Institute for New Economic Thinking AT THE OXFORD MARTIN SCHOOL

Smith School of Enterprise and the Environment

A new perspective on decarbonising the global energy system.

Oxford Energy Seminar 12th October 2021

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Dr Matthew Ives

Overview

What are decision-makers being told about climate mitigation pathways?

What is wrong with this story?

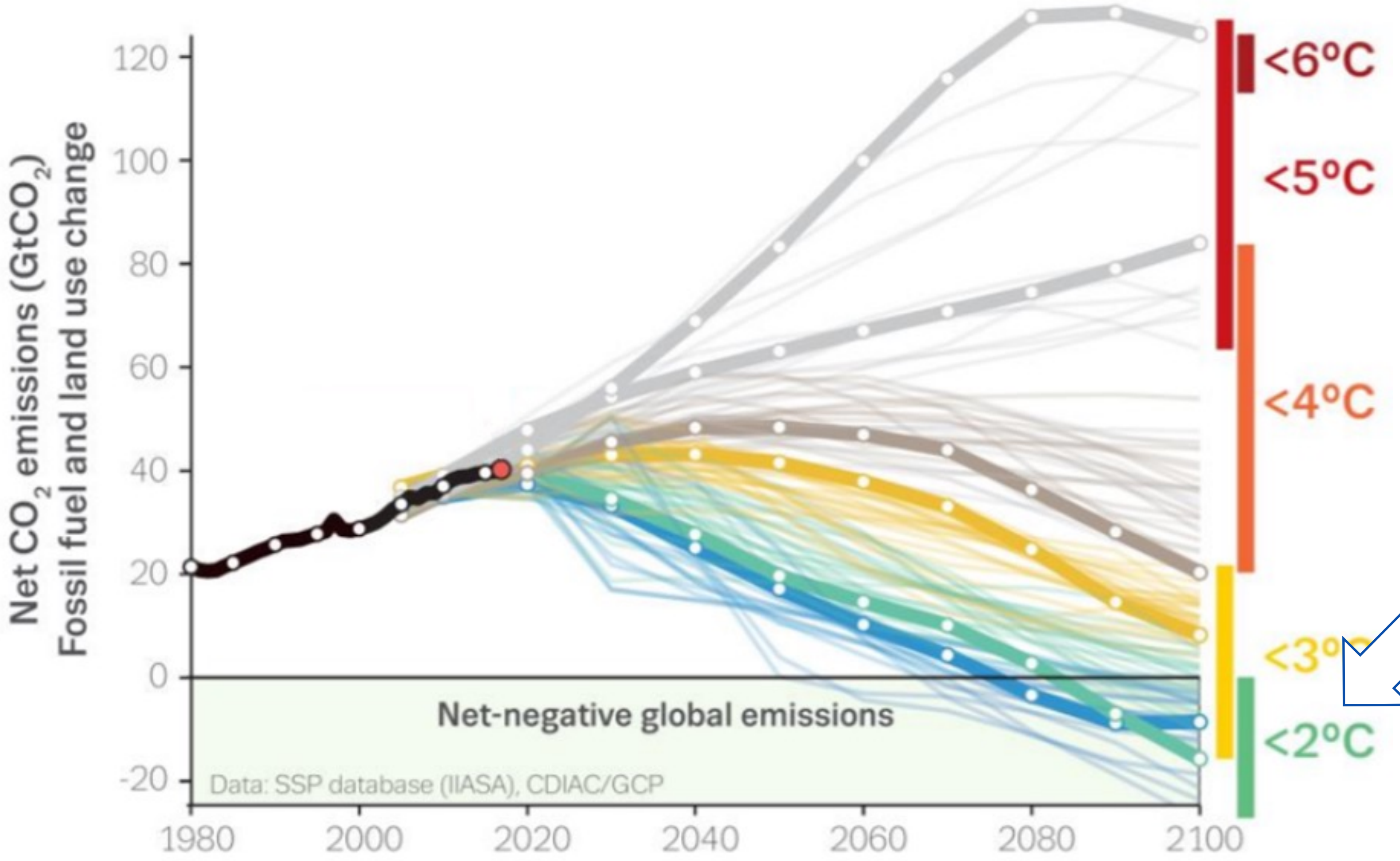
Is there a better perspective?

What is the cost of decarbonising the global energy system?

Socio-technical transitions, regional differences and emission pathways

Conclusions

“Stopping climate change will be slow or very expensive”



Source: Global Carbon Project (2017) and Bank of England (2018)

To achieve < 2 degrees:

- Economic growth must suffer
- We may need to reduce our energy usage
- We need to build 13Gt or more of Carbon Capture and Storage plants by 2100
- Electricity prices are likely to be higher

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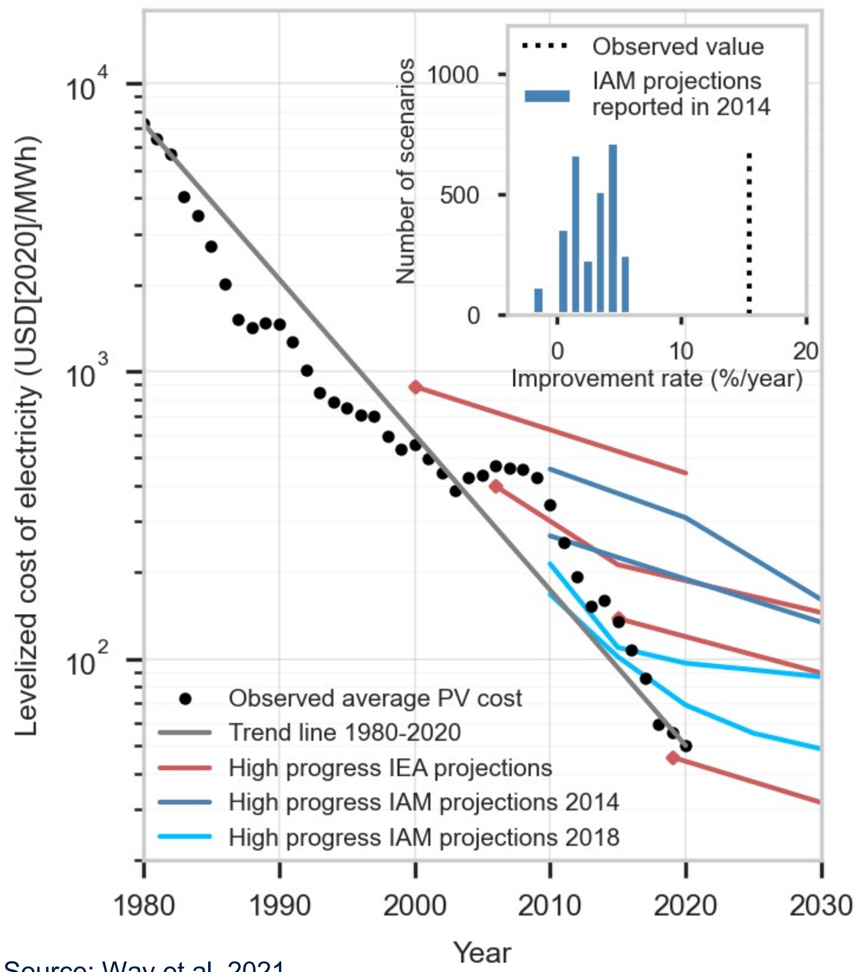
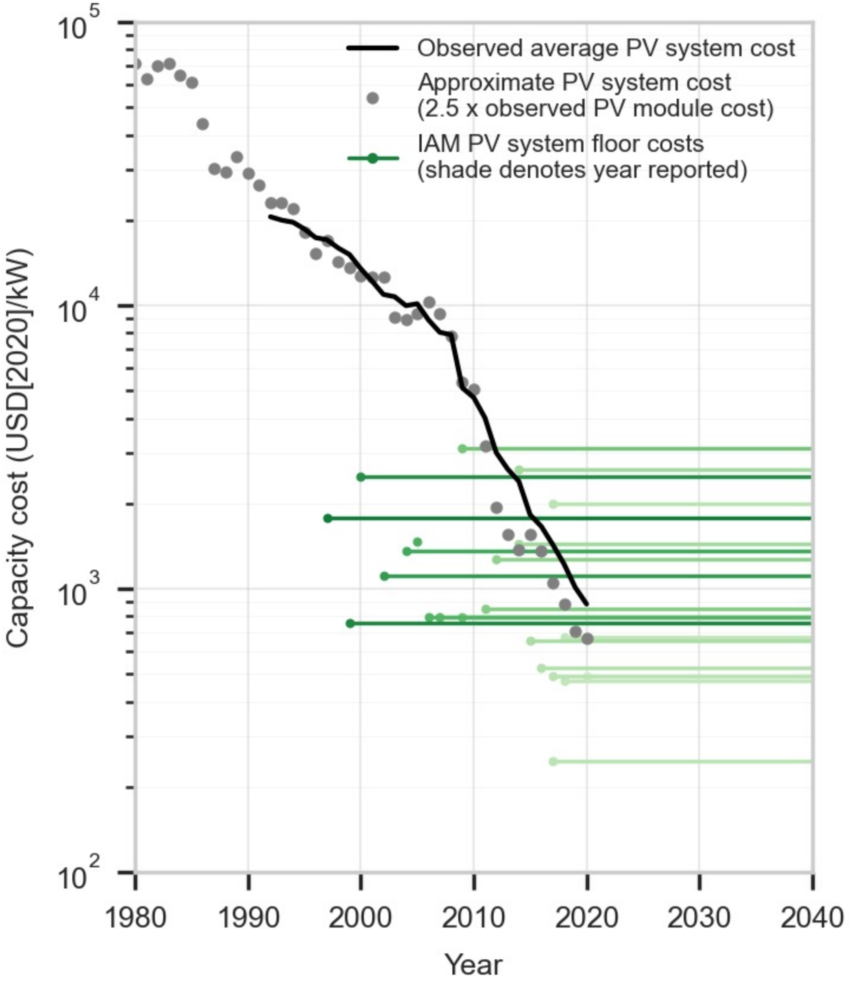
Performance of IEA and IAMs





Source: Way et al. 2021

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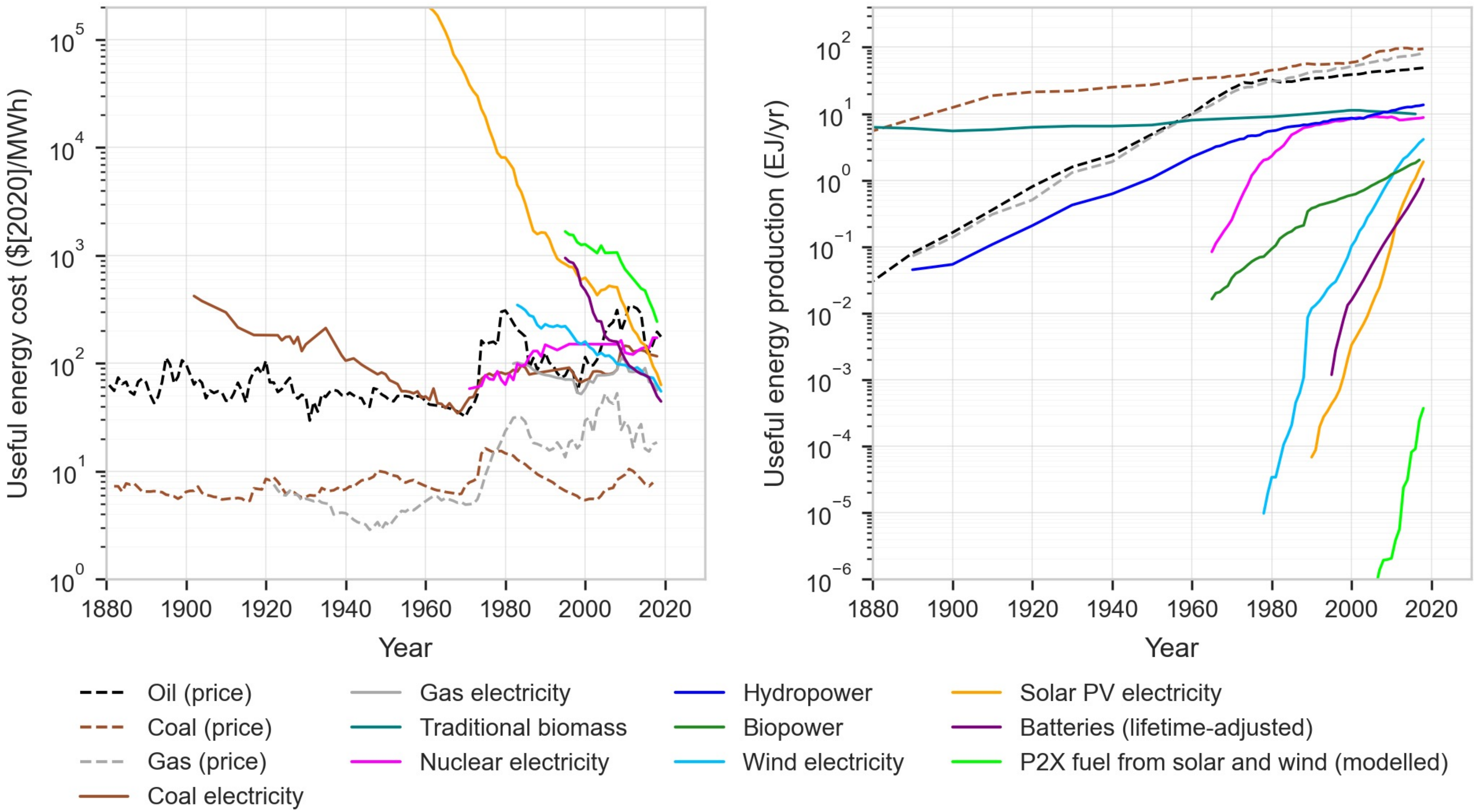
Evolution of the global energy landscape

