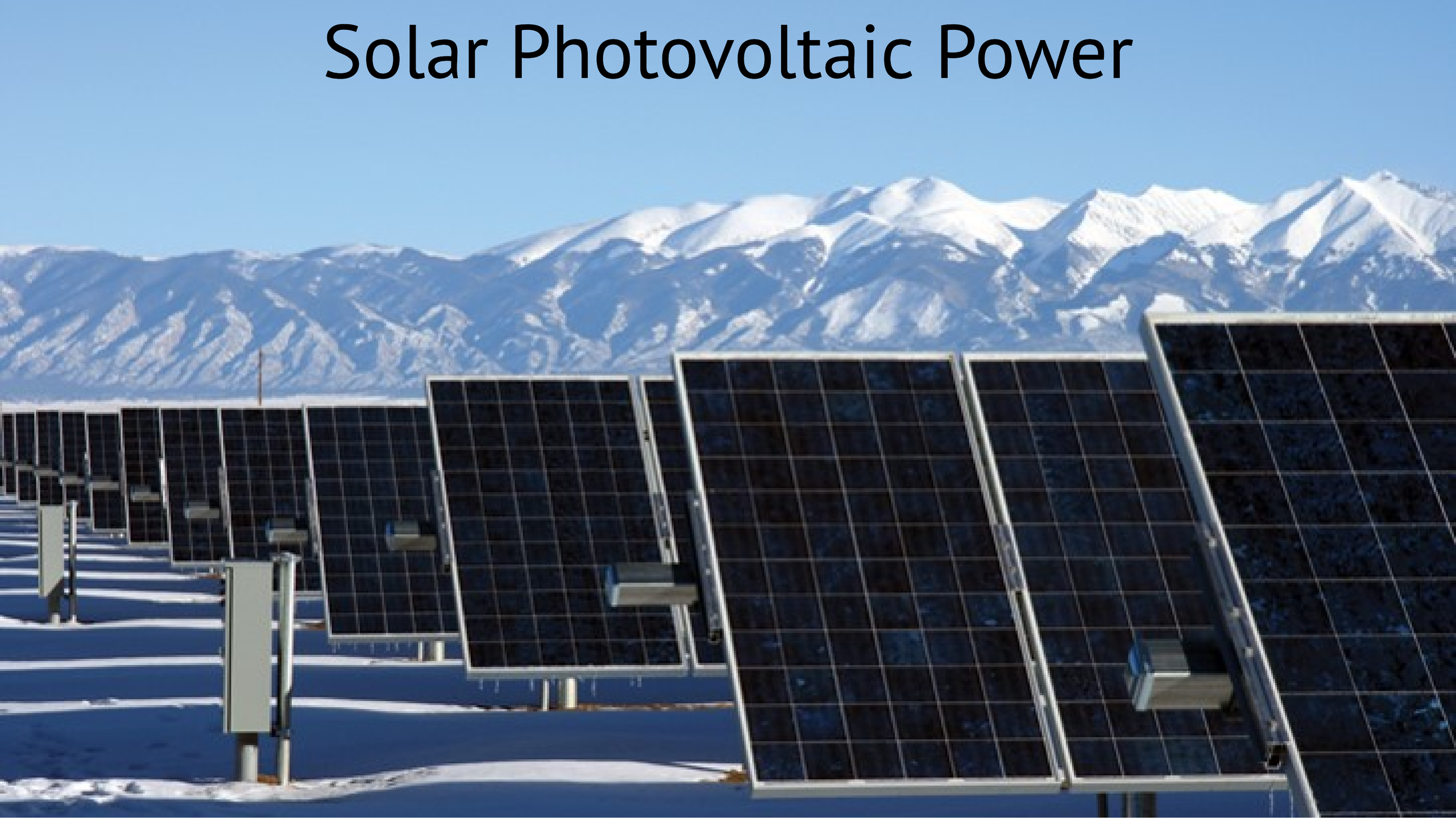
Scale of Problem: 450 ppm target



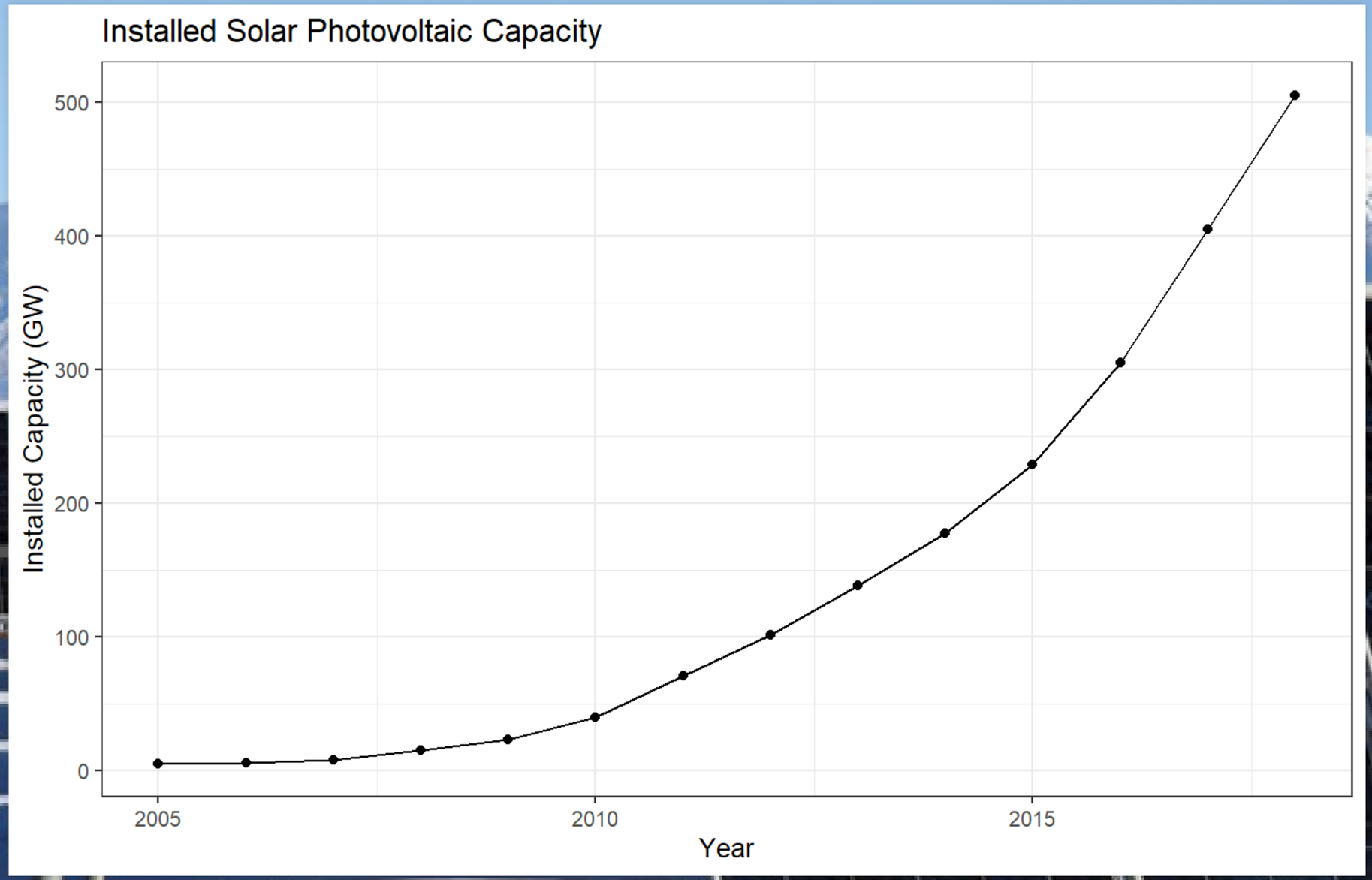
Pielke’s Policy Criteria

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

