Reducing Carbon Emissions: Bottom-Up Approaches

EES 3310/5310

Global Climate Change

Jonathan Gilligan

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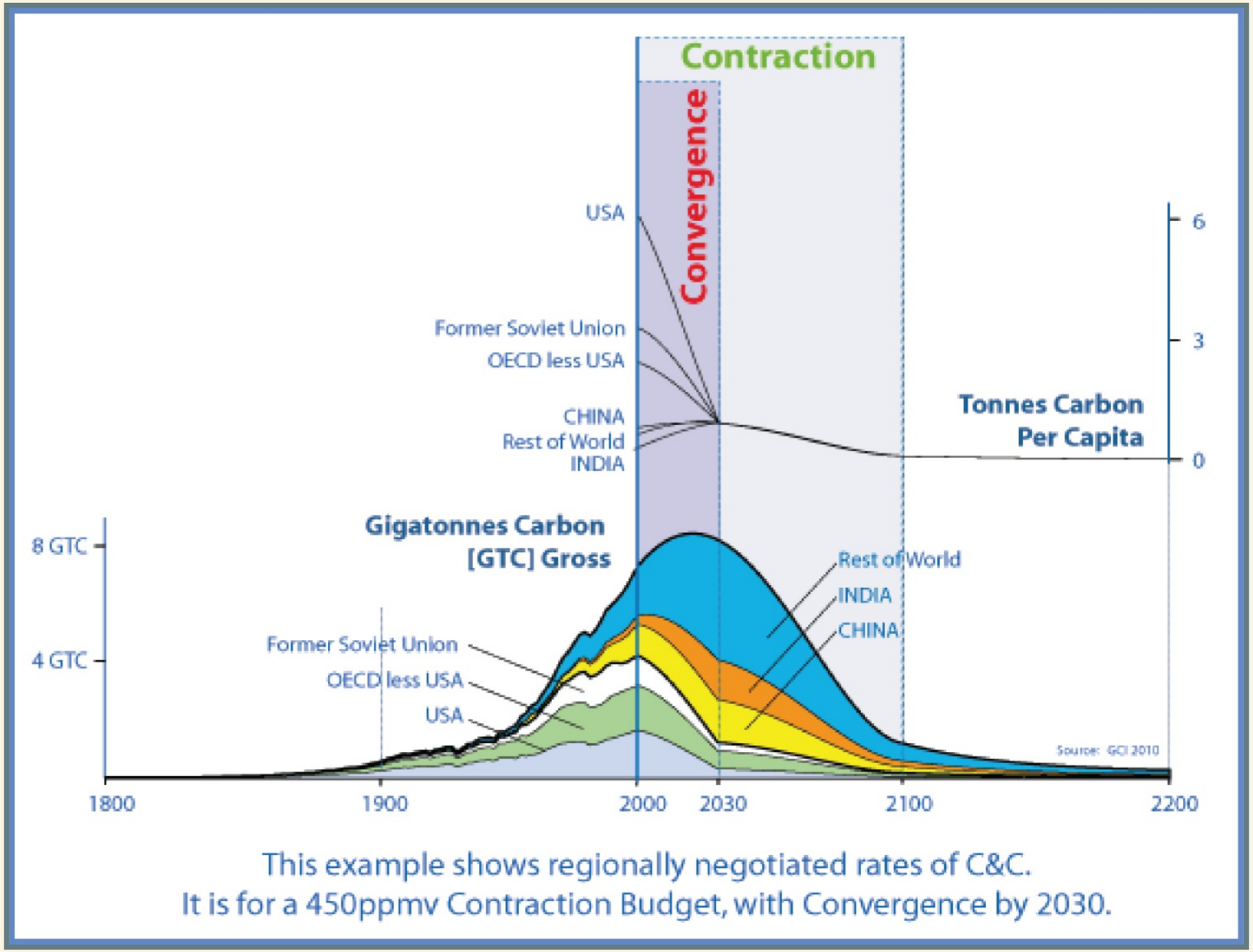
Scale of Problem:
450 ppm target