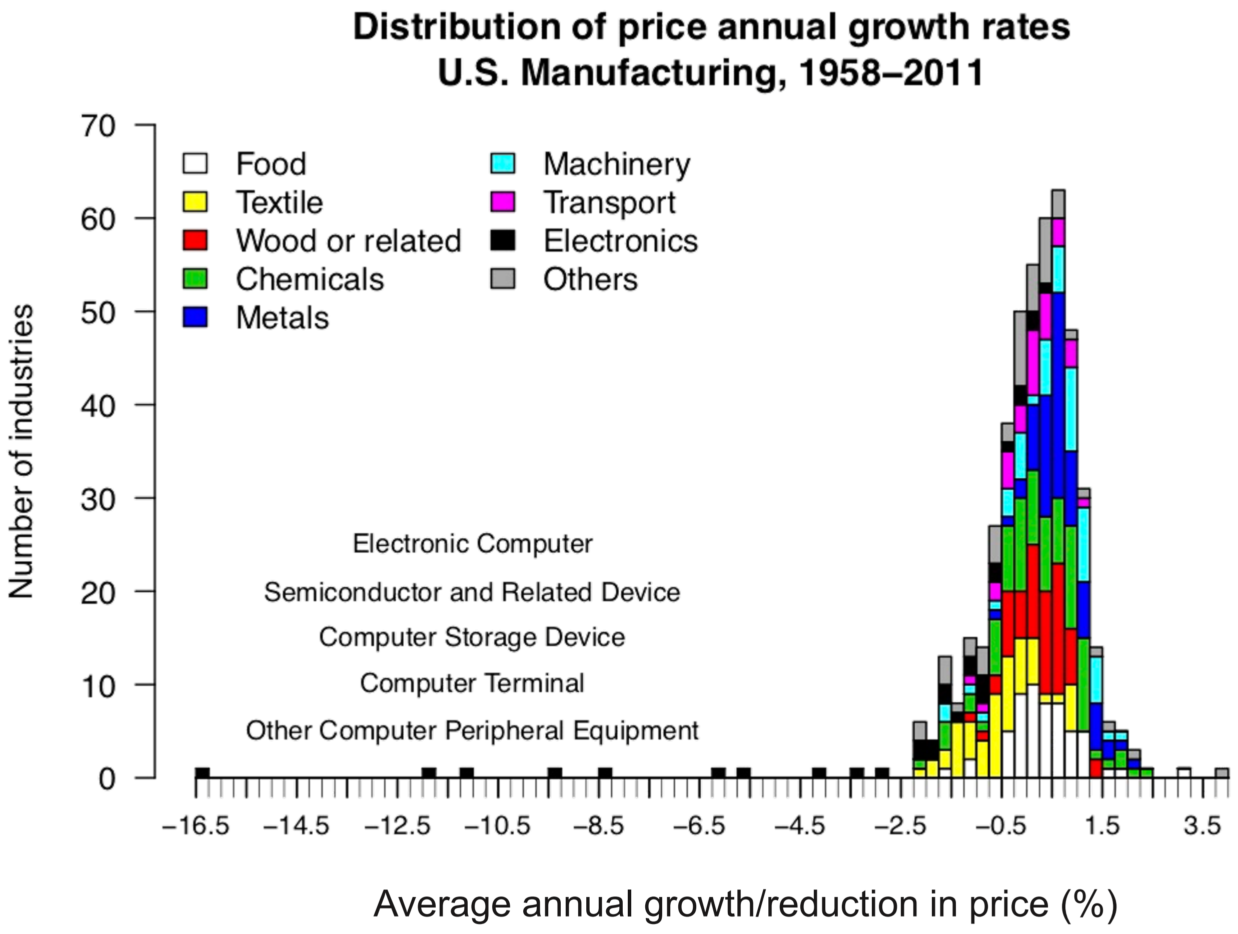


Technological change

- Technologies improve at very different rates
- The rates are highly persistent
- This is only clear with granular data

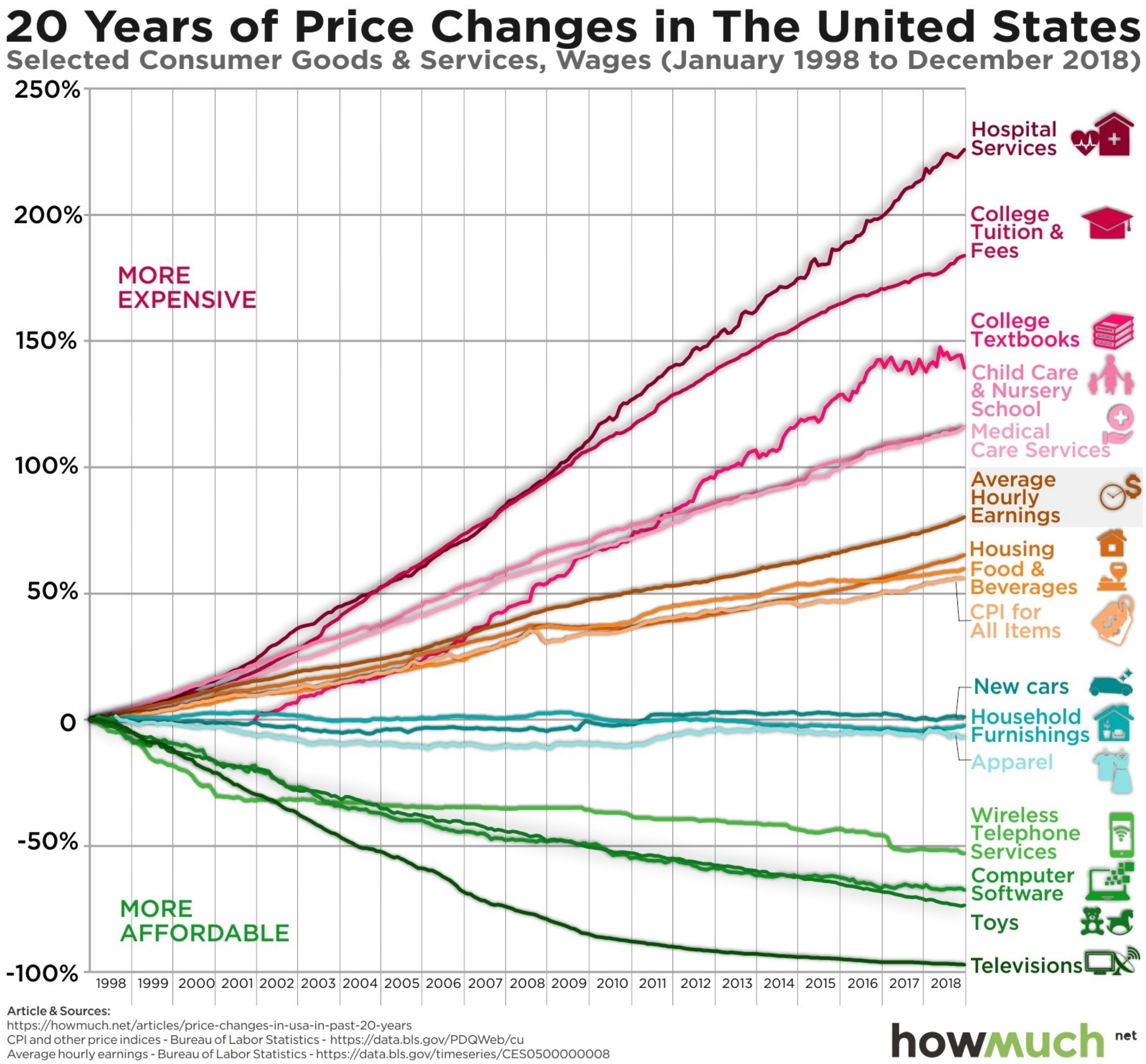
Hypothesis: *We can make far better predictions of long-term growth using fine-grained models.*

Heterogeneity of Technological progress



Thanks to François Lafond and Jangho Yang

Consumer goods

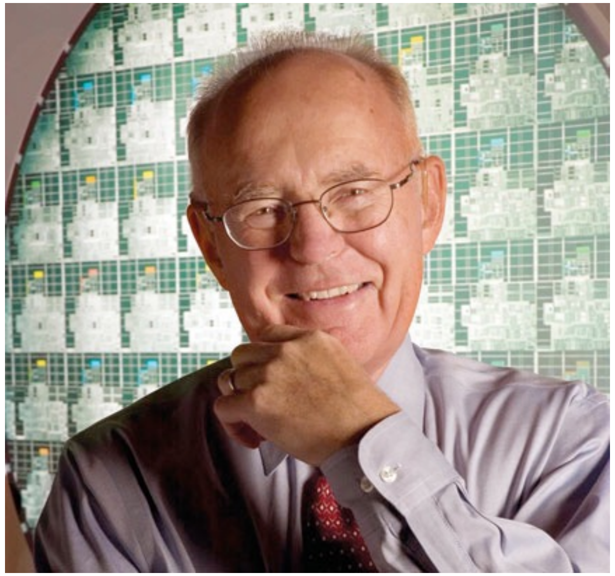


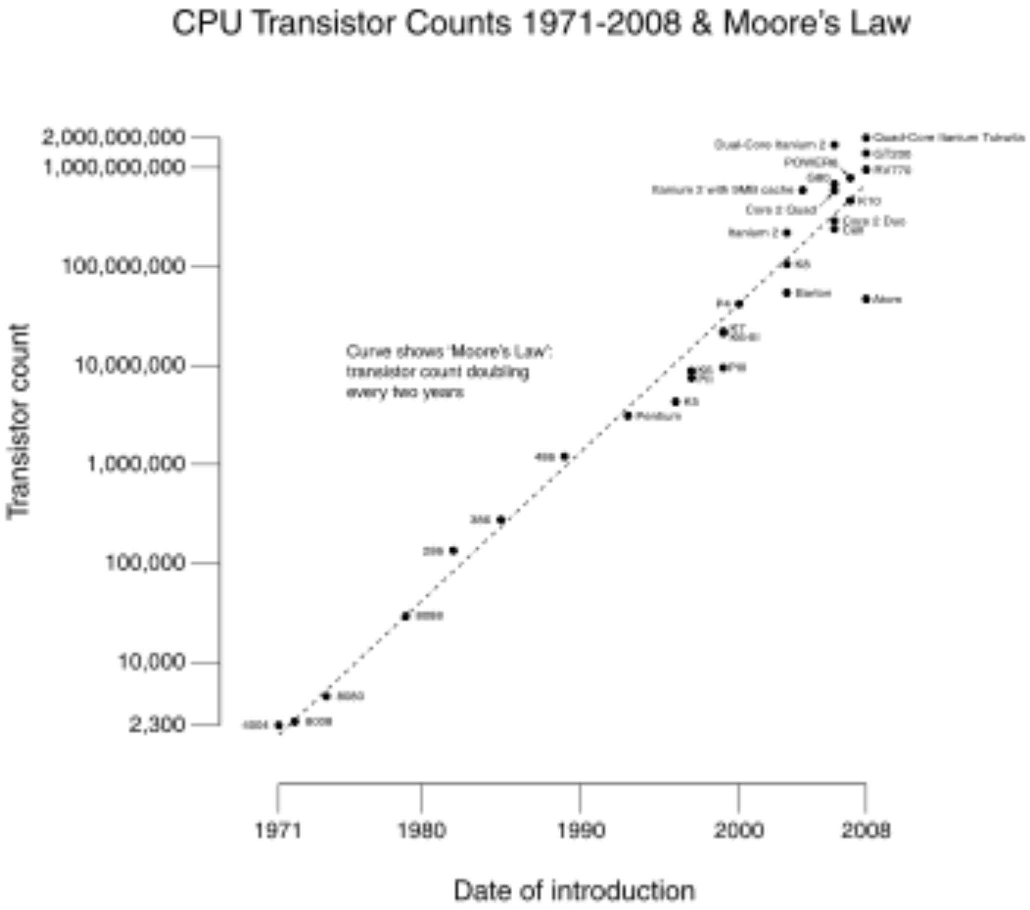
Thanks to Jangho Yang

How to take advantage of persistence and heterogeneity of technological change?

Make use of empirical laws.

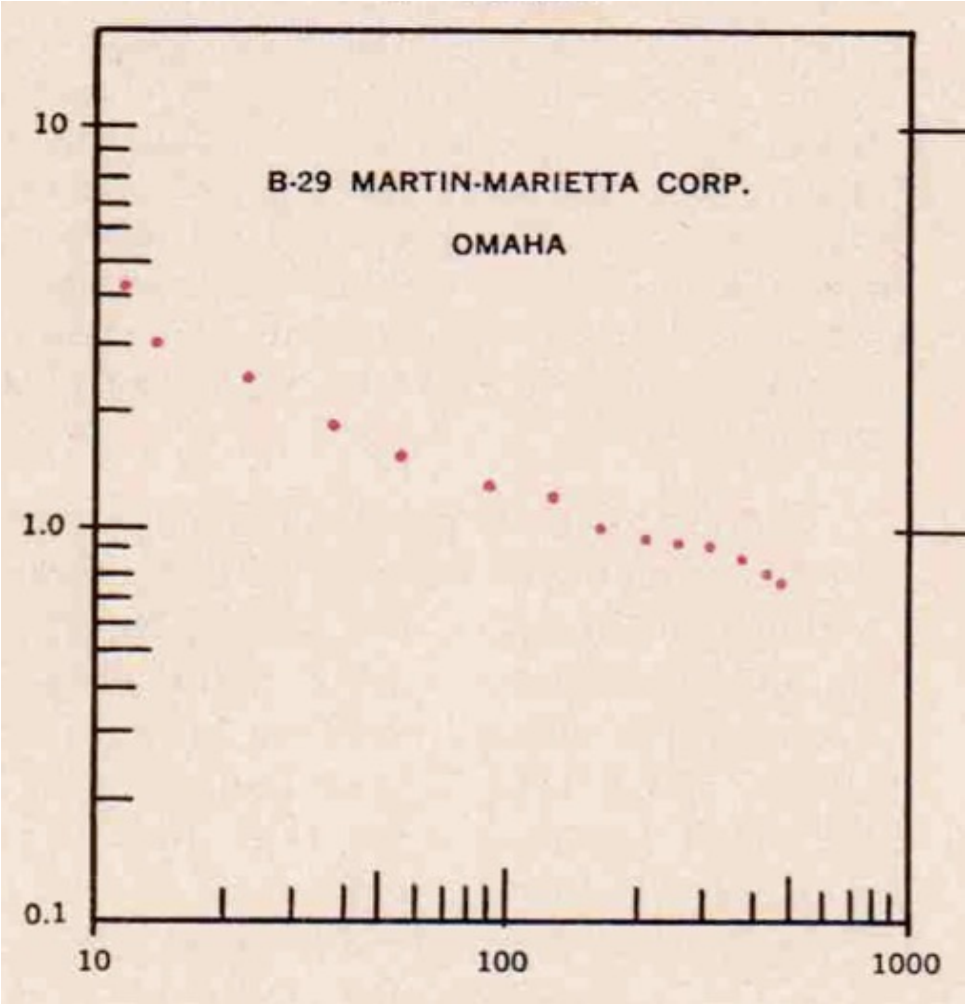
Moore's Law (1965)



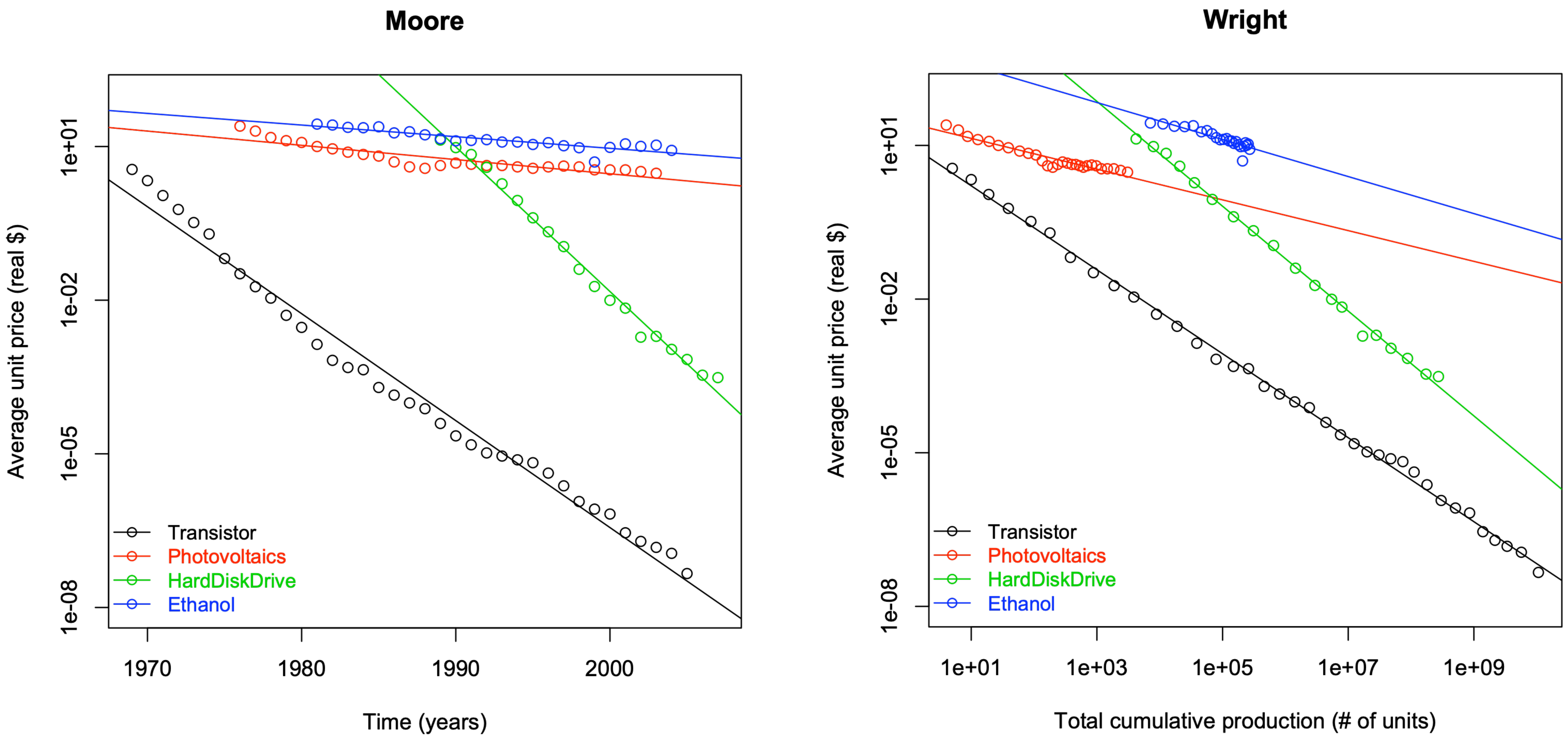


Originally a statement about density of transistors. We will use to refer to the hypothesis that **technological performance improves exponentially with time.**