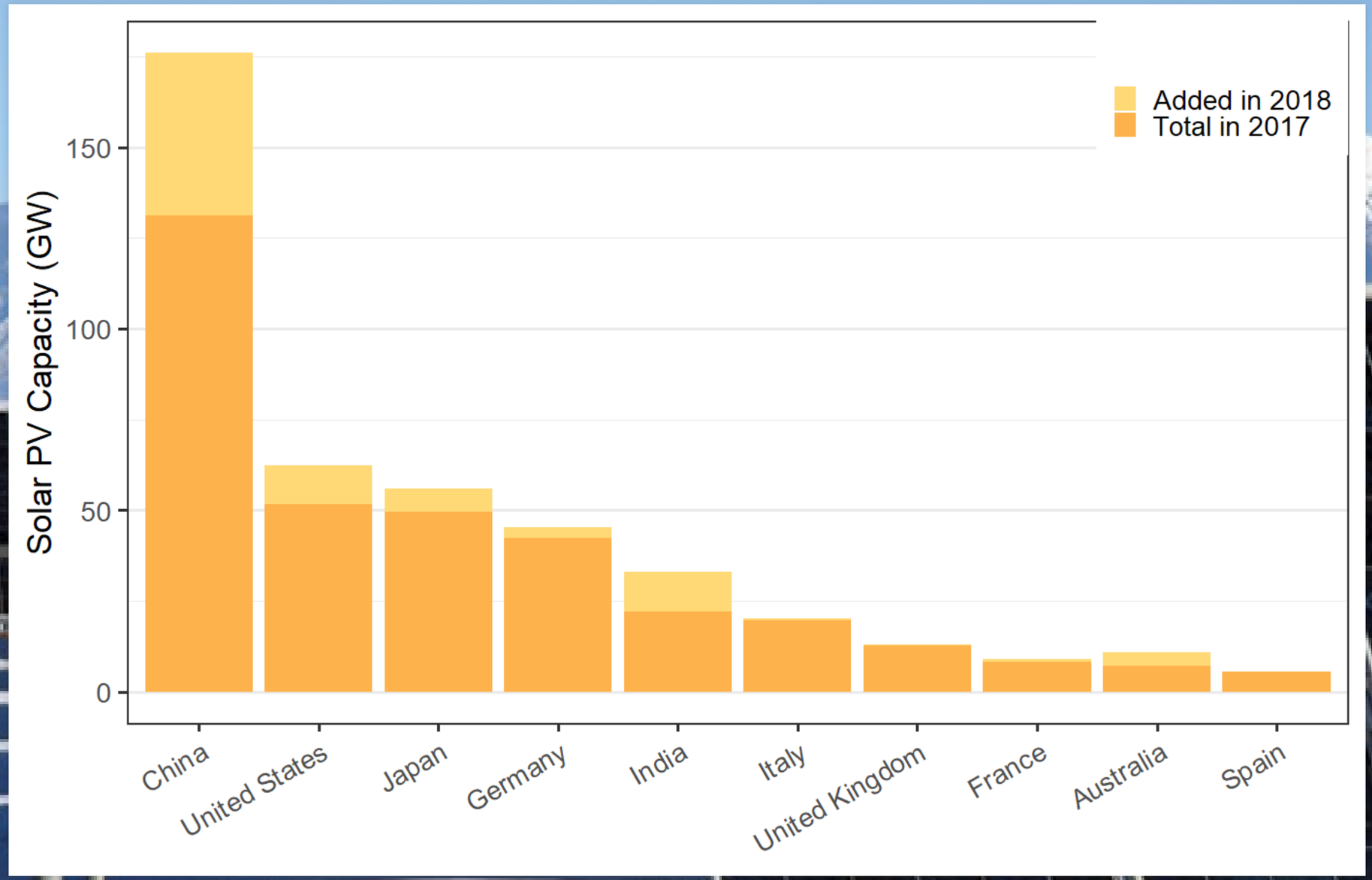


Solar Energy over Time



Renewable Energy Parity Network for the 21st Century, *Global Status Report 2019* http://www.ren21.net/status-of-renewables/global-status-report/