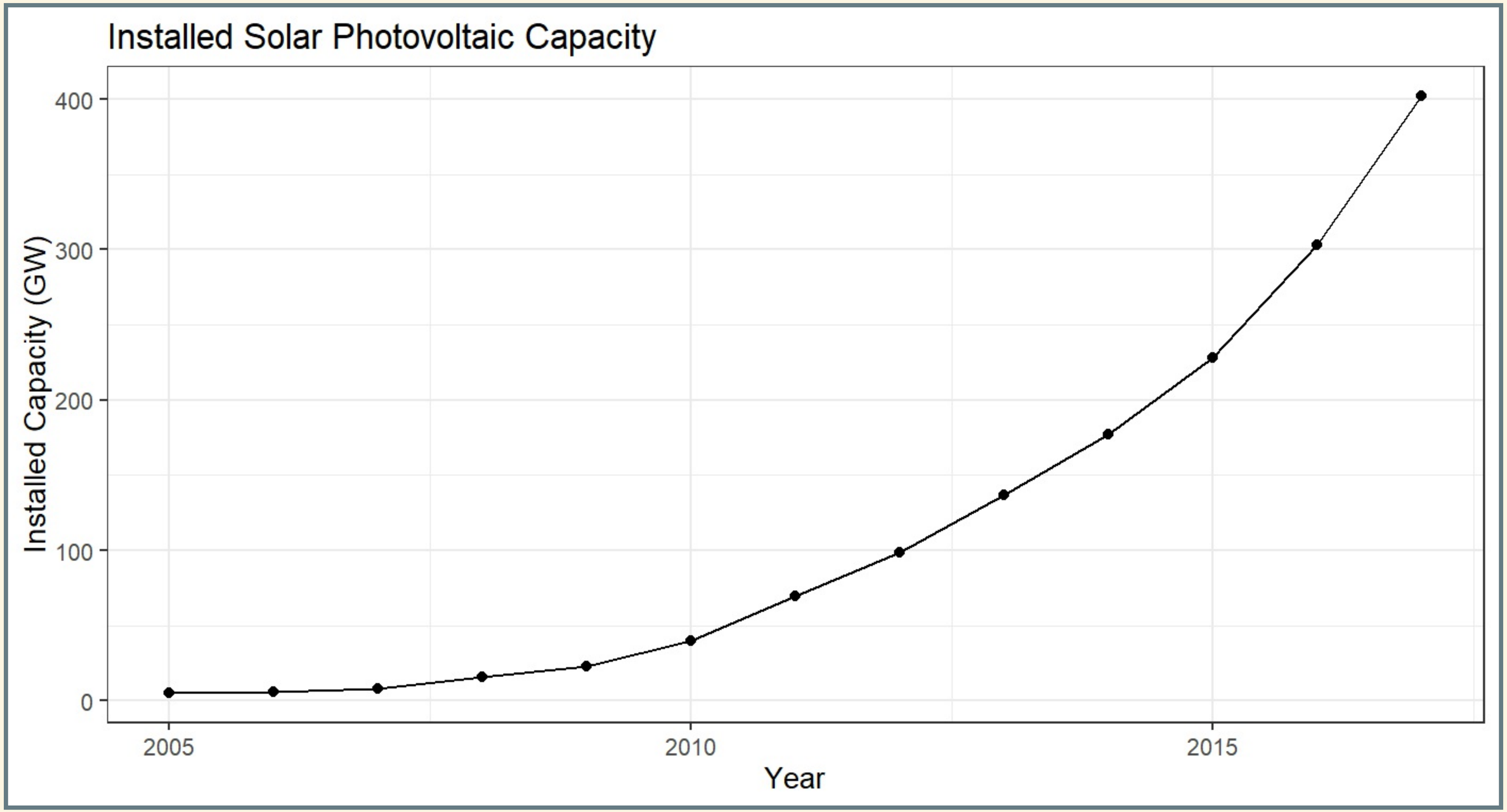


This example shows regionally negotiated rates of C&C.
It is for a 450ppmv Contraction Budget, with Convergence by 2030.