Wright's Law (1936)



Cost vs. cumulative production follows a power law: $y = x^{-\alpha}$

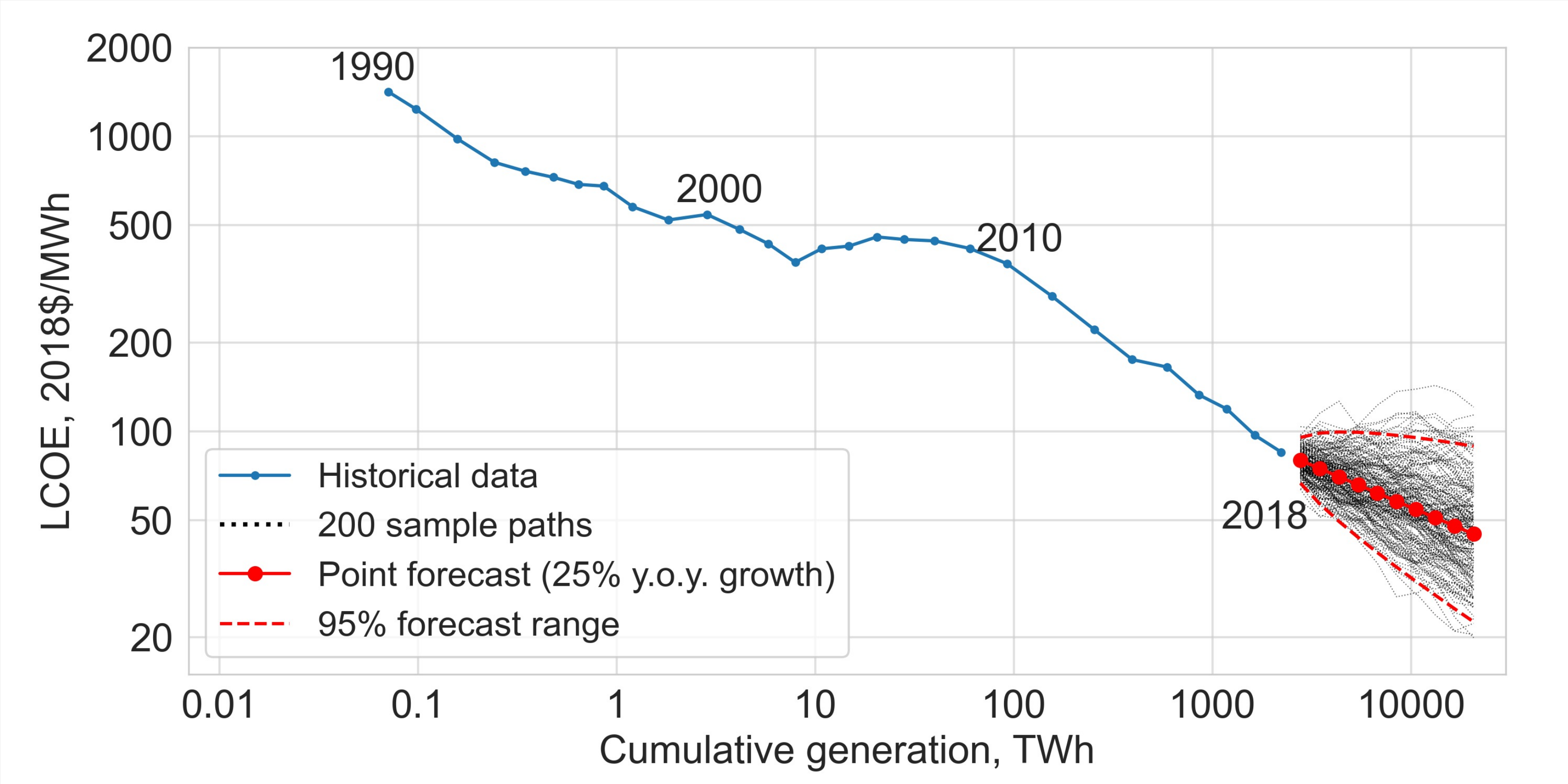


Moore
Wright
Average unit price (real $)
1e+01
1e-02
1e-05
1e-08
Transistor
Photovoltaics
HardDiskDrive
Ethanol
1970
1980
1990
2000
Time (years)
1e+01
1e+03
1e+05
1e+07
1e+09
Total cumulative production (# of units)

Cause and effect?

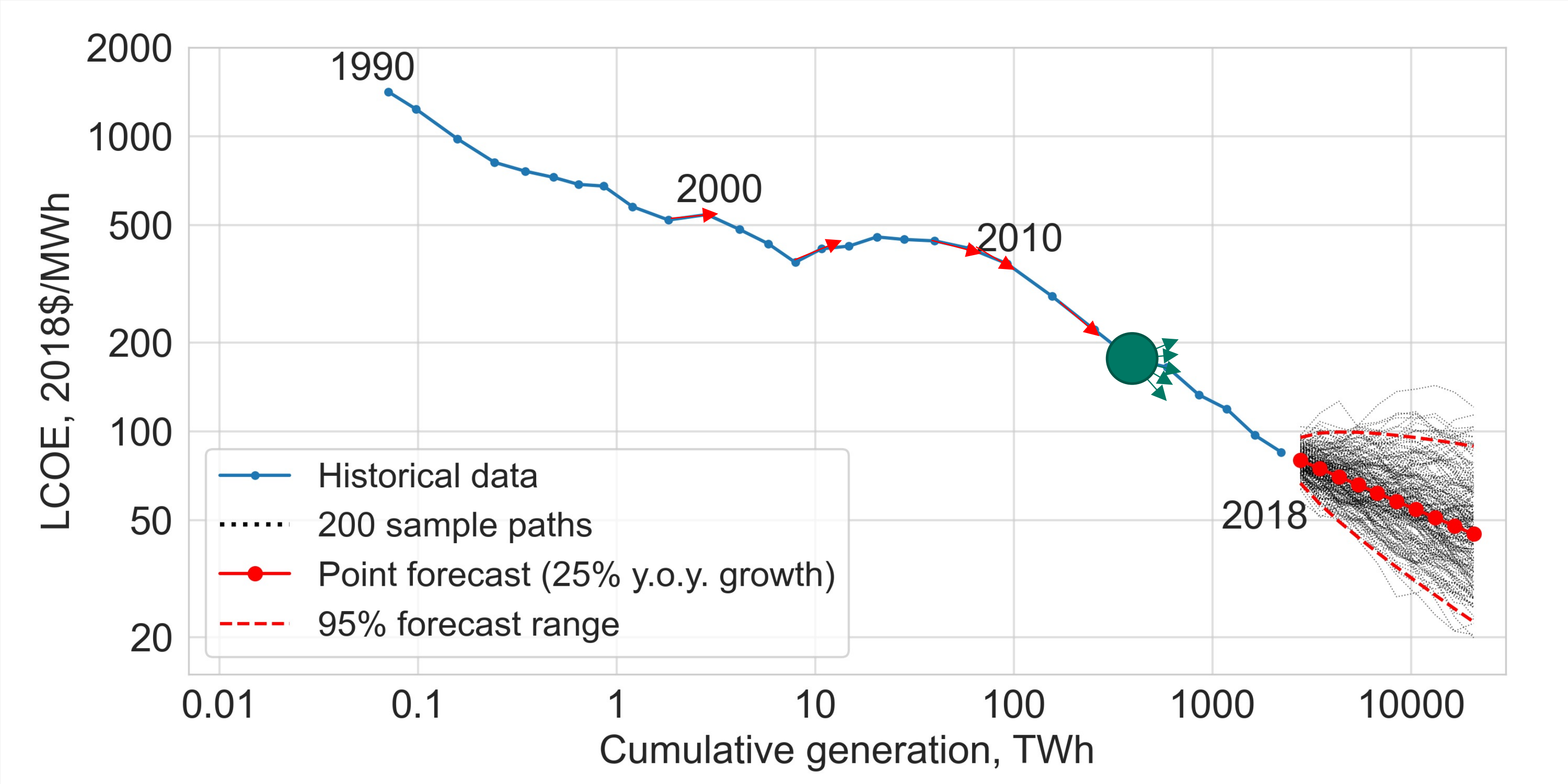
- Do lower costs cause higher production or does higher production cause lower costs?
- Studied US production in World War II (Lafond, Greenwald, Farmer)
- Causality is reasonably clear
- Cumulative production (experience) explains about half; overall trend explains the other half

How to make forecasts: the stochastic experience curve



- Reformulate Wright's law as a time series model (Lafond et al, 2018)

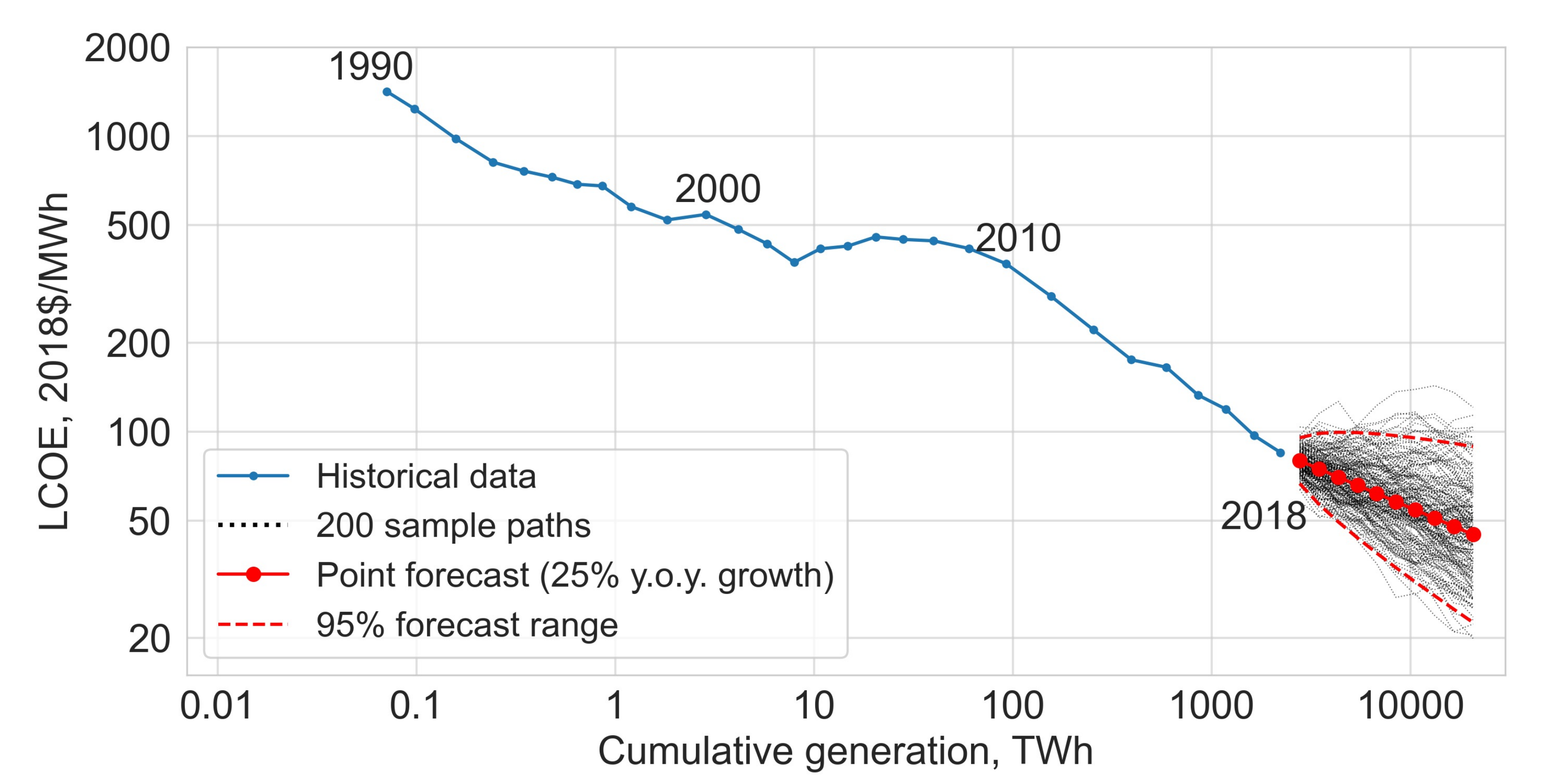
How to make forecasts: the stochastic experience curve



- Pretend to be at a given time in the past
- Forecast each "future" date
- Repeat for all past dates
- Score methods based on forecasting errors