Top-10 Nations for Solar PV



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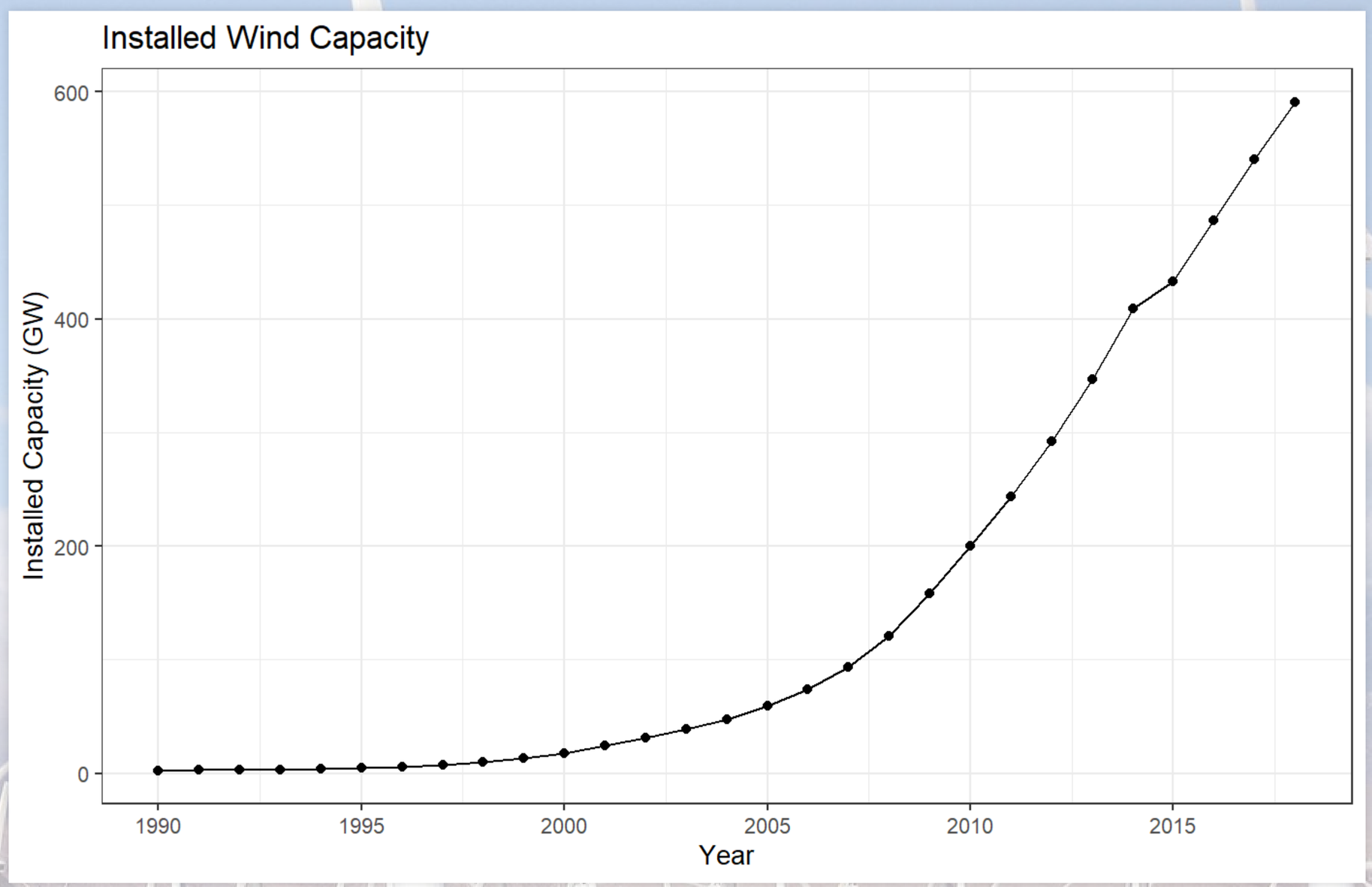
Wind Power

Wind Energy over Time



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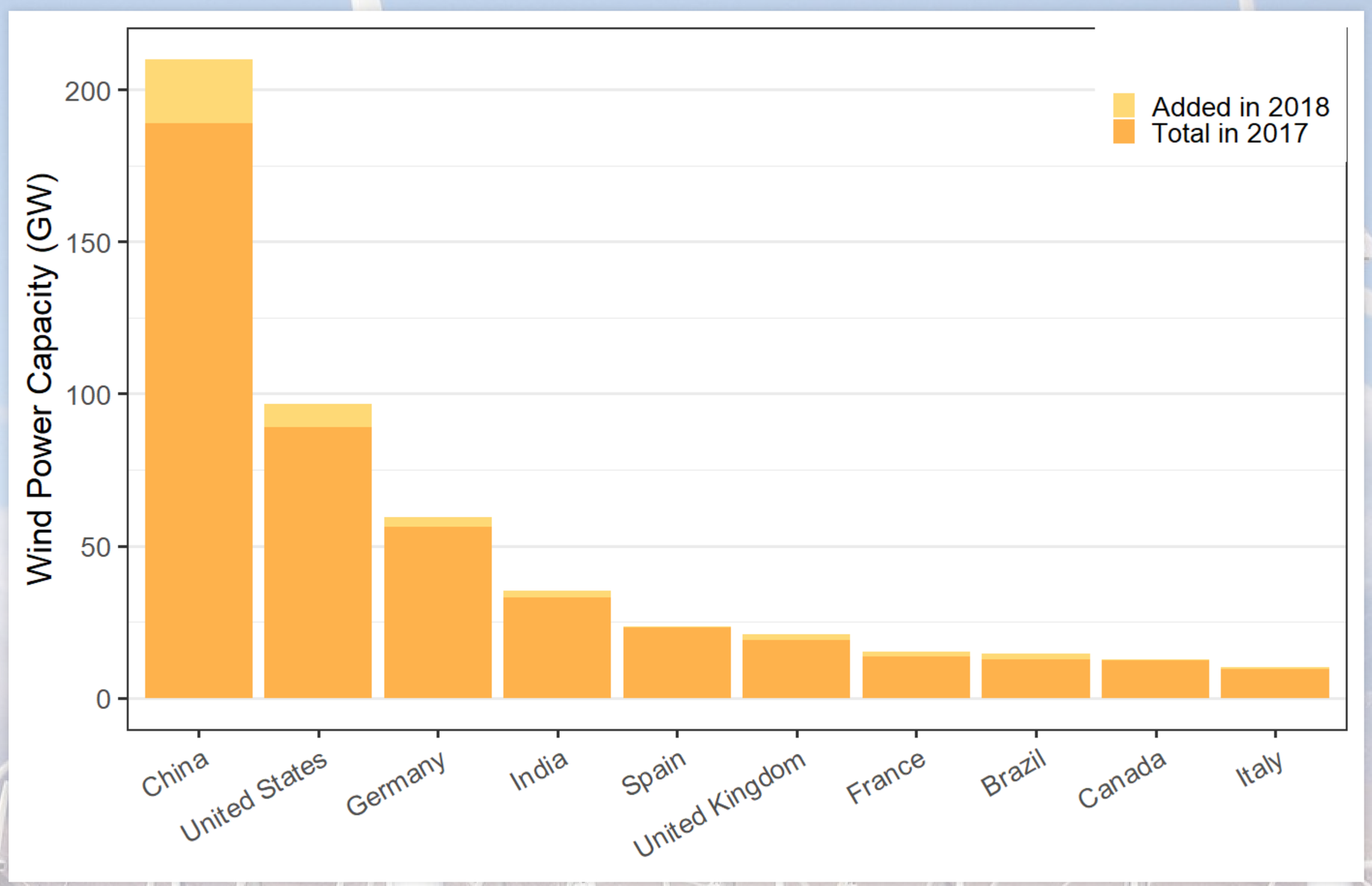
Top-10 Nations for Wind