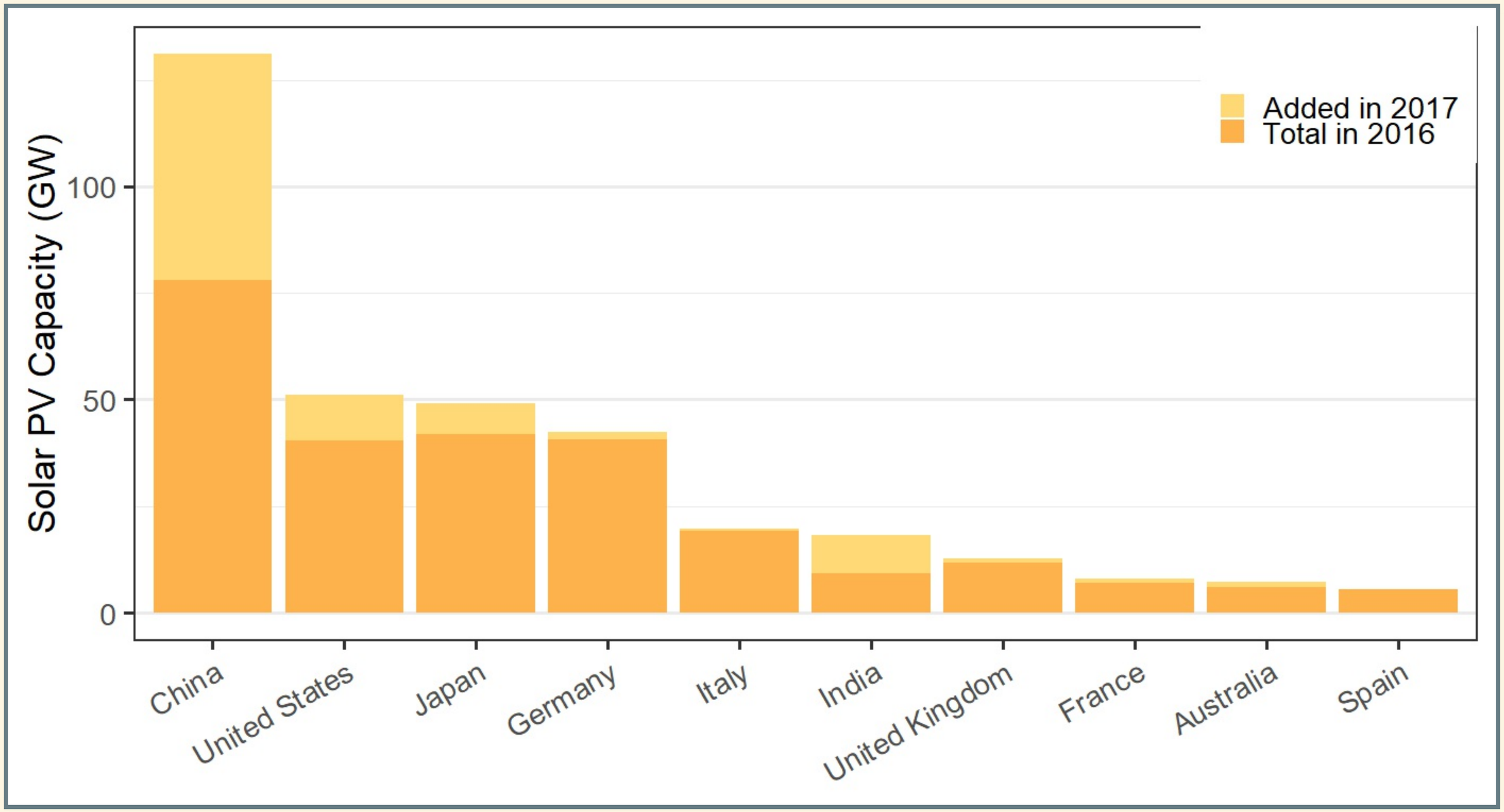
Pielke's Policy Criteria

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

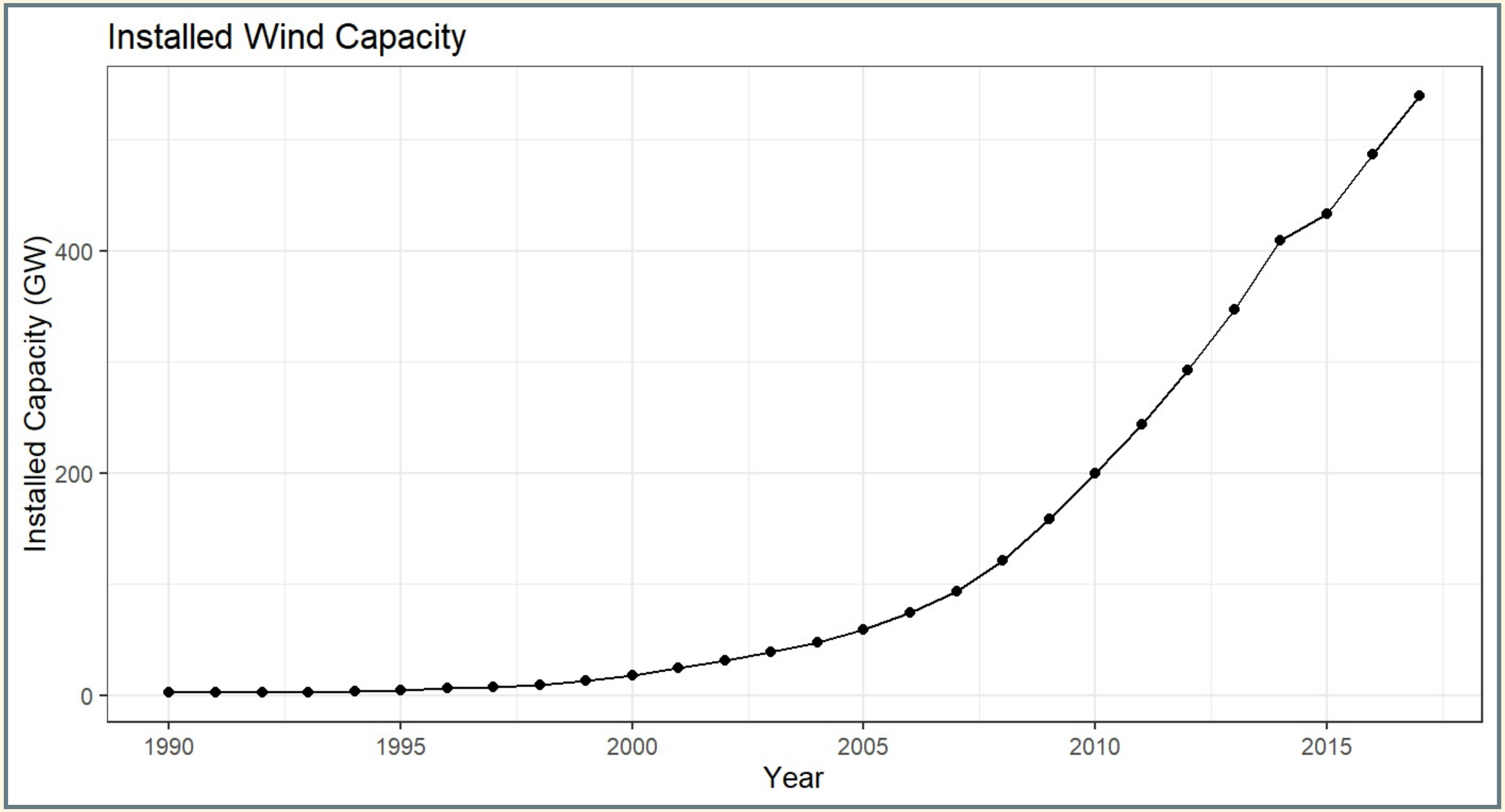
Solar Energy over Time



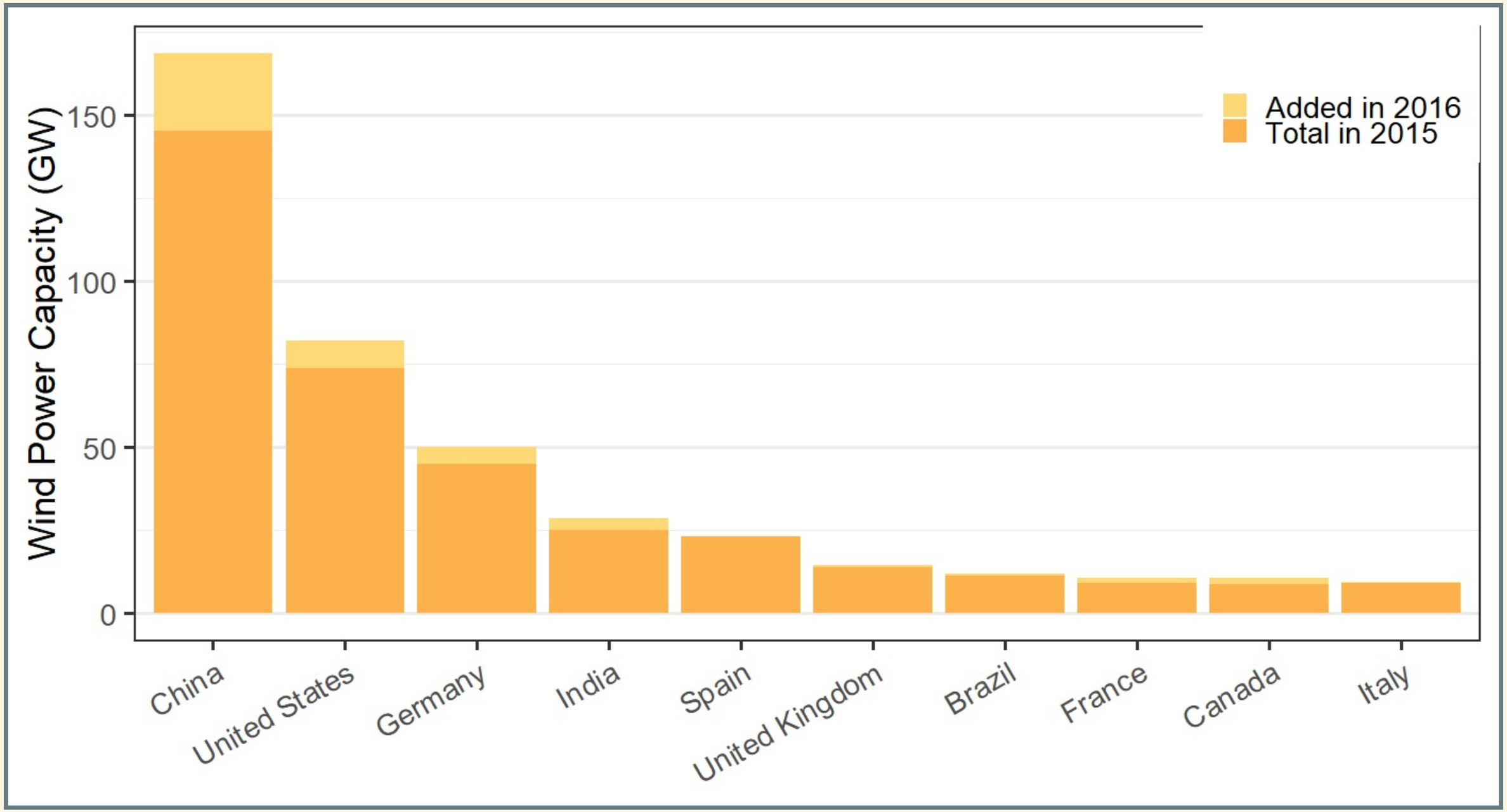
Top-10 Nations for Solar PV



Wind Energy over Time