Assume process is same for all technologies, but parameters differ

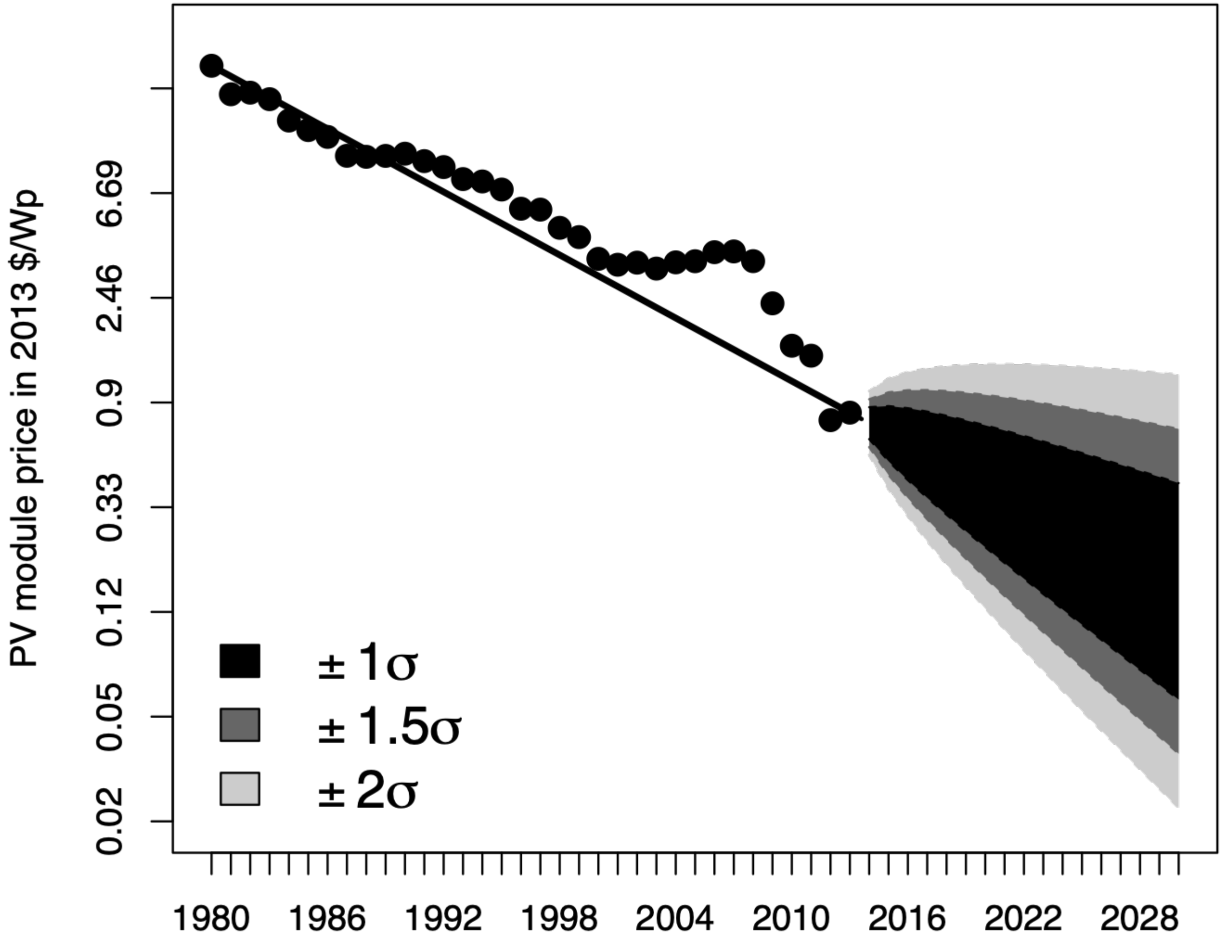
How to make forecasts: the stochastic experience curve



Tested by making 6,000 forecasts for 50 different Technologies

- Provides experience curve forecasts with reliable error bars
- Forecasts are scenario-dependent: the more we produce, the higher our probability of moving down the experience curve

Distributional forecast of solar PV assuming business as usual



Farmer and Lafond (2016)

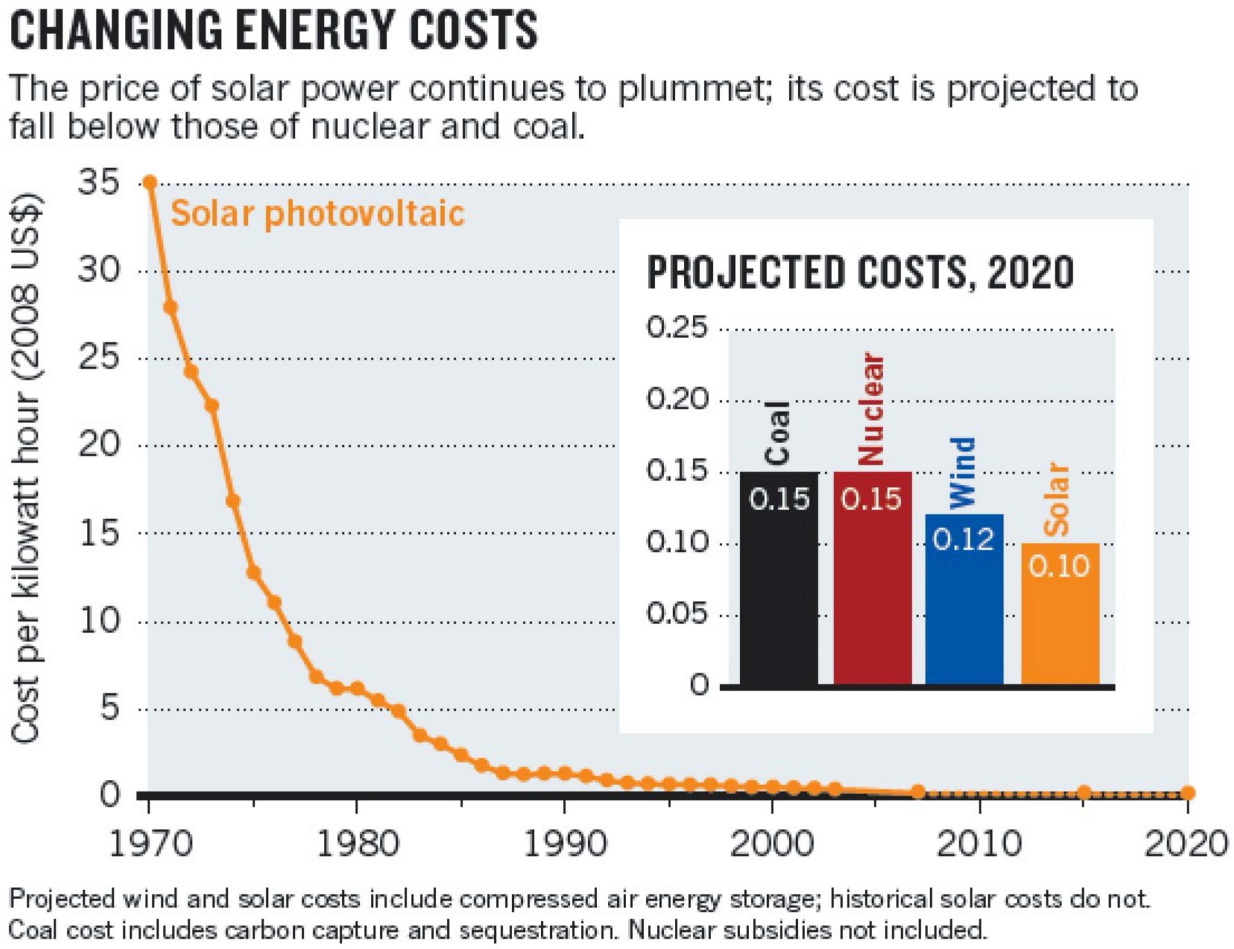
Contrasting forecasts of solar energy costs

"Solar power is by far the most expensive way to reduce carbon emissions."

The Economist (2014)

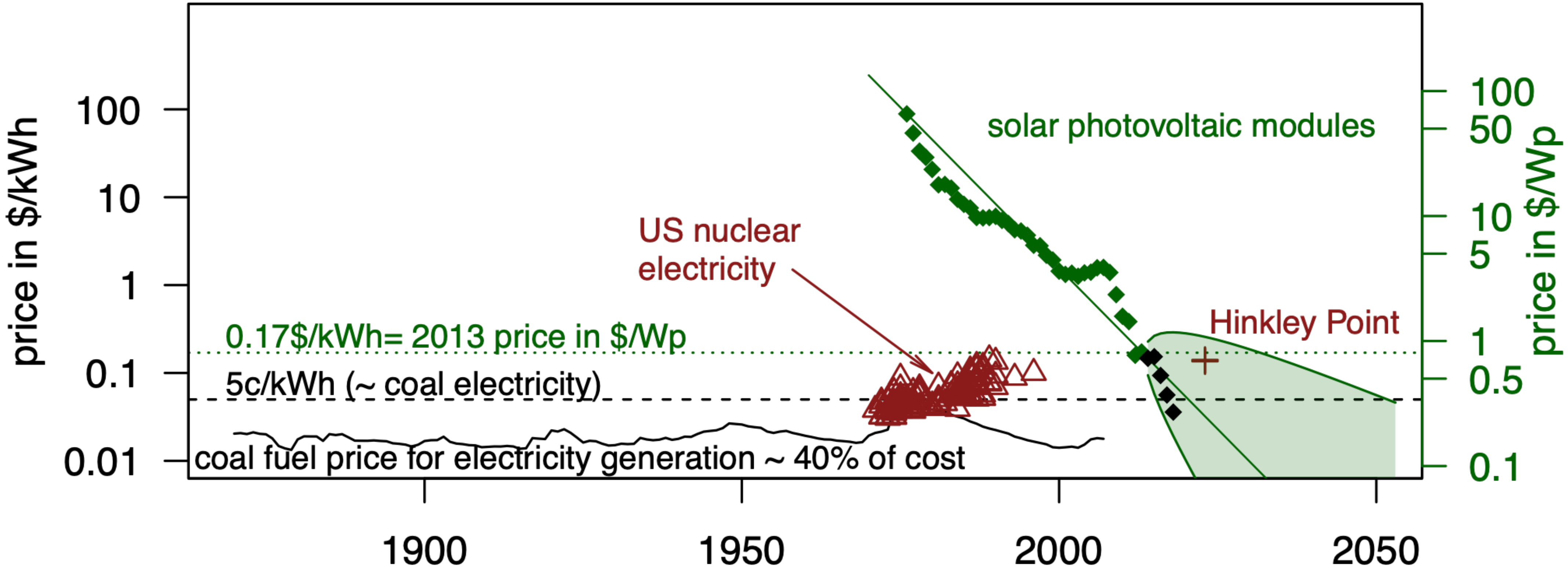
"For projects with low-cost financing that tap high-quality resources, solar PV is now the cheapest source of electricity in history."

International Energy Agency (2020)



Ferguson et al. (2010)

Energy technology costs improve at different rates



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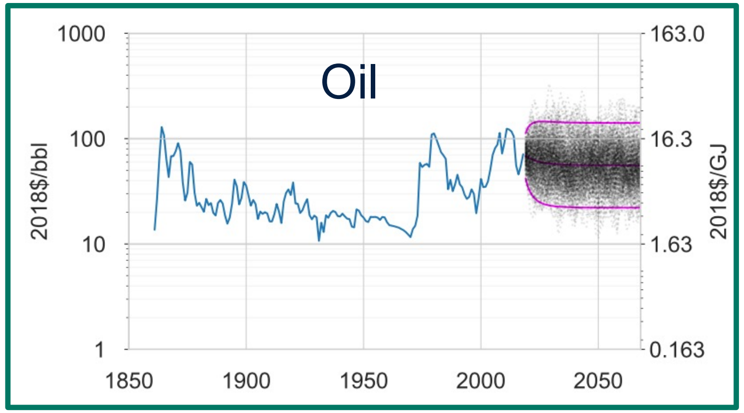
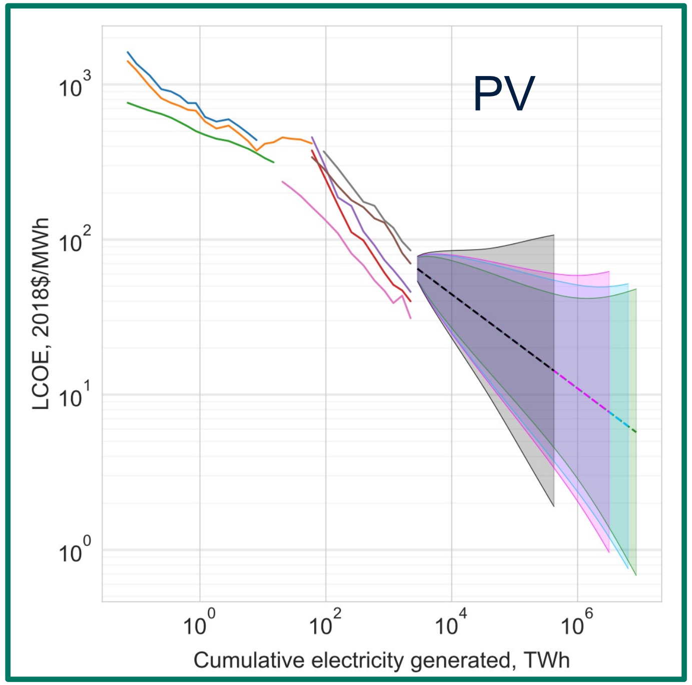
Designing an energy system model around the data

- We know how to make reliable forecasts for single techs: AR(1), Wright's law
- How do we combine forecasts to say something about the full system?
- ➢ Need a system model: lots of techs, in suitable quantities (scenarios)
- Note key features of forecasts:
  - Data-intensive
  - Probabilistic
  - Scenario-dependent