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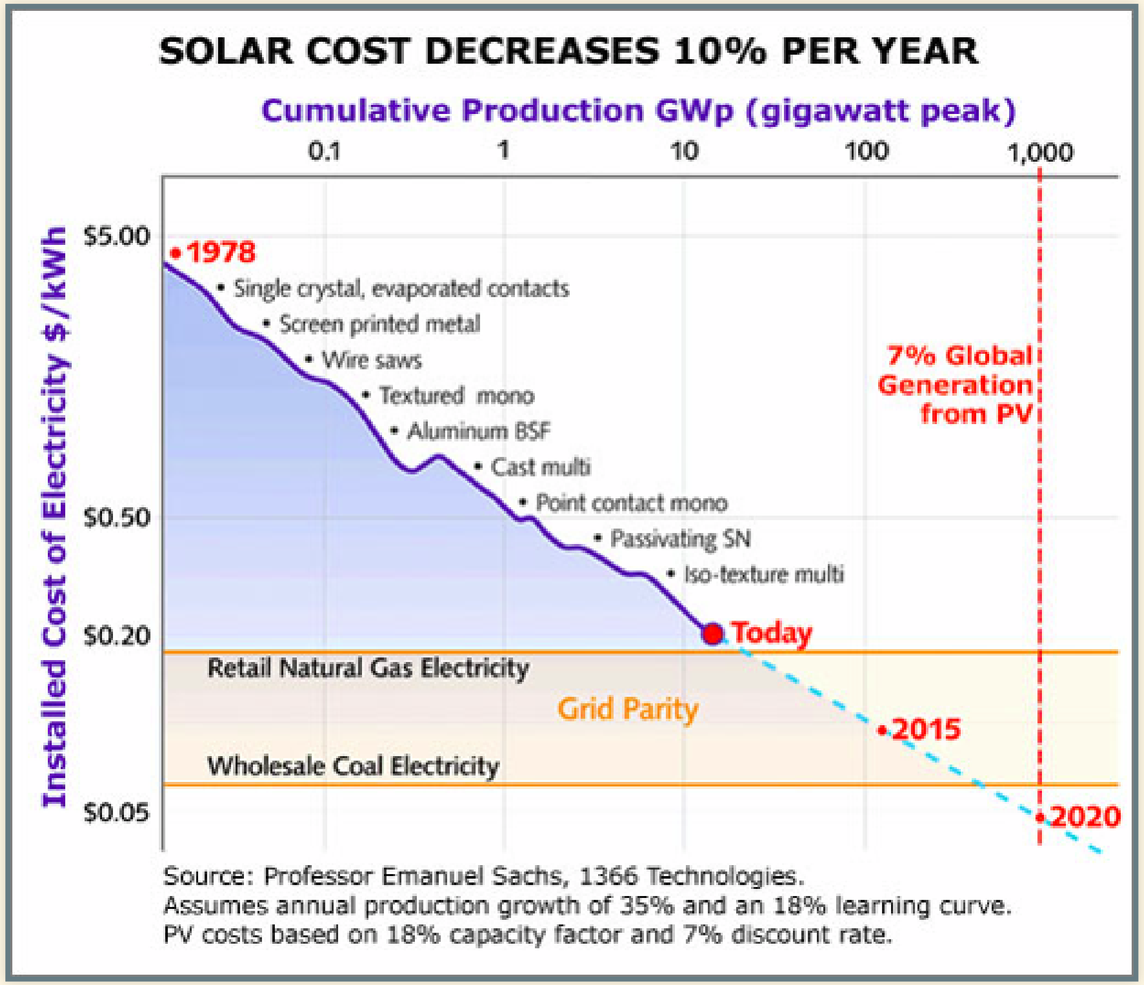
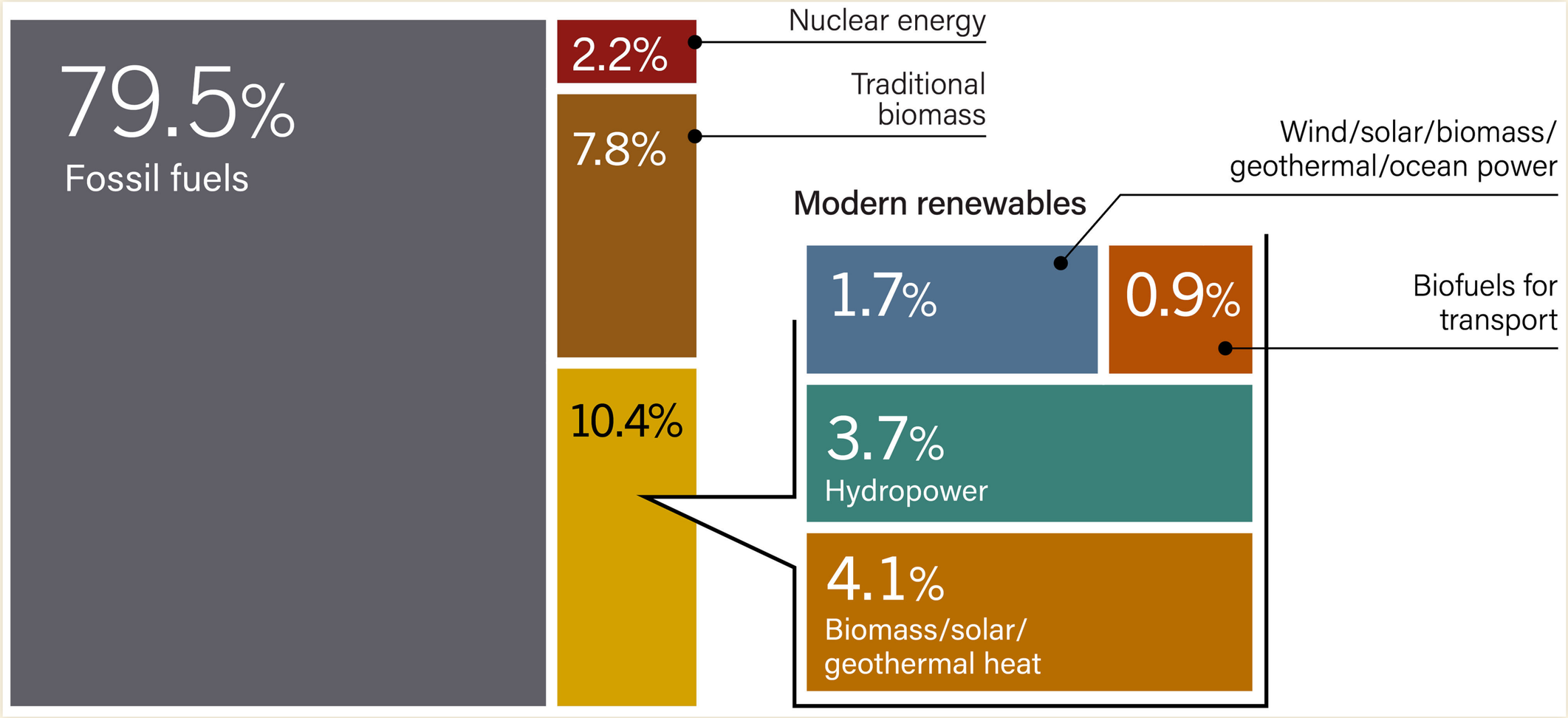
Prospects for Future Renewable Energy