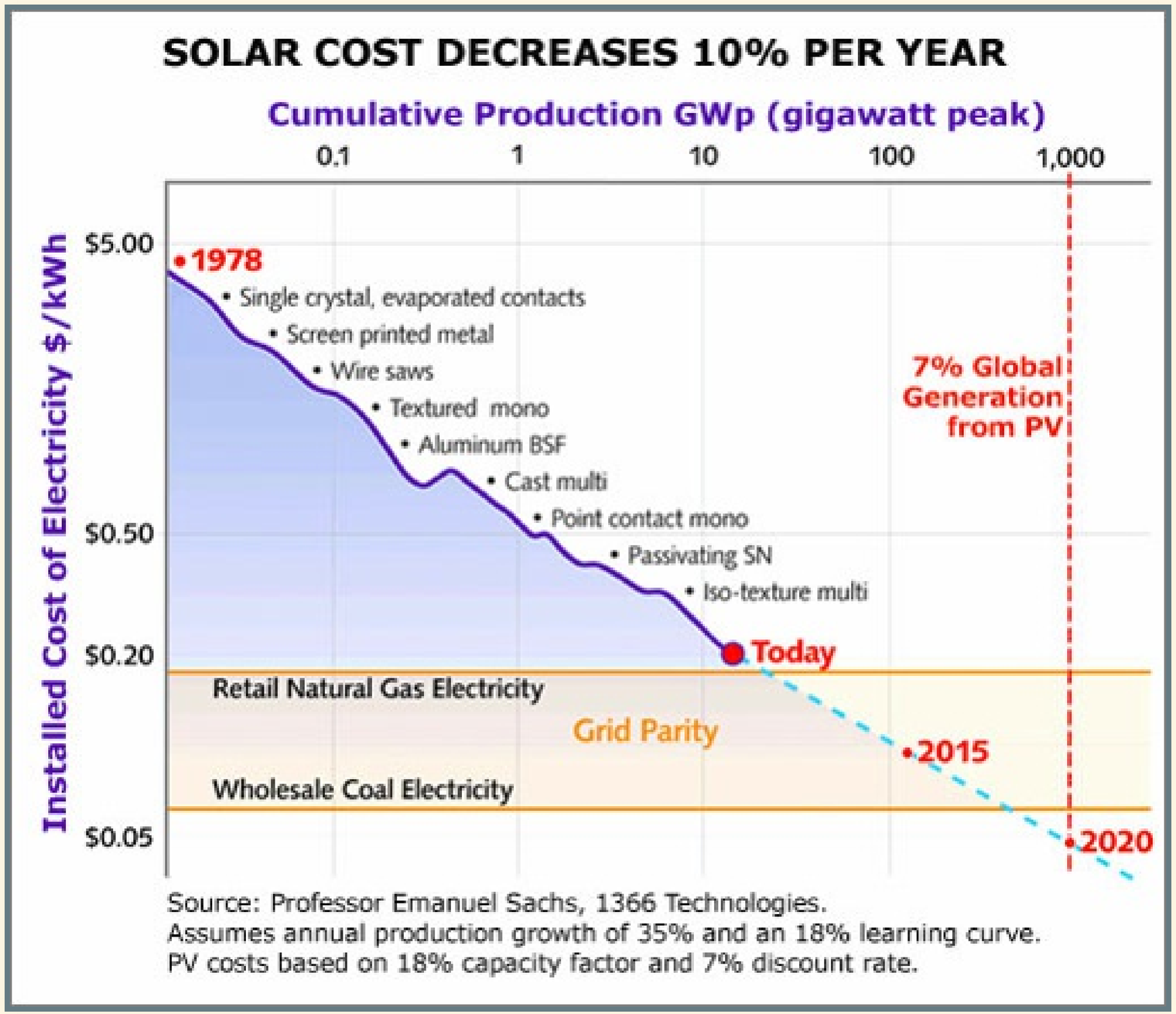


Top-10 Nations for Wind

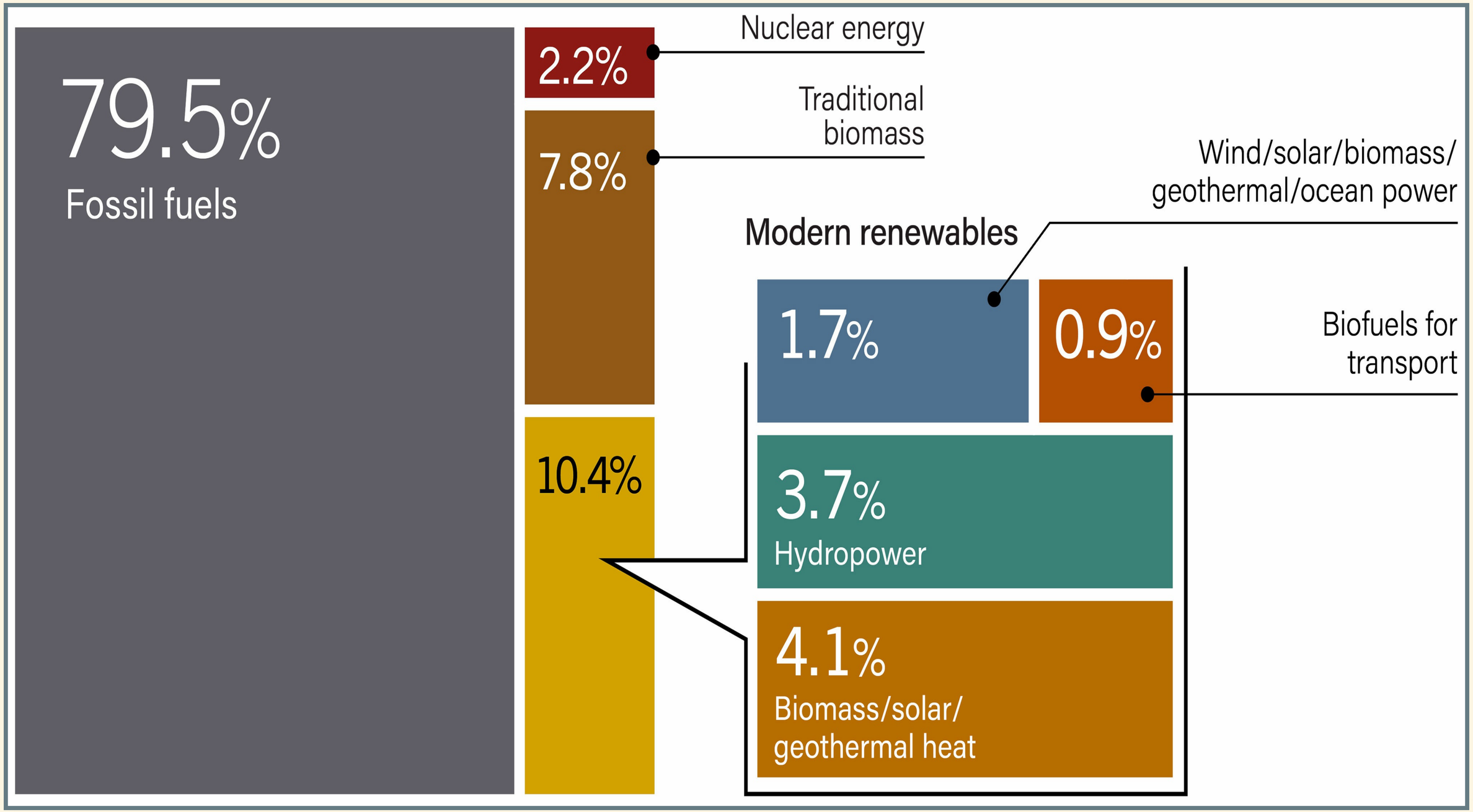


Prospects for Future Renewable Energy

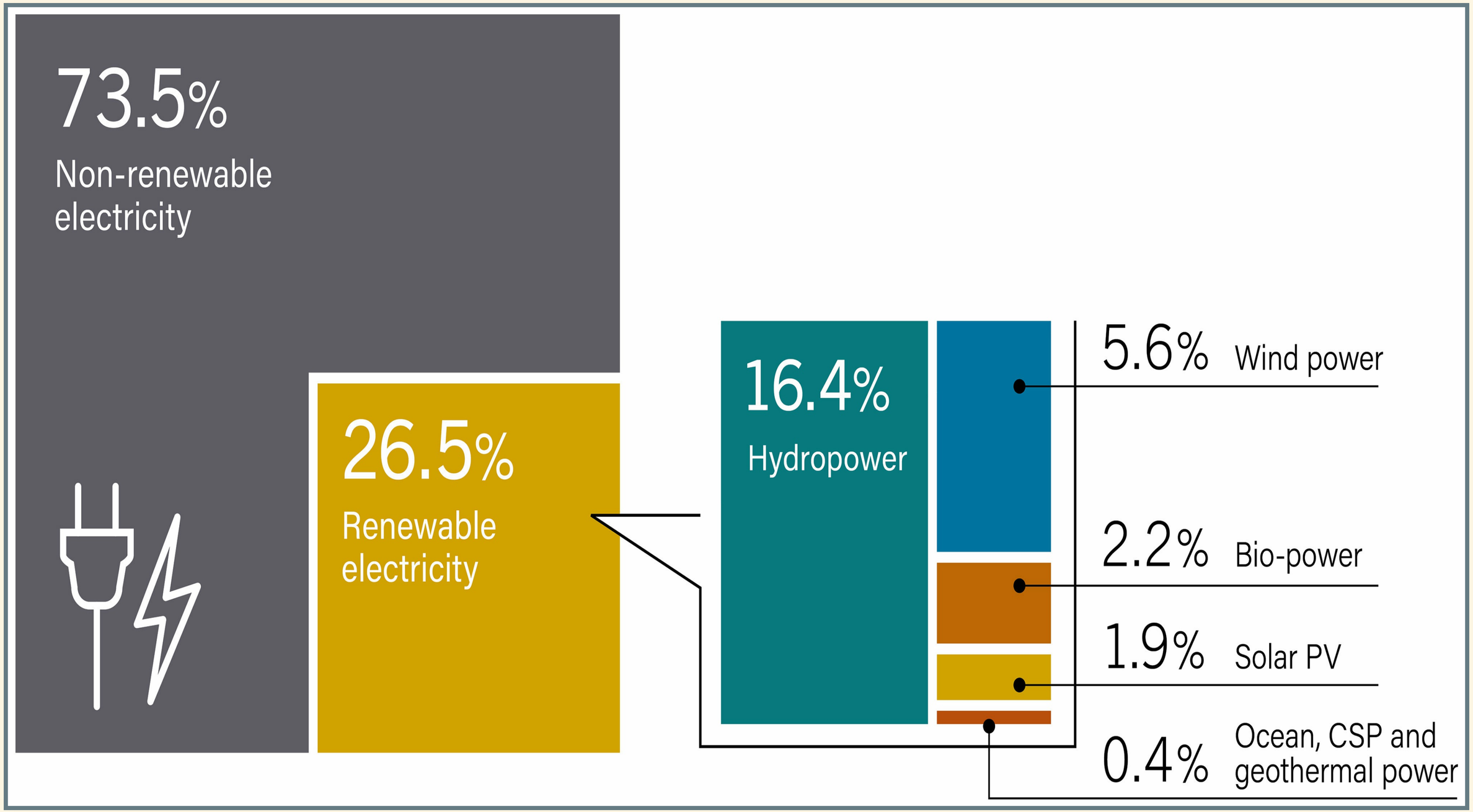
Solar PV


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
2015
2020
7% Global Generation from PV
Retail Natural Gas Electricity
Grid Parity
Wholesale Coal Electricity
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



World Electricity Generation



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/

Bottom-Up Analysis

Decarbonization Explorer

Country

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 (2017)	Projected (2050)
P (billion)	1.41%	7.53	12
g ($1000 per person)	1.50%	10.6	17.5
e (quad per $trillion)	-0.88%	6.7	5.01
f (MMT per quad)	-0.20%	229	214
ef (metric ton per $ million)	-1.08%	1,531	1,072
G (trillion dollars)	2.92%	80.1	210
E (quad)	2.04%	536	1,051
F (MMT CO2)	1.84%	122,628	224,763