- These lead to different design than other models

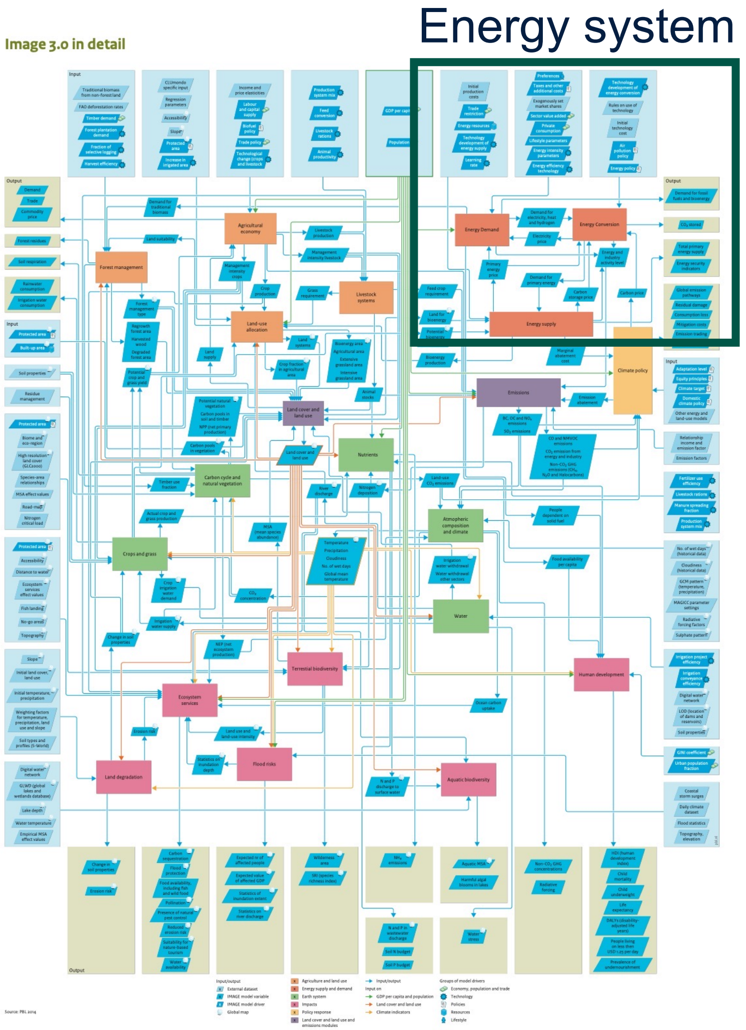
Model philosophy / wish list

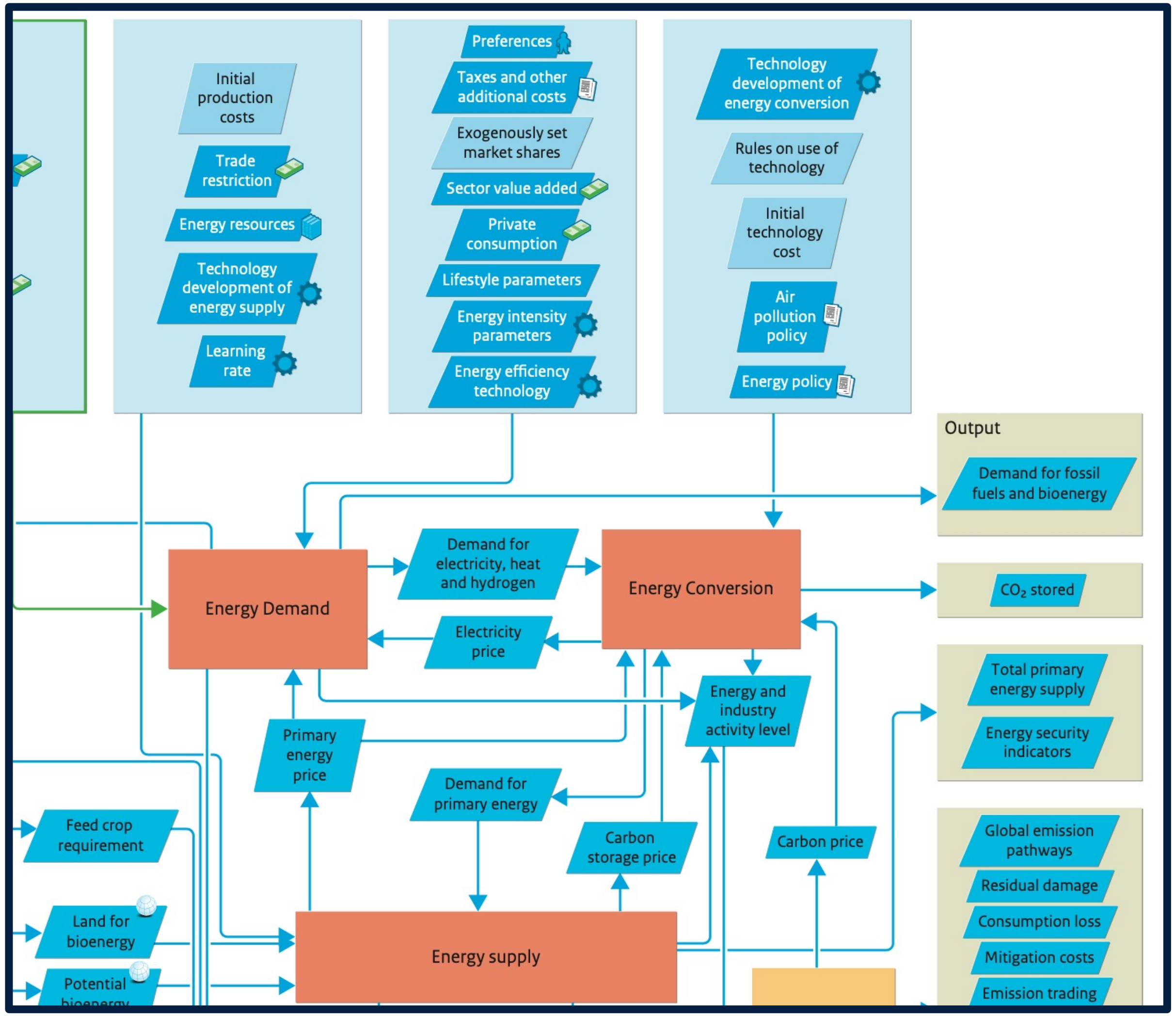
- Simple to understand and communicate
- Closely tied to data
- Easy to update with new data
- Quick to run, test, experiment
- Represent all the most important parts of the energy system
- Faithfully represent technology dynamics (costs, growth rates, substitutions…)
- *Reliable, trustworthy*

-> Want as few variables as possible while retaining sufficient realism

-> Major bottleneck is data, we spent a lot of time on this

In contrast: an Integrated Assessment Model (IMAGE)





What data exists?

Technology	Data	Cost trend	Forecast model
Oil, coal, gas	~100 years	Flat	AR(1)
Coal & gas electricity	~40 years	Flat	AR(1)
Nuclear power	~40 years	Flat / increasing	Wright
Hydropower, biopower	10-20 years	Weak progress / flat	Wright
PV, wind, Li-ion batteries, PEM electrolysers	10-50 years	Strong progress	Wright

- Data exists for global costs and global production, not regional
- Limited data: CCS, biofuels, traditional biomass, heat, pumped storage, marine, tidal, geothermal, concentrated solar, *flow batteries, electricity networks*

How we choose which technologies to include in the model

1. *Data availability* – can only use techs with sufficient data
2. *System coverage* – techs with large production
3. *System dynamics* – techs with large growth rates
4. *Flexibility & functionality* – energy storage, transport & conversion techs

How we choose which technologies to include in the model

1. *Data availability* – can only use techs with sufficient data
2. *System coverage* – techs with large production
    - Primary fuels: crude oil, coal, gas
    - Electricity: coal, gas, nuclear, hydropower, biopower
3. *System dynamics* – techs with large growth rates
    - *Wind, PV, others below*
4. *Flexibility & functionality* – energy storage, transport & conversion techs
    - Batteries (Li-ion and VRF), electrolyzers (PEM), electricity networks

What do we exclude? CCS, geo, biofuels, traditional biomass, marine, tidal, geothermal, CSP, petrochemical feedstock (plastics), pumped storage

How other models construct scenarios

- Co-“construct” costs and deployment – they *forecast* both things at once
- ➢ Small early errors get magnified over time
- Some use endogenous technological learning (but with point forecasts)
- Can be myopic or optimize over longer time horizon
- Impose extra ad hoc constraints (floor costs, deployment growth constraints, deployment limits etc…)
- Their past record is very bad for fast moving techs
- Hard to make scenarios match past or current trends

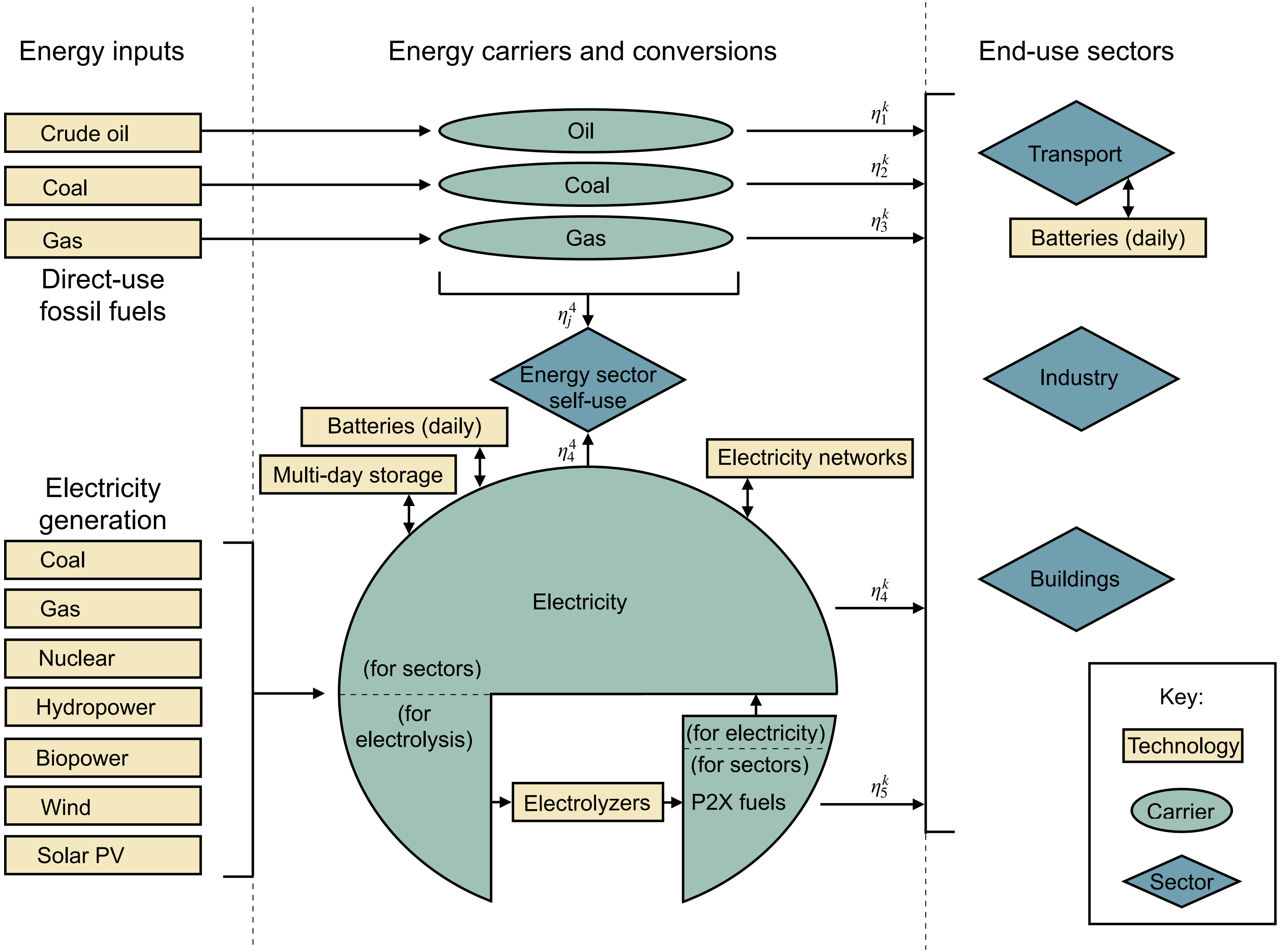
How we construct scenarios

- **Exogenously** and **based on empirical trends**

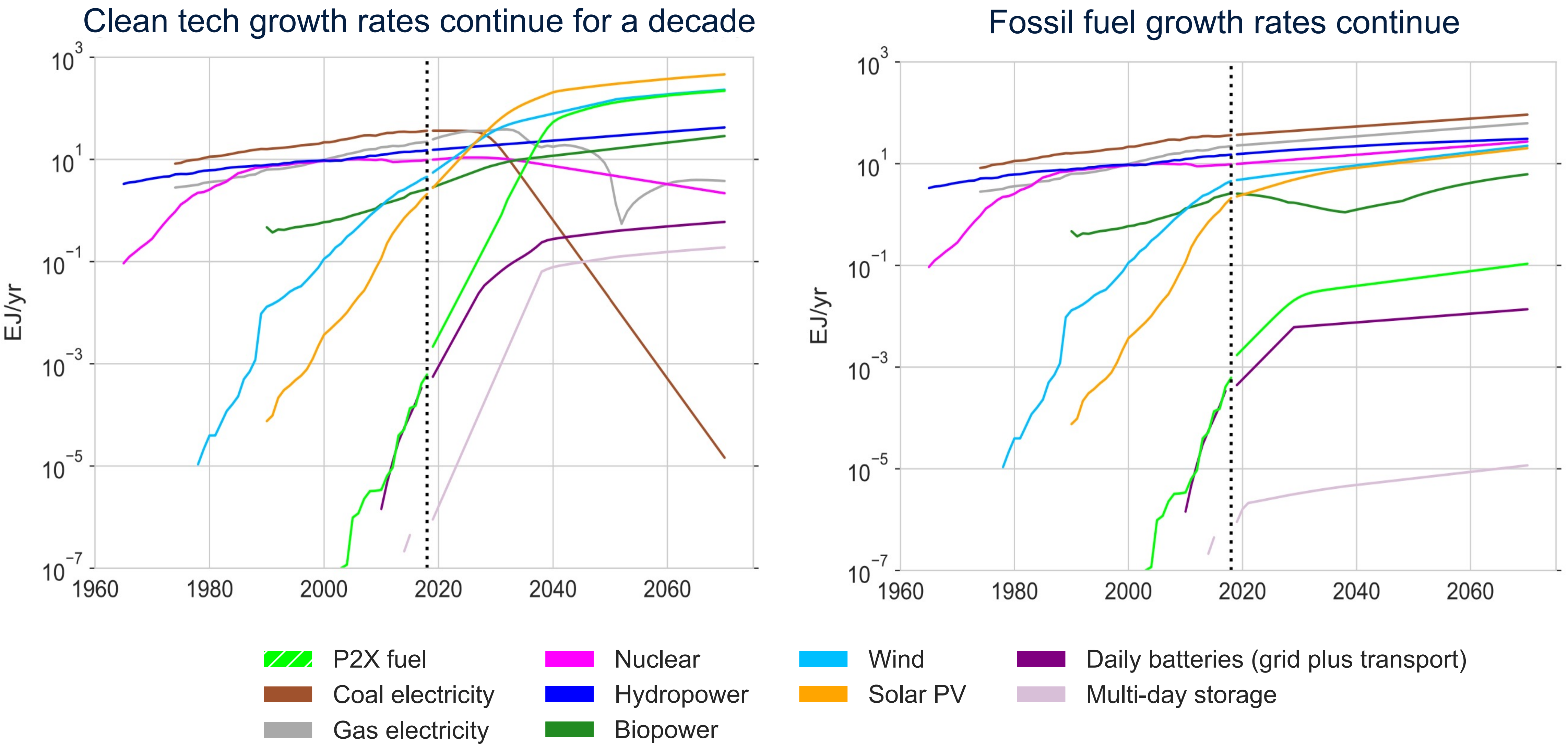
1) 14 technologies / 5 energy carriers / 4 sectors
2) Key assumption: total useful energy grows at 2% (and within sectors)
3) Allow different combinations of techs to grow at current rates for around a decade, then relax back to system-wide rate
4) … subject to a few extra constraints:
    - Electrification % is capped (per sector) - some fuels are still provided
    - VRE deployment matched by long- and short-term storage, fixed %