Solar PV


SOLAR COST DECREASES 10% PER YEAR
Cumulative Production GWp (gigawatt peak)
0.1
1
10
100
1,000
Installed Cost of Electricity $/kWh
$5.00
$0.50
$0.20
$0.05
1978
Single crystal, evaporated contacts
Screen printed metal
Wire saws
Textured mono
Aluminum BSF
Cast multi
Point contact mono
Passivating SN
Iso-texture multi
Today
7% Global Generation from PV
Retail Natural Gas Electricity
Grid Parity
2015
Wholesale Coal Electricity
2020
Source: Professor Emanuel Sachs, 1366 Technologies.
Assumes annual production growth of 35% and an 18% learning curve.
PV costs based on 18% capacity factor and 7% discount rate.

Current World Mix of Energy



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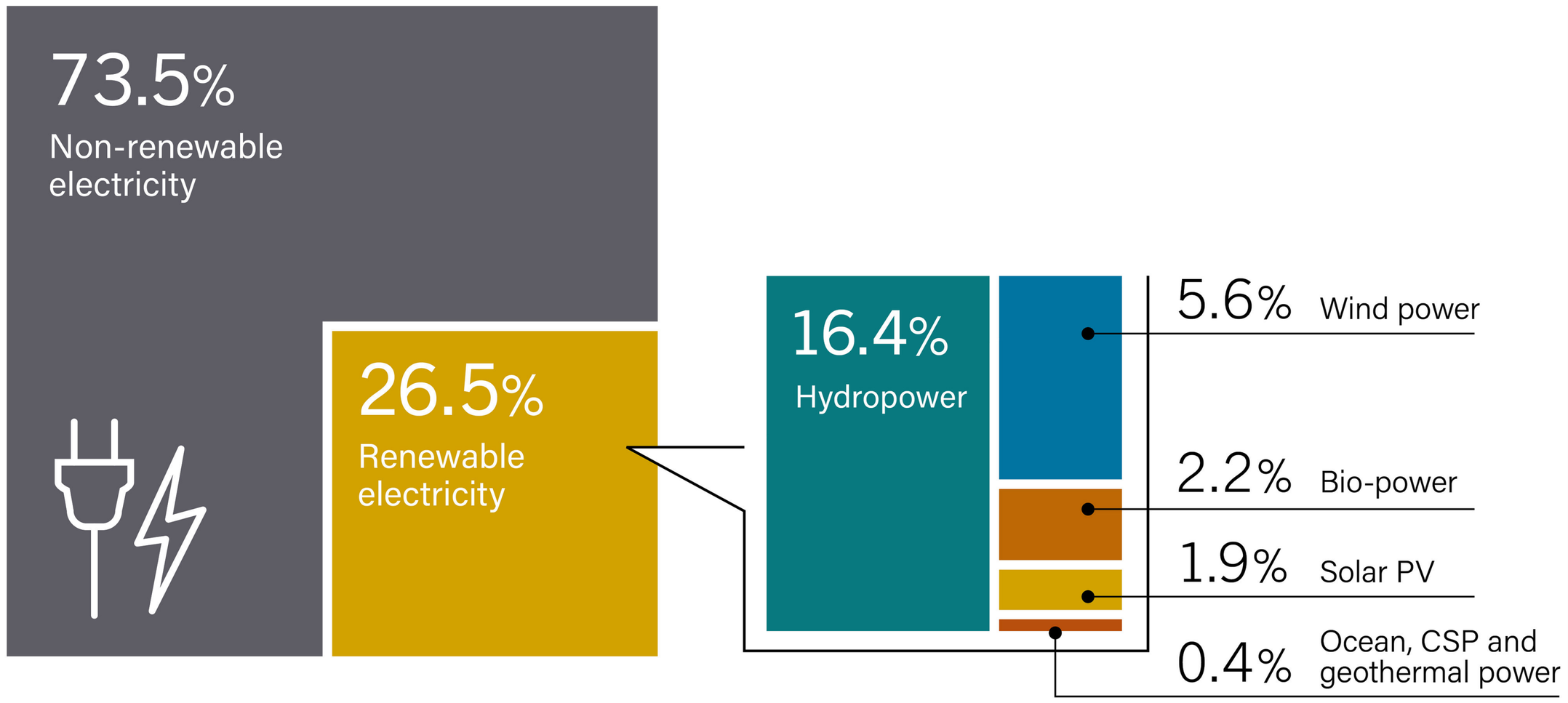
World Electricity Generation