1990 emissions = 78,083 MMT CO2

2050 target: 80% below 1990 = 15,617 MMT

Trends | Calculations | Implied Decarbonization | Energy Mix | Historical

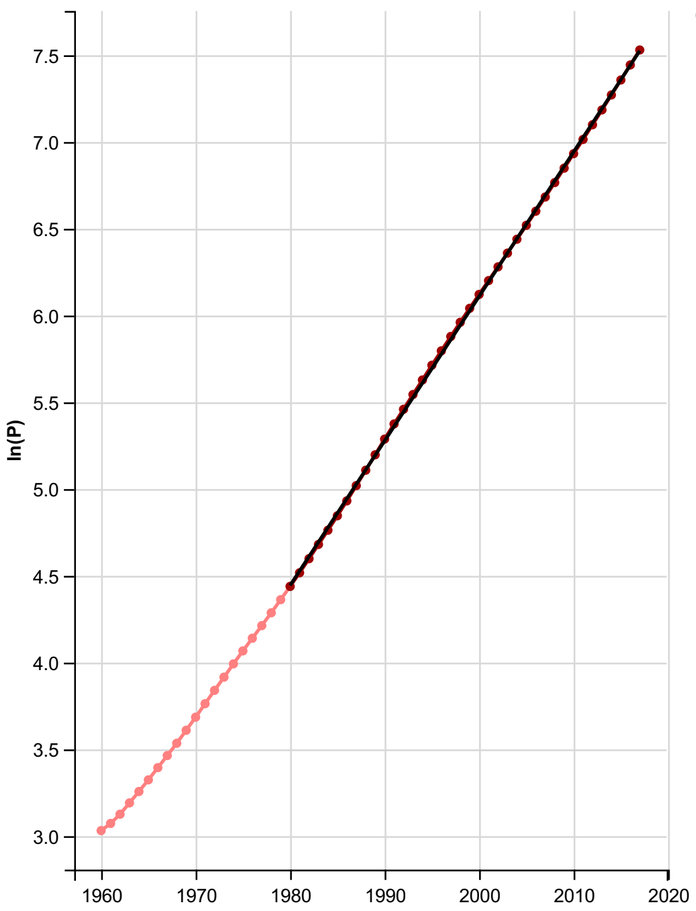
Historical Trends for World

Variable

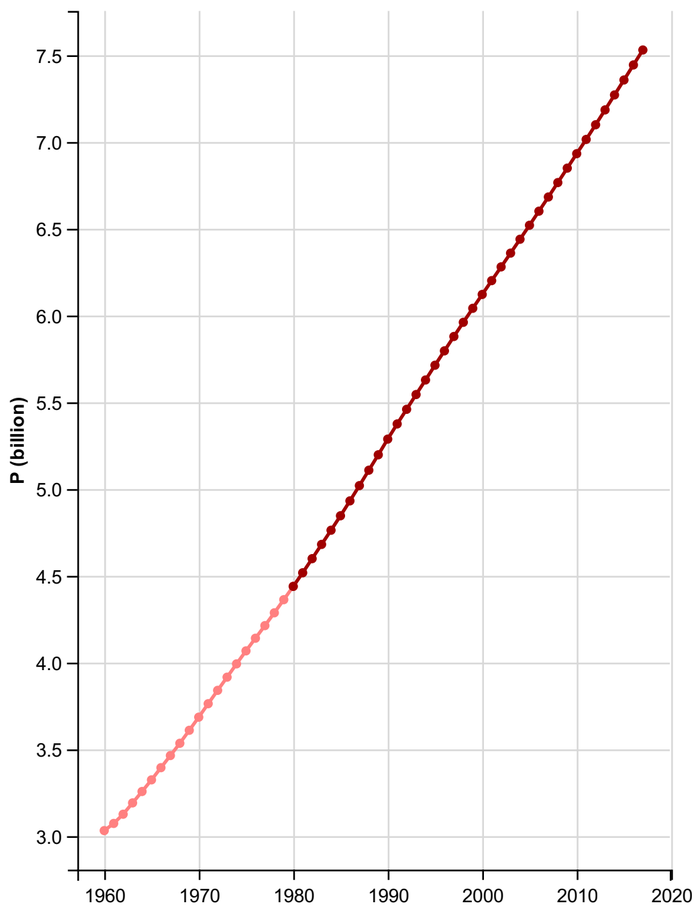
P

Population (billion people): Rate of change of *P* = 1.41% per year
Calculated from the slope of ln(*P*) starting in 1980

ln(Population)



Population



Bottom-Up Analysis

- GDP(2017) = $2.81 billion
  - Emissions intensity *ef*(2017) = 520 tons per $1000
- Business as usual:
  - If growth follows historical trends
    - Population *P* grows at 0.43%,
    - per-capita GDP *g* grows at 1.88%,
    - GDP grows at 0.43% + 1.88% = 2.31%

$$\begin{aligned} GDP(2050) &= GDP(2017) \times \exp(0.0231 \times (2050 - 2017)) \\ &= \$2.81 \text{ trillion} \times \exp(0.0231 \times 33) \\ &= \$6.02 \text{ trillion} \end{aligned}$$

Bottom-Up Analysis

- F(2017) = 1460 million tons CO_2.
- F(1990) = 2174 million tons CO_2.
- Goal: Emissions in 2050 are 80% less than in 1990:
  - $F(2050) = 0.20\ F(1990) = 0.20 \times 2174\ \text{MMT} = 435\ \text{MMT}$
  - Implied growth rate of F:

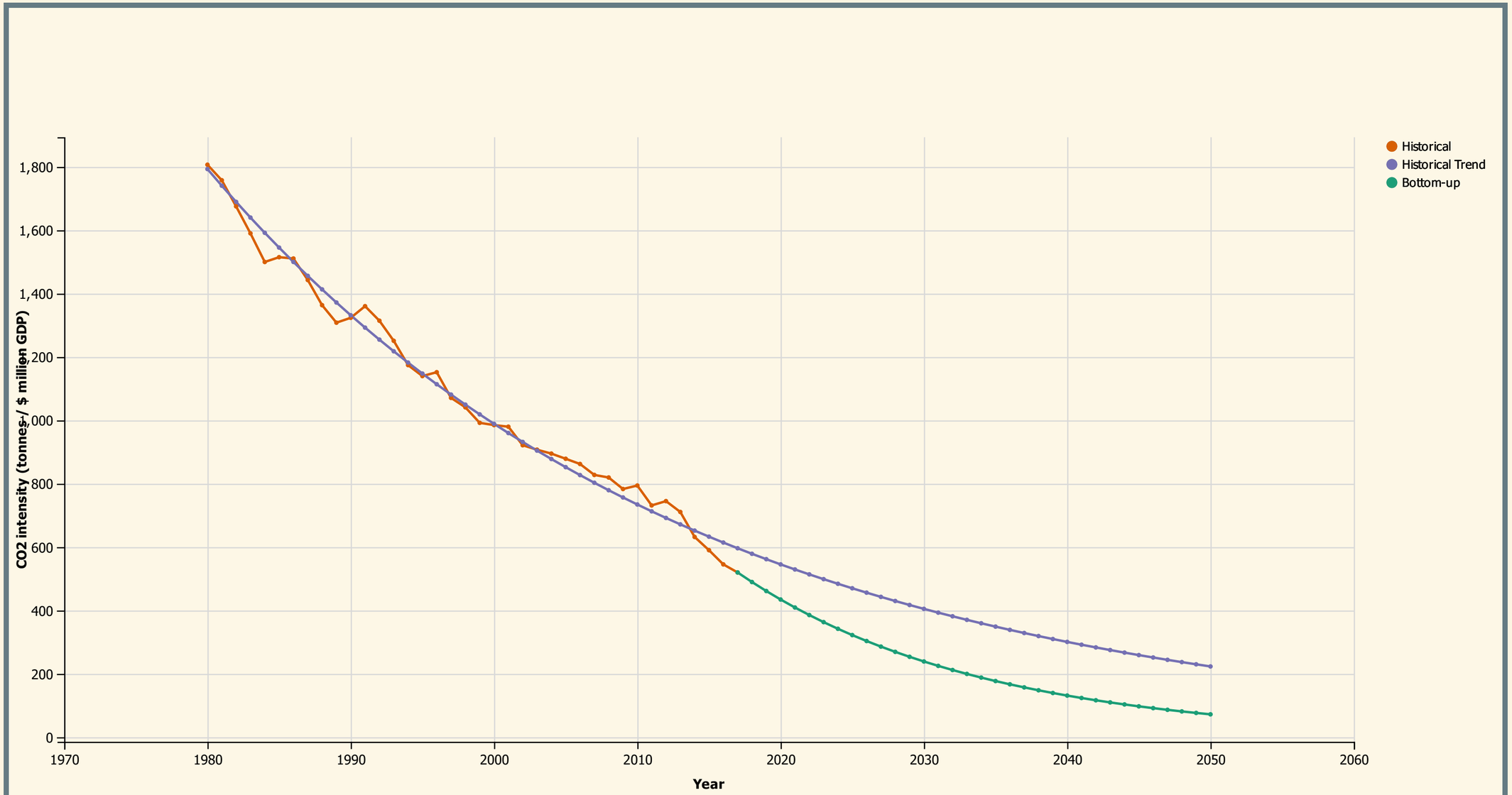
$$
\begin{aligned}
r_F &= \ln(F(2050)/F(2017))/33\ \text{years} \\
&= \ln(435/1460)/33 \\
&= -3.67\%.
\end{aligned}
$$