- NB. Scenarios are exogenous - not constructed by optimization

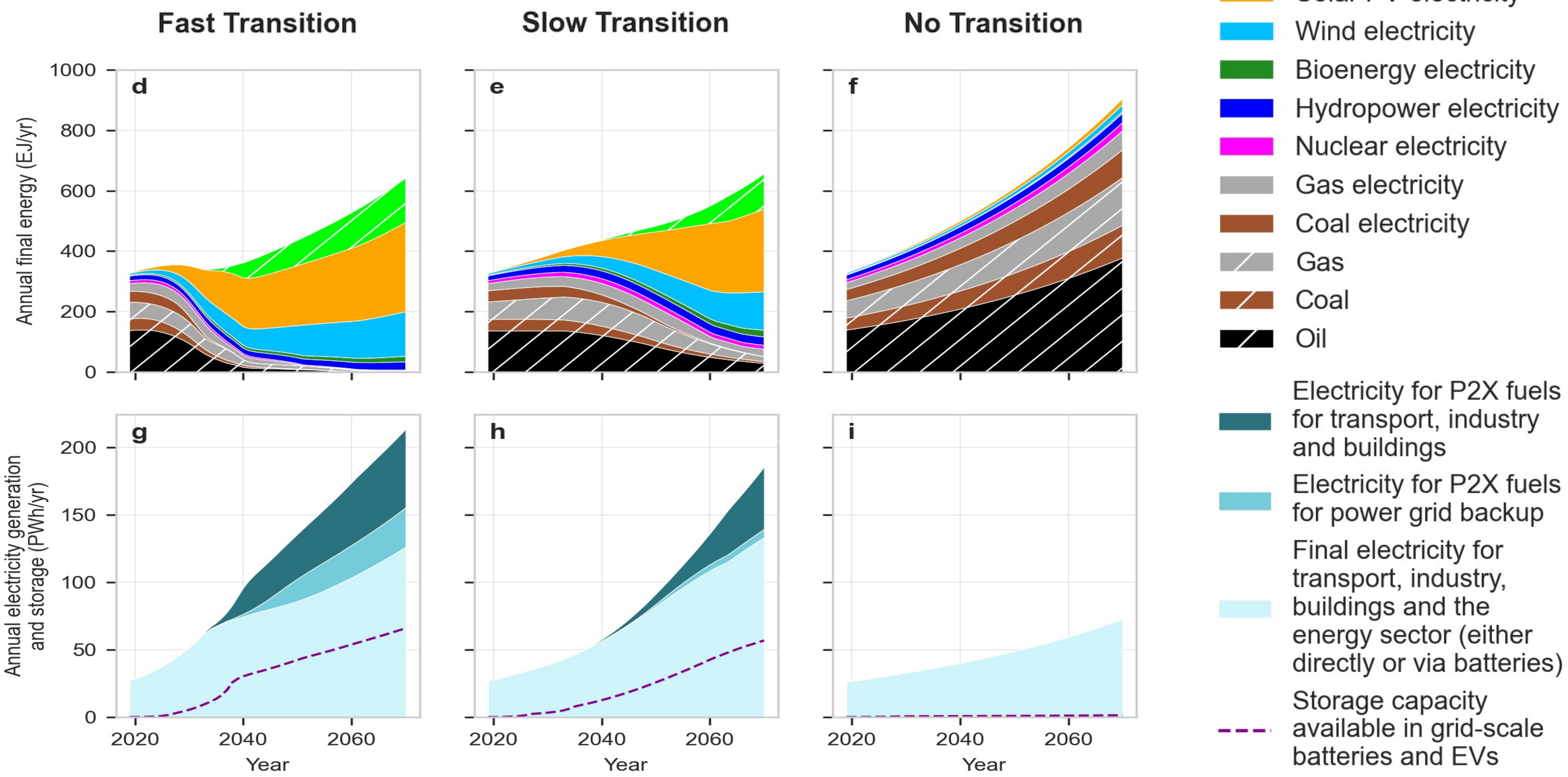
Our system model



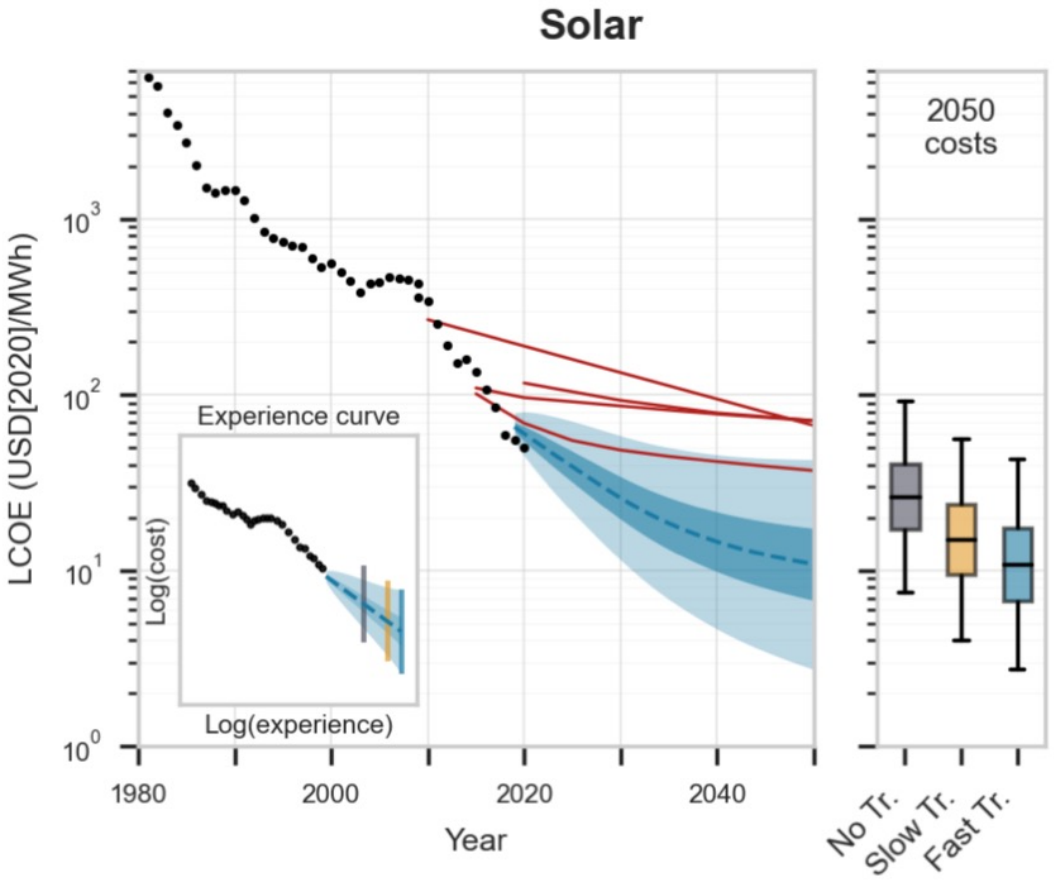
How we construct scenarios by letting trends continue

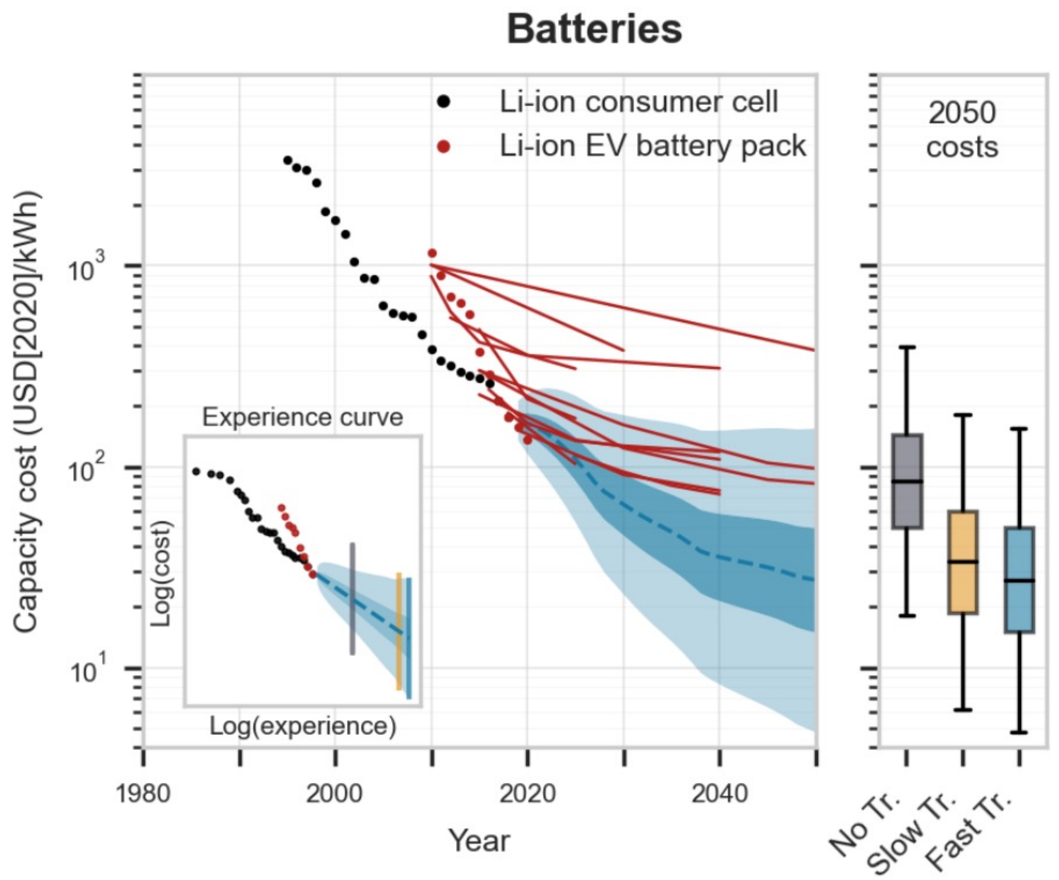


Focus on three scenarios

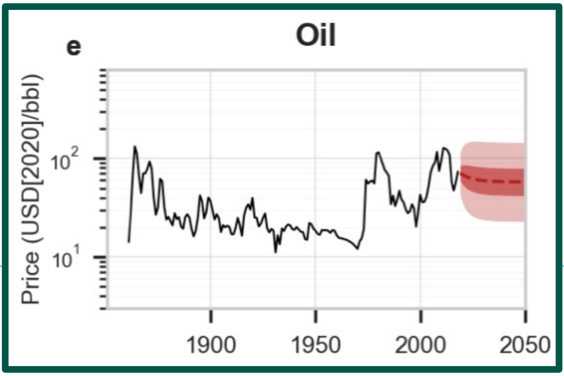


Forecasts generated by our scenarios

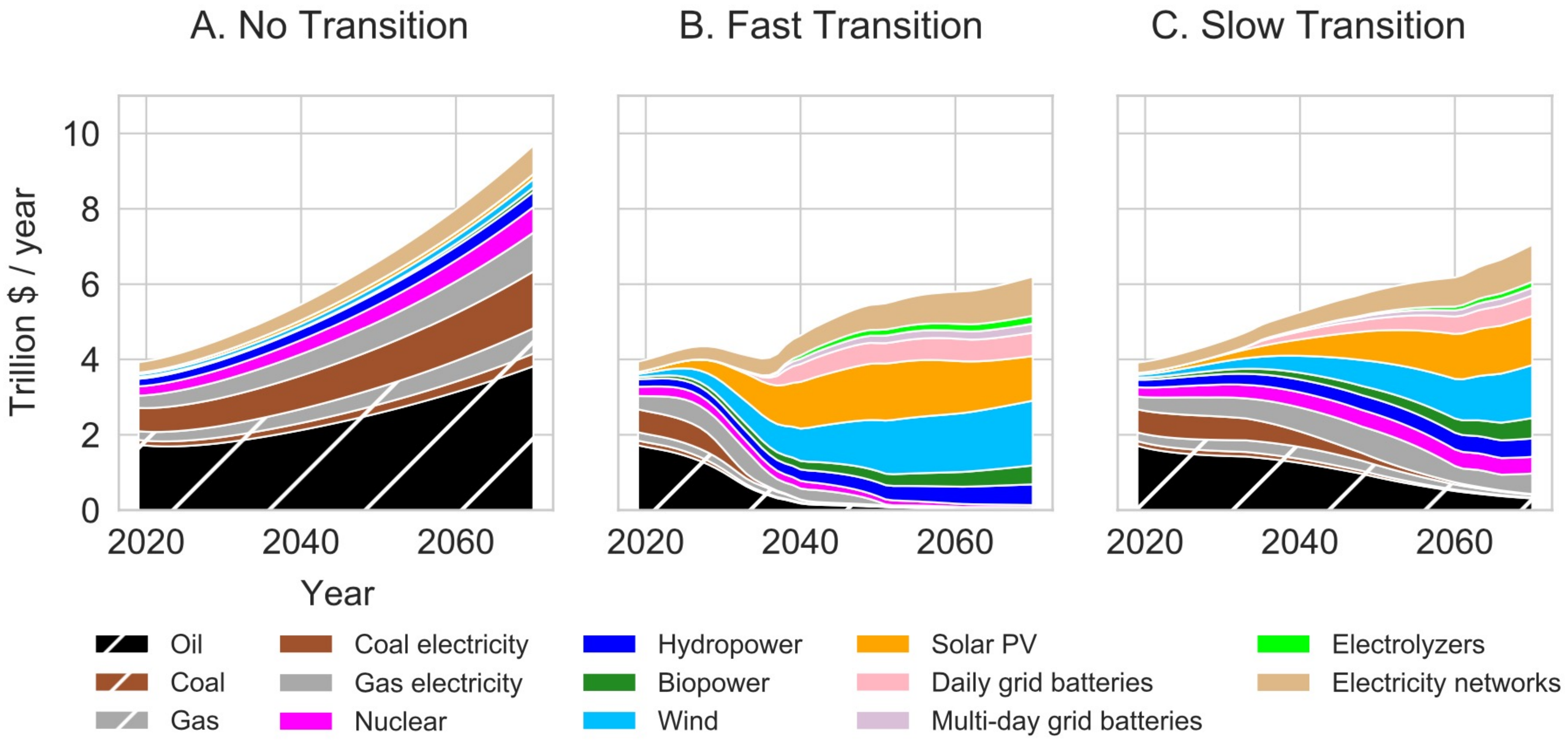




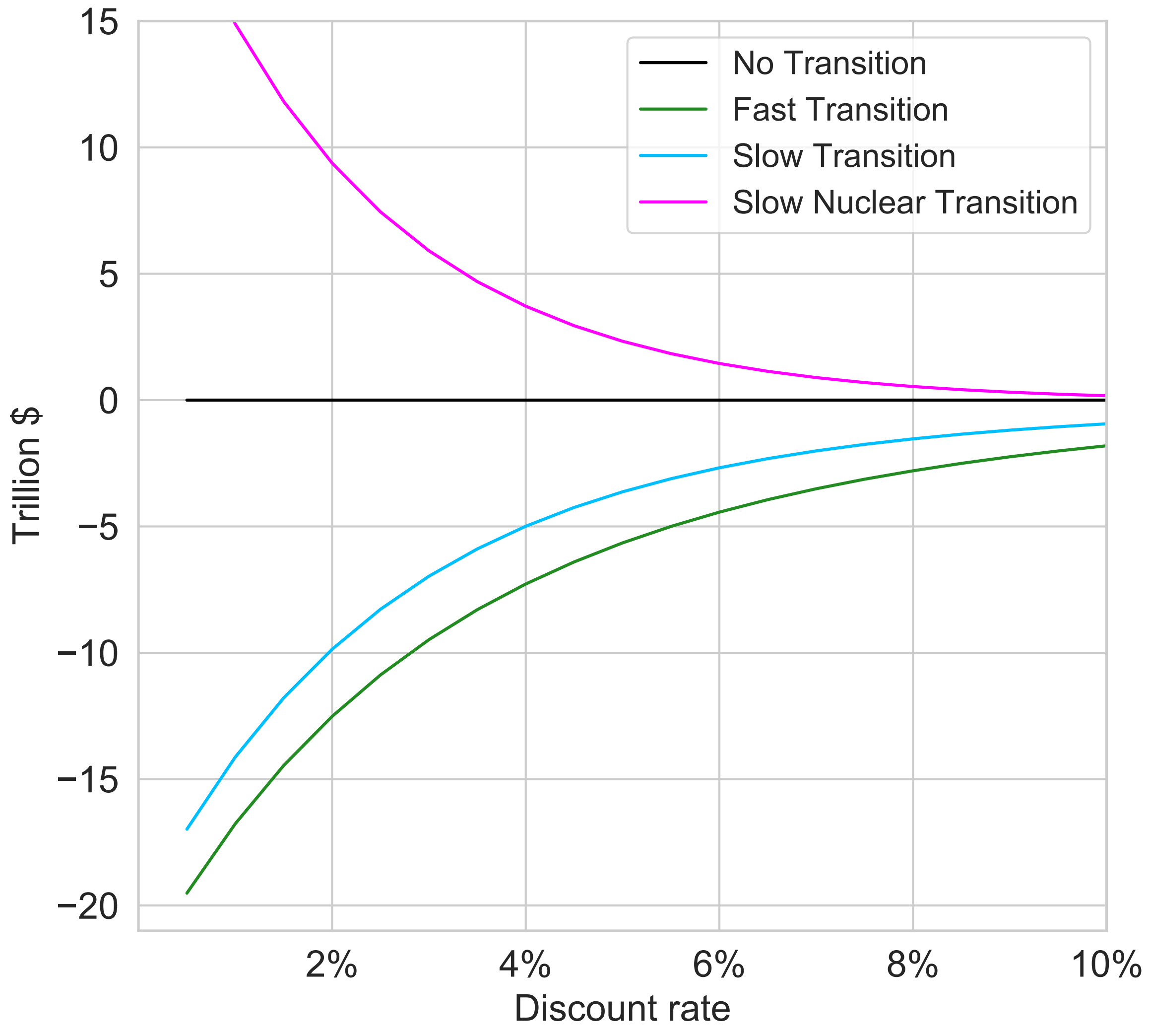
- Observed global average technology costs
- Probabilistic Wright's law forecast under Fast Transition scenario (median, 50% C.I. and 95% C.I.)
- High progress IAM or IEA cost projections
- Probabilistic AR(1) forecast (median, 50% C.I. and 95% C.I.)