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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.

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).

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

World

Target year

2050

Emissions reduction (%)

80

Reference year for emissions reduction

1990

Calculate trends starting in

1980

Policy goal: 2050 emissions 80% below 1990

Decarbonization Analysis

	Rate of Change	Current (2018)	Projected (2050)
P (billion)	1.40%	7.59	11.9
g ($1000 per person)	1.52%	10.9	17.7
e (quad per $trillion)	-0.89%	6.67	5.02
f (MMT per quad)	-0.21%	61.6	57.6
ef (metric ton per $ million)	-1.10%	411	289
G (trillion dollars)	2.92%	82.5	210
E (quad)	2.03%	550	1,053
F (MMT CO2)	1.82%	33,891	60,701

1990 emissions = 21,290 MMT CO2

2050 target: 80% below 1990 = 4,258 MMT

Trends | Calculations | Implied Decarbonization | Energy Mix | Historical

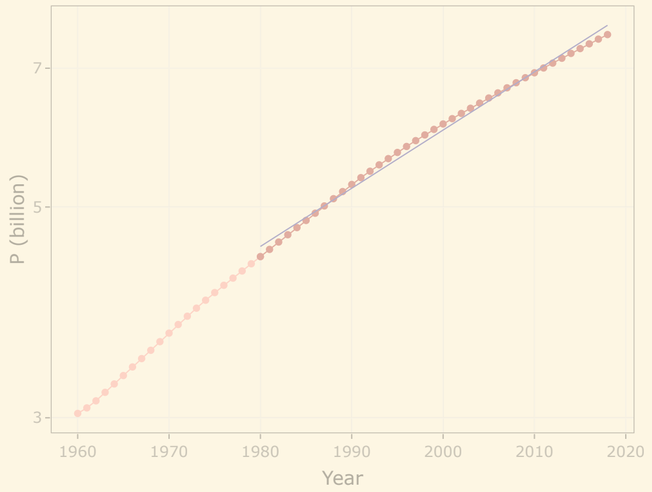
Historical Trends for

Variable

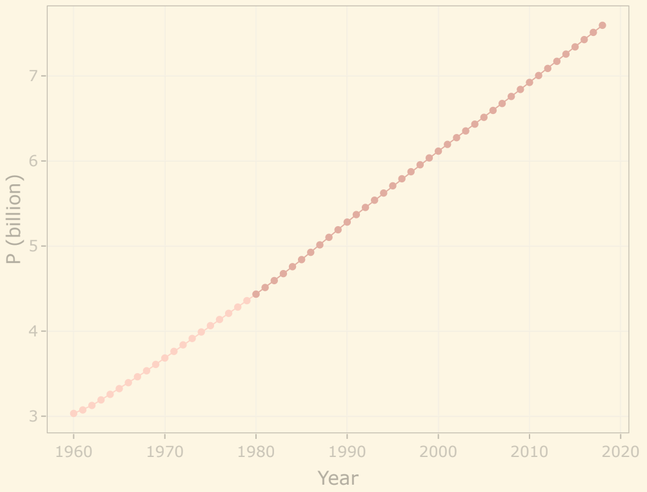
P

Population (billion people): Rate of change of P = 1.40% per year
Calculated from the slope of ln(P) starting in 1980

ln(Population)



Population



Bottom-Up Analysis

- GDP(2018) = $2.88 billion
  - Emissions intensity *ef*(2018) = 137 tons per $1000
- Business as usual:
  - If growth follows historical trends
    - Population *P* grows at 0.44%,
    - per-capita GDP *g* grows at 1.92%,
    - GDP grows at 0.44% + 1.92% = 2.37%

$$
\begin{aligned}
GDP(2050) &= GDP(2018) \times \exp(0.0237 \times (2050 - 2018)) \\
&= \$2.88 \text{ trillion} \times \exp(0.0237 \times 32) \\
&= \$6.14 \text{ trillion}
\end{aligned}
$$

Bottom-Up Analysis

- F(2018) = 394 million tons CO_2.
- F(1990) = 593 million tons CO_2.
- Goal: Emissions in 2050 are 80% less than in 1990:
  - $F(2050) = 0.20\ F(1990) = 0.20 \times 593\ \text{MMT} = 119\ \text{MMT}$
  - Implied growth rate of F:

$$\begin{aligned} r_F &= \ln(F(2050)/F(2018))/32\ \text{years} \\ &= \ln(119/394)/32 \\ &= -3.75\%. \end{aligned}$$