Implied decarbonization rates:

- GDP ($P \times g$) grows at 2.31%
- Implied growth rate of F: $r_F = -3.67\%$.
- Implied growth rate of *ef* (carbon intensity of the economy):
  - $F = Pgef$, so
  - $r_F = r_{Pg} + r_{ef} = r_G + r_{ef}$

    $$\begin{aligned} r_{ef} &= r_F - r_G \\ &= -3.67\% - 2.31\% \\ &= -5.98\% \end{aligned}$$
- The implied $r_{ef} = -5.98\%$
- The historical $r_{ef} = -2.97\%$
- To meet the goal, the UK would have to decarbonize 2.0 times faster than it has for the last several decades.

Implied decarbonization for UK



Implied Decarbonization for Australia

Australia's Emissions Trading Scheme

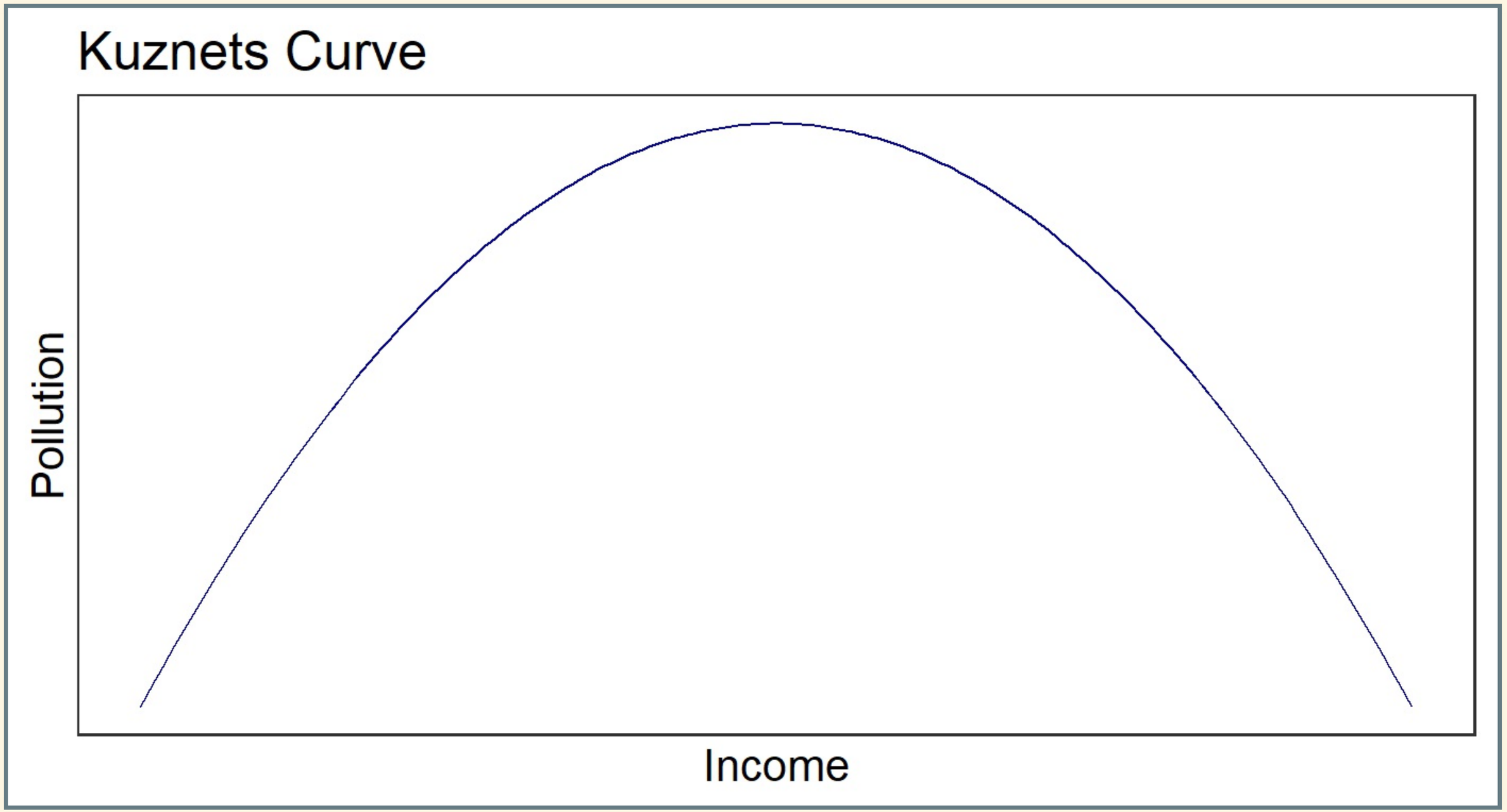
- PM Kevin Rudd calls for cutting emissions 60% below 2000 levels by 2050
- $F(2050) = 0.40\, F(2000) = 0.40 \times 1271 \text{ MMT} = 508 \text{ MMT}$

Implied Decarbonization for Australia

- Historical decarbonization rate: $r_{ef} = -1.39\%$
- Implied decarbonization rate: $r_{ef} = -6.49\%$

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?