Results - median expenditures on each technology



Results – relative net present costs of scenarios



Obvious discussion points to come back to…

- Model granularity (technologies, geography) – what level is best?
  - Sub-techs, tech vintages, regional diversity in costs
- Storage and electrification %s (our own “ad hoc” assumptions)
- Tech surprises – what can’t we predict?
- We made consistently pessimistic assumptions re costs and performance of clean technologies (e.g. assume FF costs don’t rise, no DSM)
- Interpretation – we don’t say *how* to achieve any scenario… policy
- New techs likely to make a fast transition even cheaper – structural batteries, grid-forming inverters, hot-rock storage…

What is the cost of decarbonising the global energy system?

- **Commonly assumed that clean energy transition will be very expensive.**

- **But wind, solar have dropped in price for many decades, in contrast to coal, oil, gas, nuclear…**

- **Converting to renewables plus storage quickly is likely to deliver net savings, above and beyond climate change mitigation benefits**

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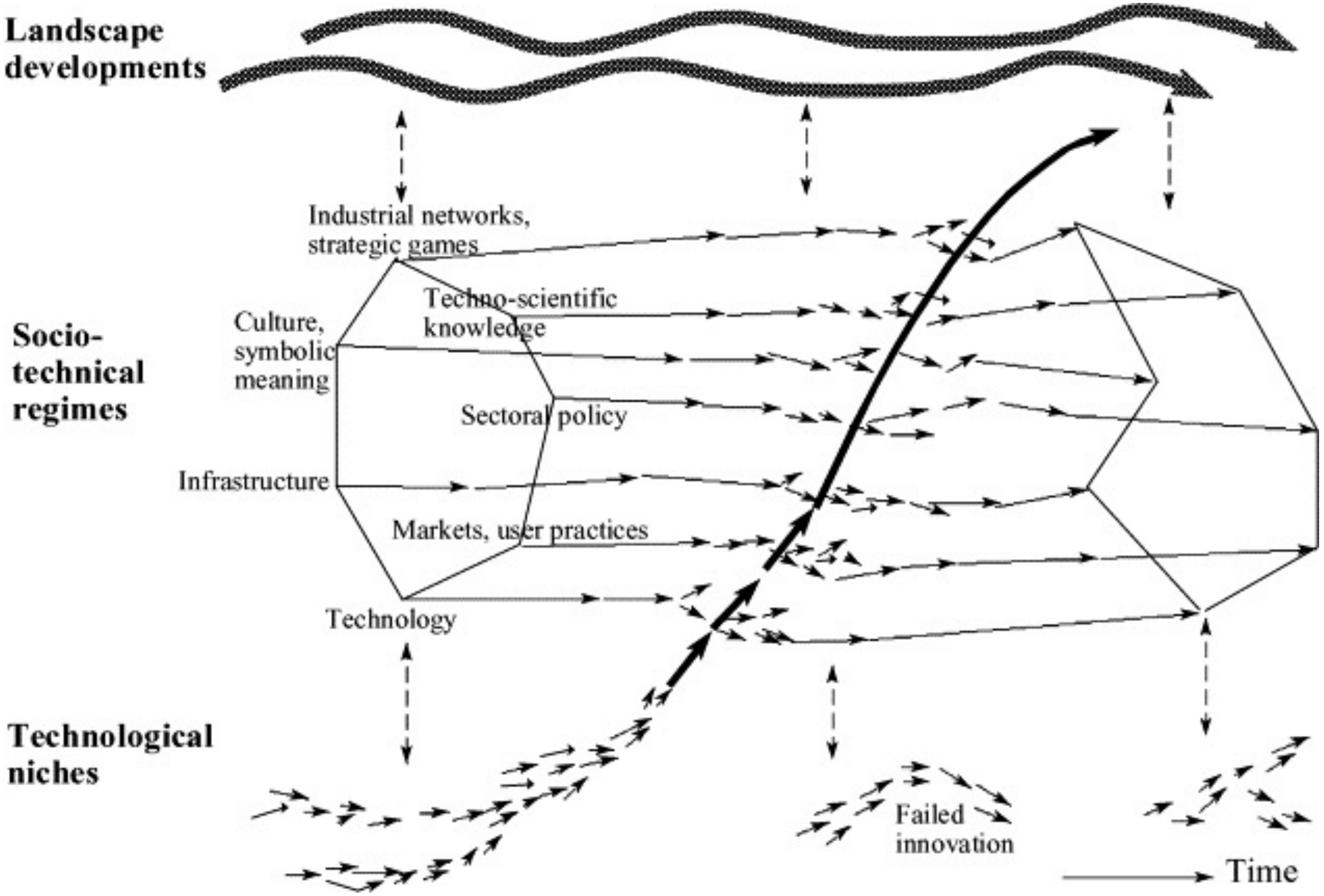
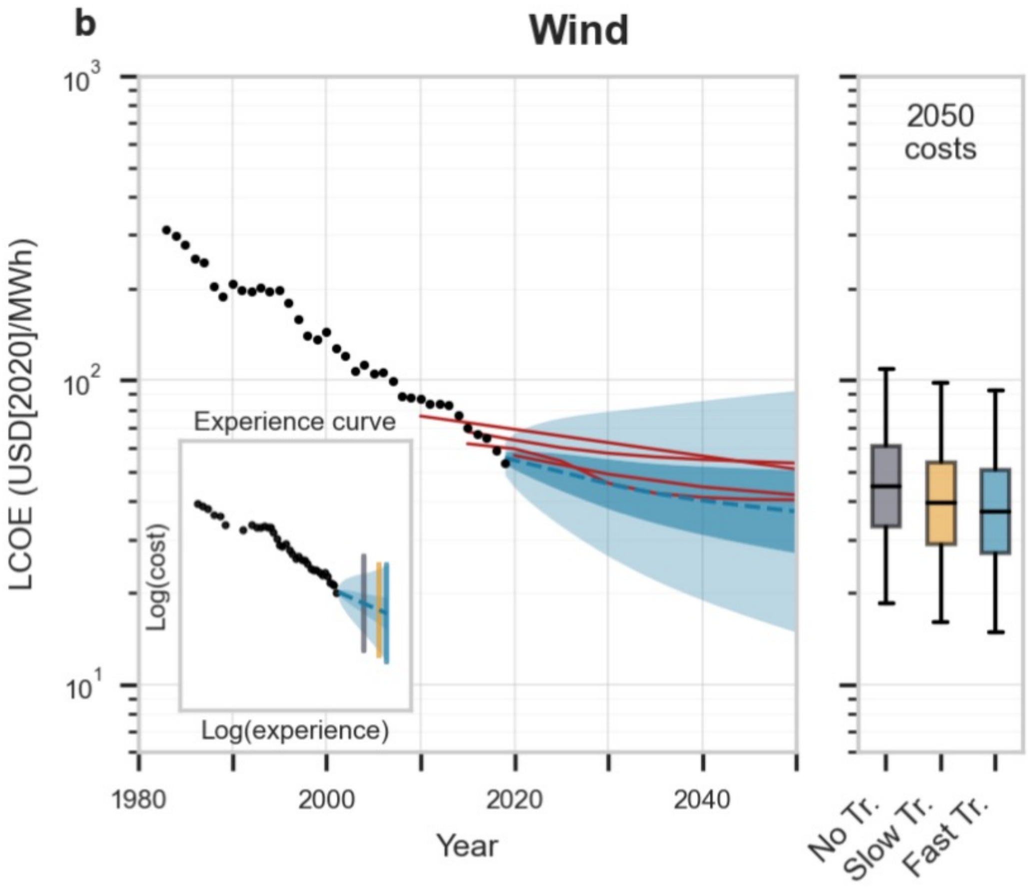
Socio-technical transitions and experience curves



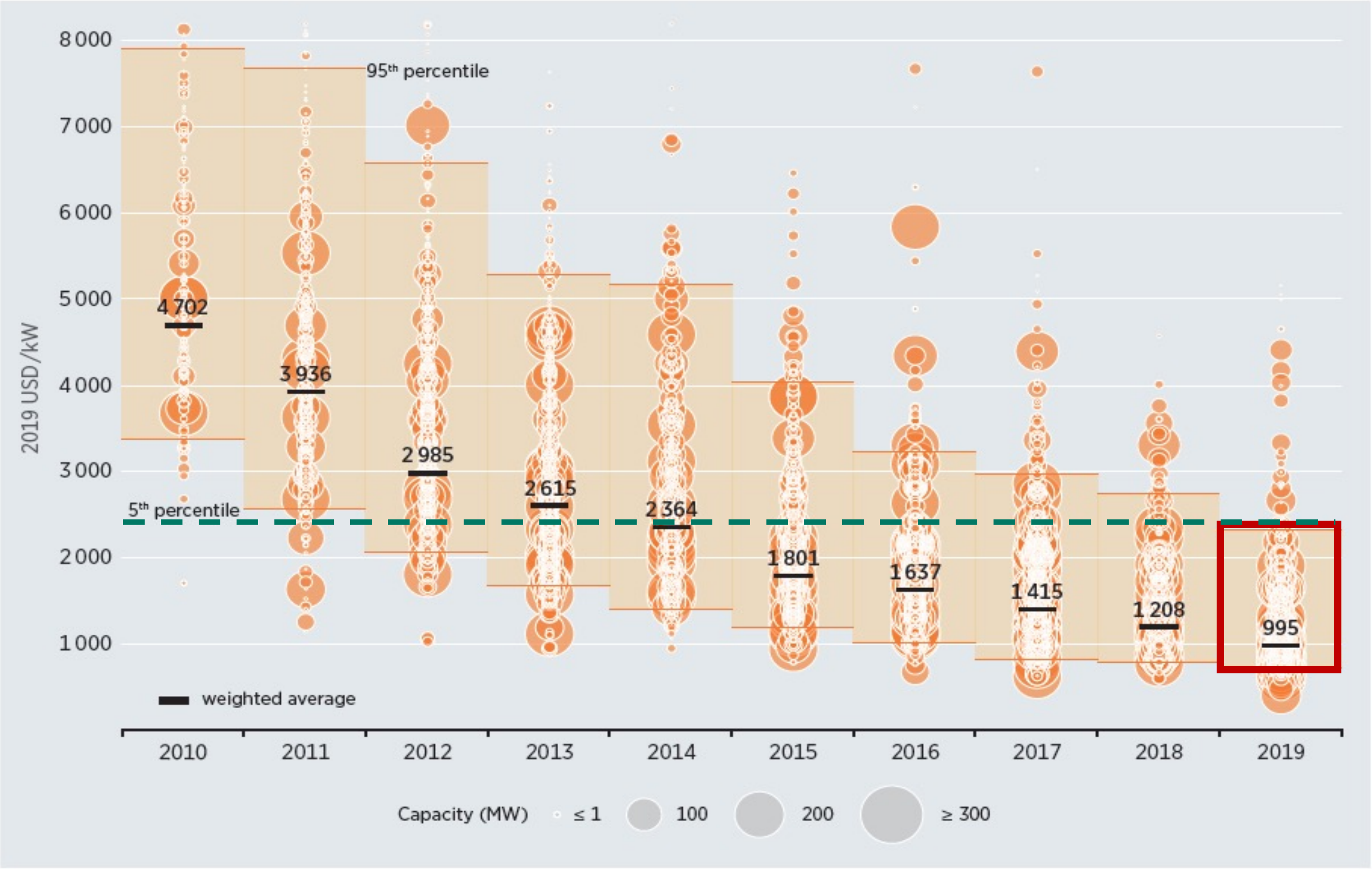


(Geels 2019)

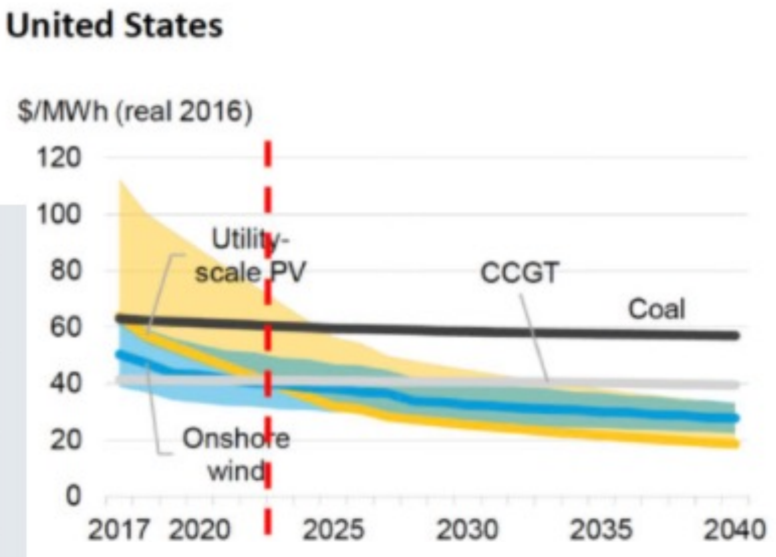
Renewables cheaper than fossil fuels within 5 years for China and US

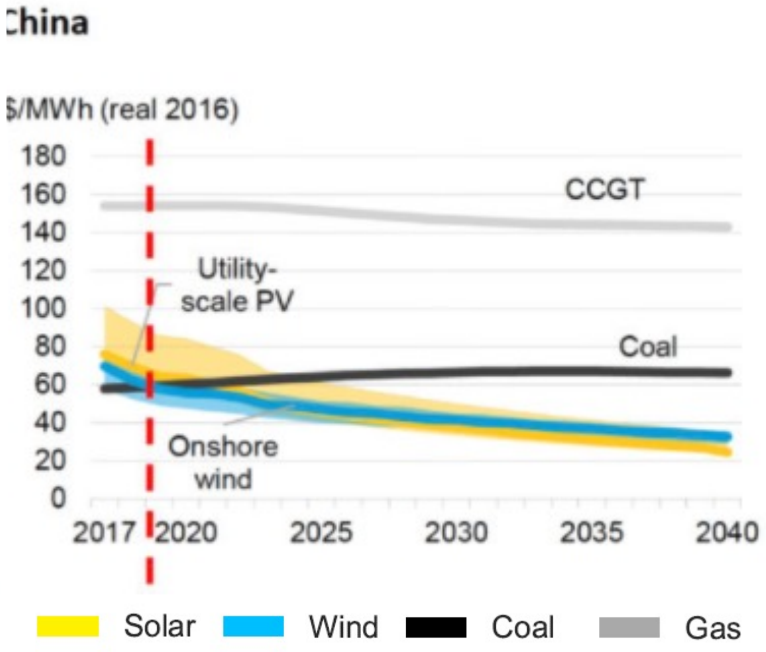
Figure 3.5 Detailed breakdown of utility-scale solar PV total installed costs by country, 2019

Figure 3.3 Total installed PV system cost and weighted averages for utility-scale systems, 2010-2019