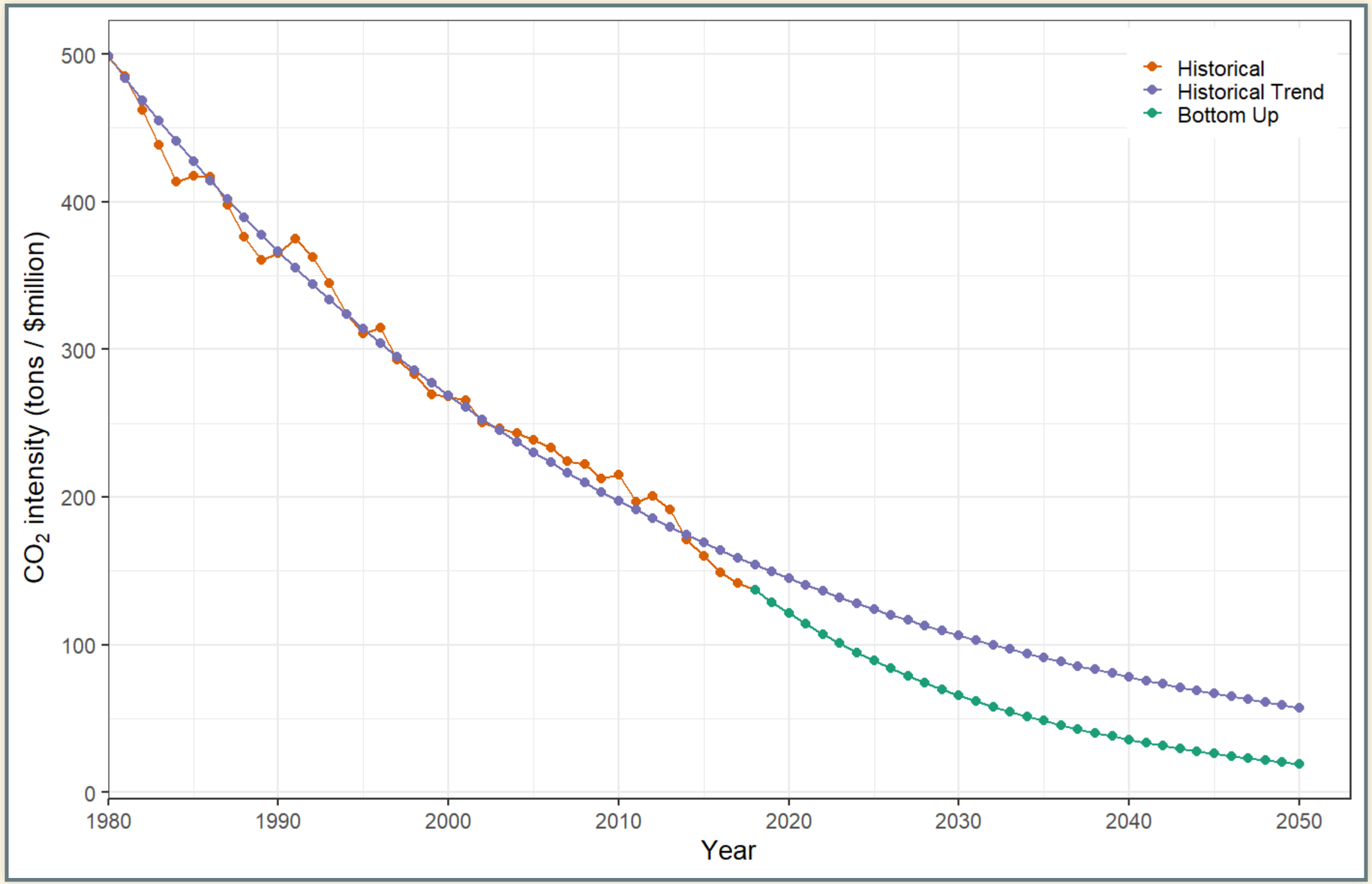
Implied decarbonization rates:

- GDP ($P \times g$) grows at 2.37%
- Implied growth rate of F: $r_F = -3.75\%$.
- Implied growth rate of ef (carbon intensity of the economy):
  - $F = Pgef$, so
  - $r_F = r_{Pg} + r_{ef} = r_G + r_{ef}$

$$\begin{aligned} r_{ef} &= r_F - r_G \\ &= -3.75\% - 2.37\% \\ &= -6.12\% \end{aligned}$$

- The implied $r_{ef} = -6.12\%$
- The historical $r_{ef} = -3.09\%$
- To meet the goal, the UK would have to decarbonize 2.0 times faster than it did for the previous several decades.
- However, since 2010, decarbonization has accelerated!

Implied decarbonization for UK



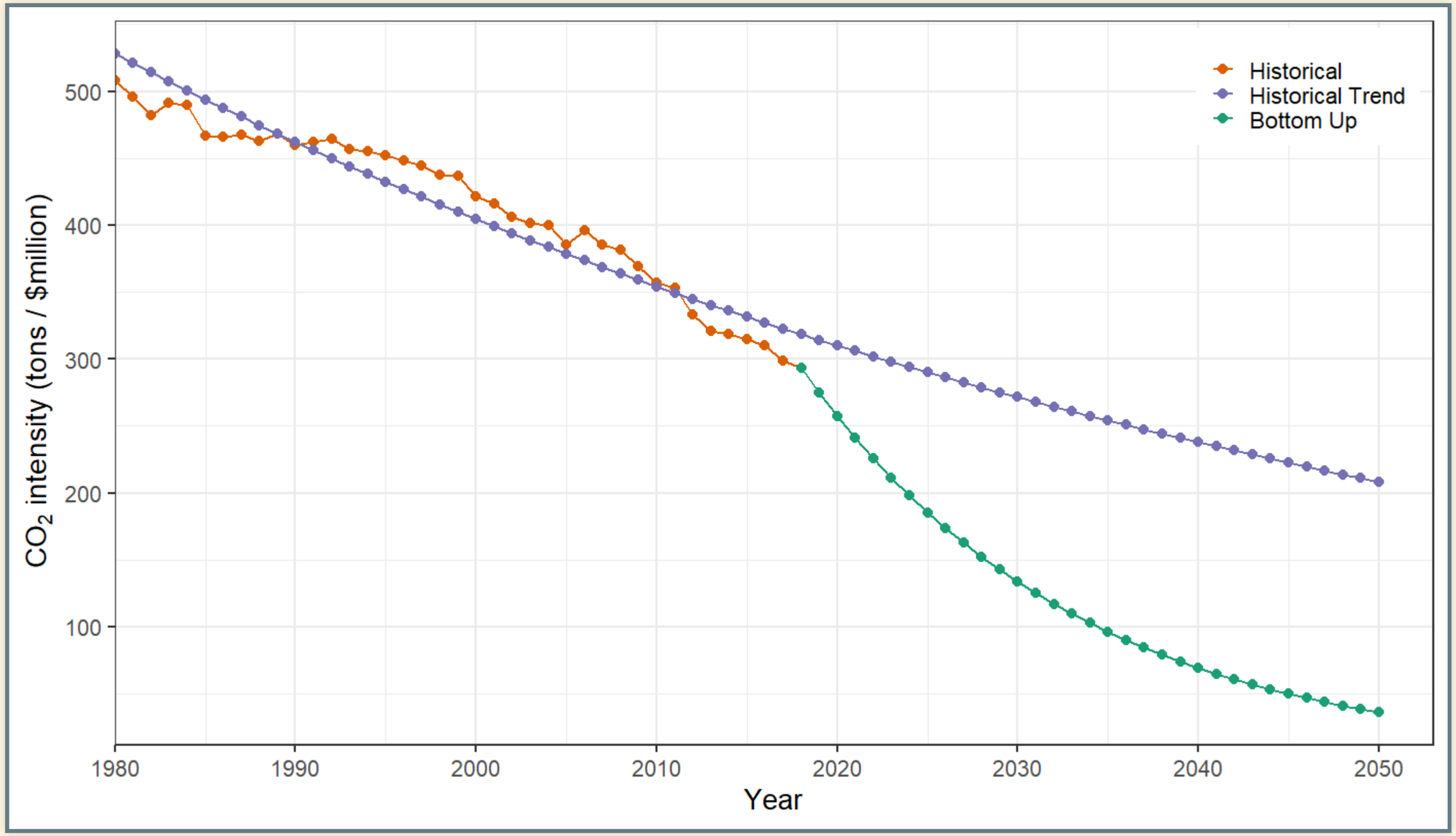
Implied Decarbonization for Australia

Australia's Emissions Trading Scheme

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

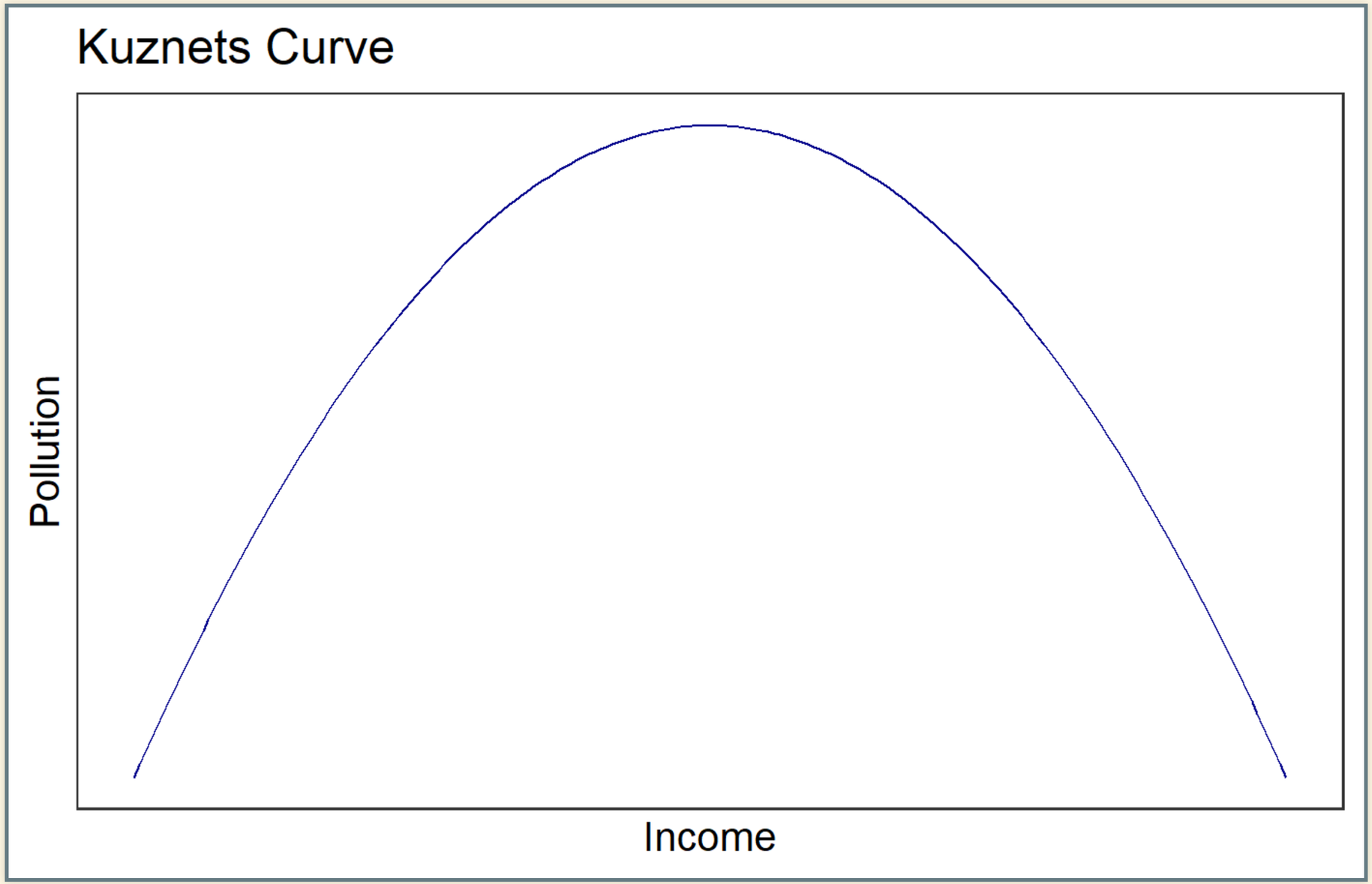
Implied Decarbonization for Australia

- Historical decarbonization rate: $r_{ef} = -1.33\%$
- Implied decarbonization rate: $r_{ef} = -6.56\%$



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?