Source: *IRENA Renewable Cost Database.*

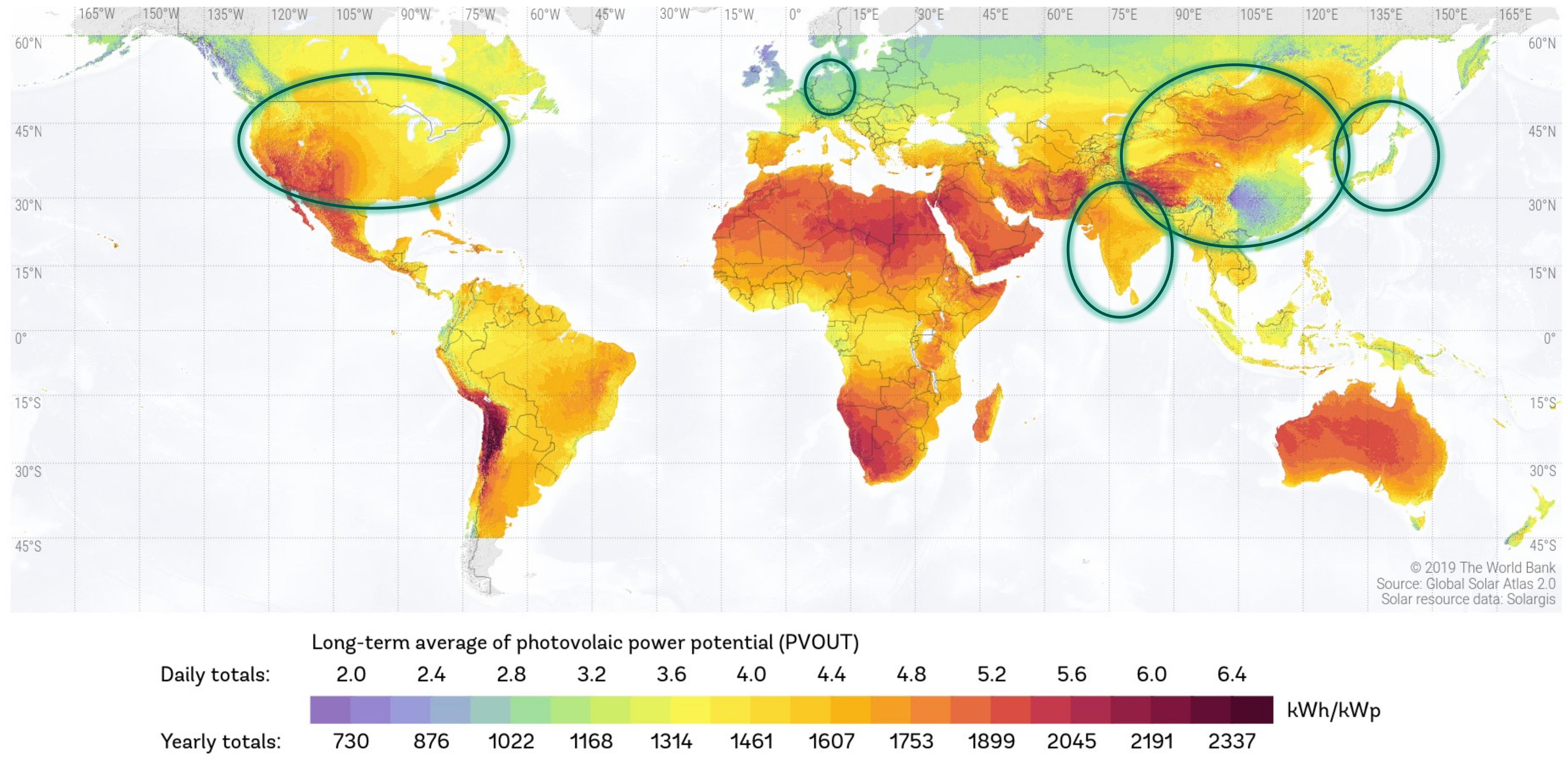




Source: Bloomberg New Energy Finance

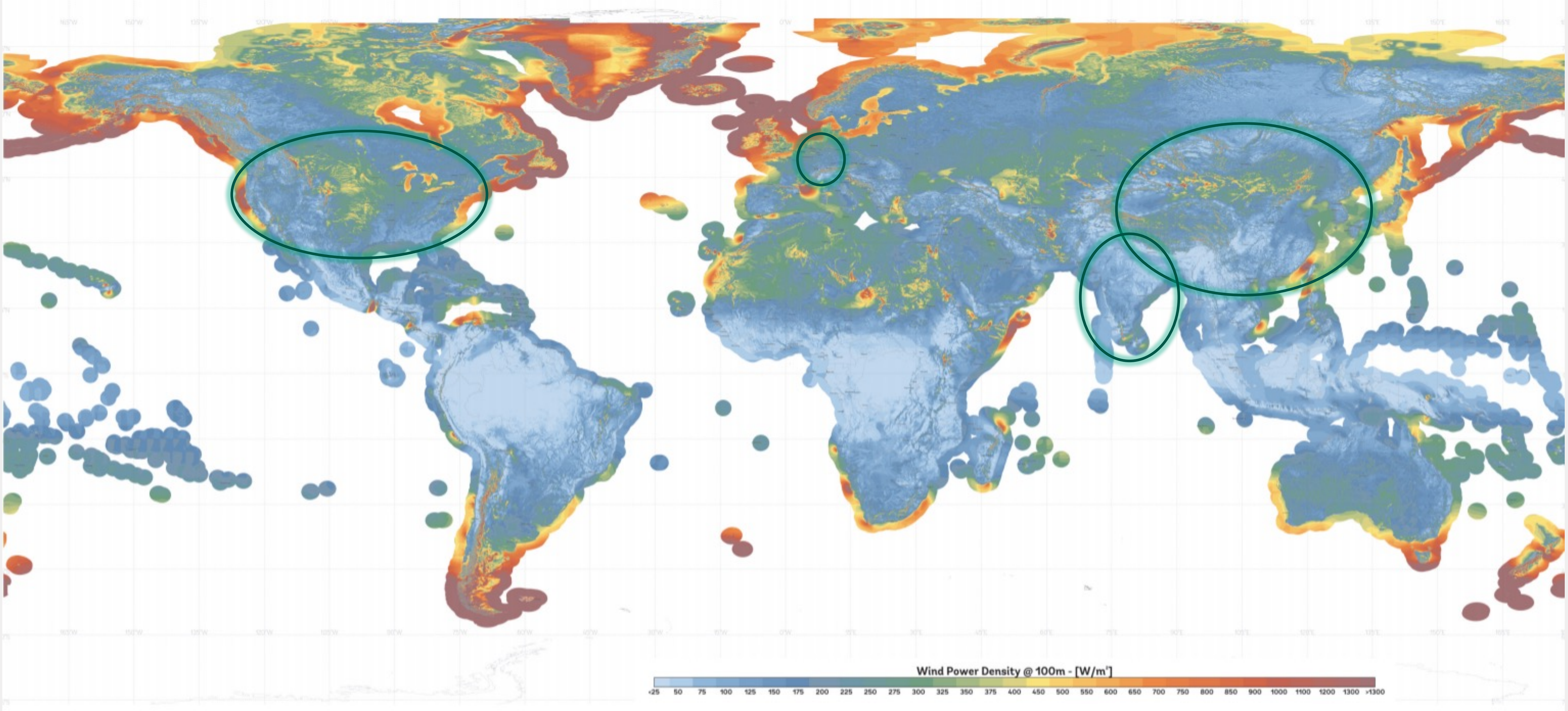
Green Energy Potential: Solar

Most solar capacity is situated in China (255 GW), the United States (76 GW), Japan (68 GW), Germany (54 GW), and India (39 GW)

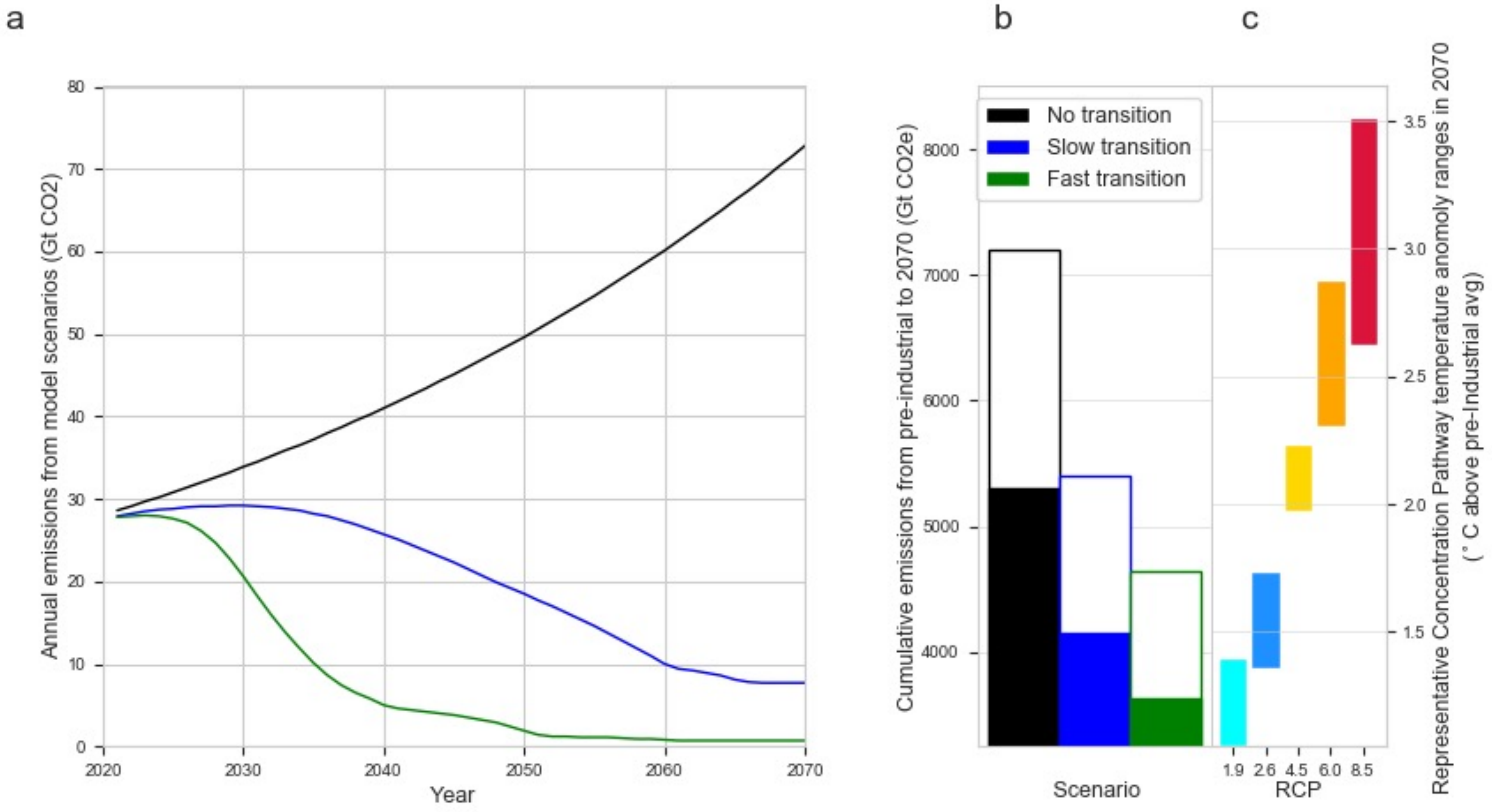


Green Energy Potential: Wind

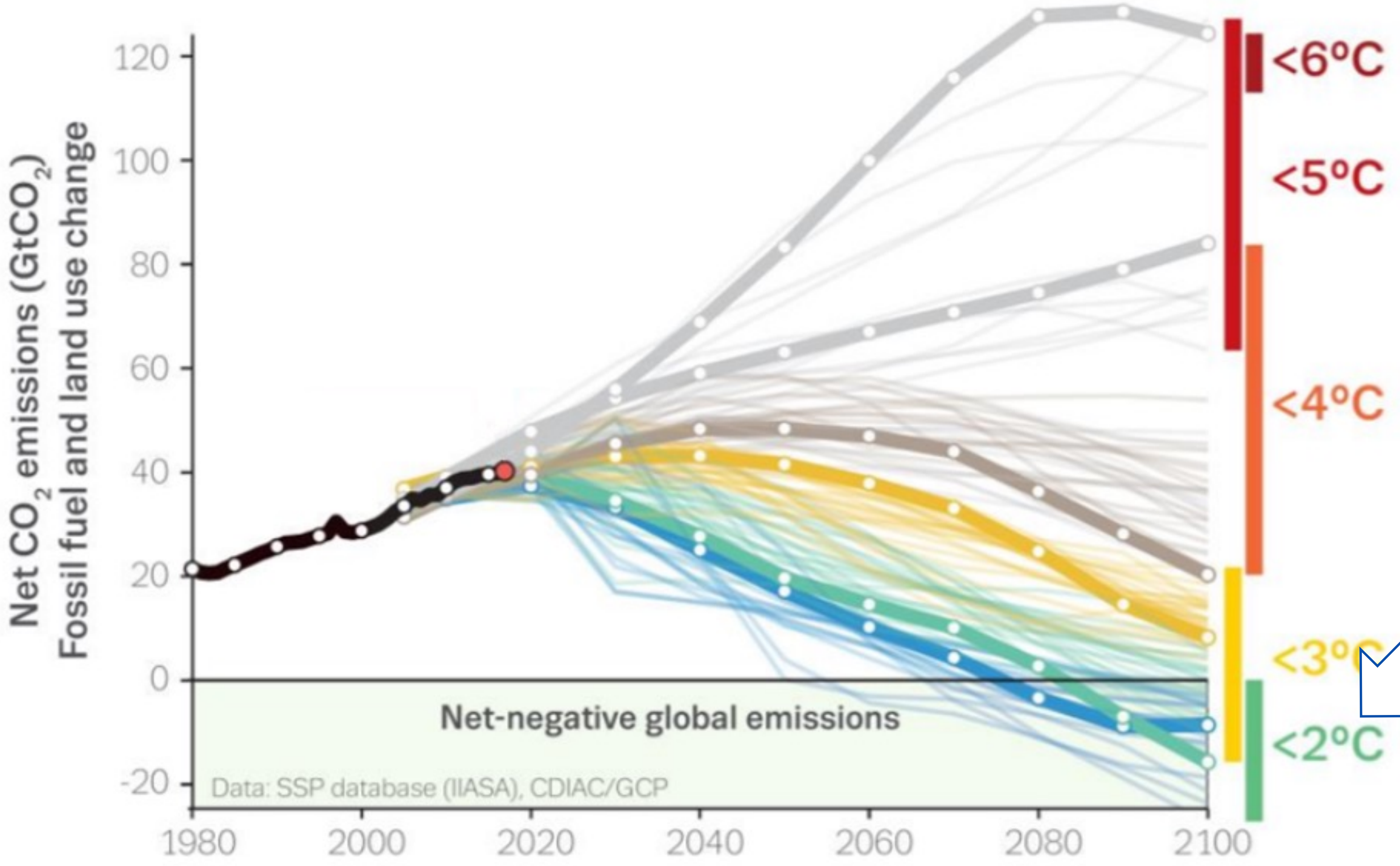
Most wind capacity is situated in China (288 GW), the United States (122 GW), Germany (62 GW), and India (39 GW)



Paris compliance will still require effort on non-energy emissions



The IPCC story of meeting the Paris goals seems unachievable

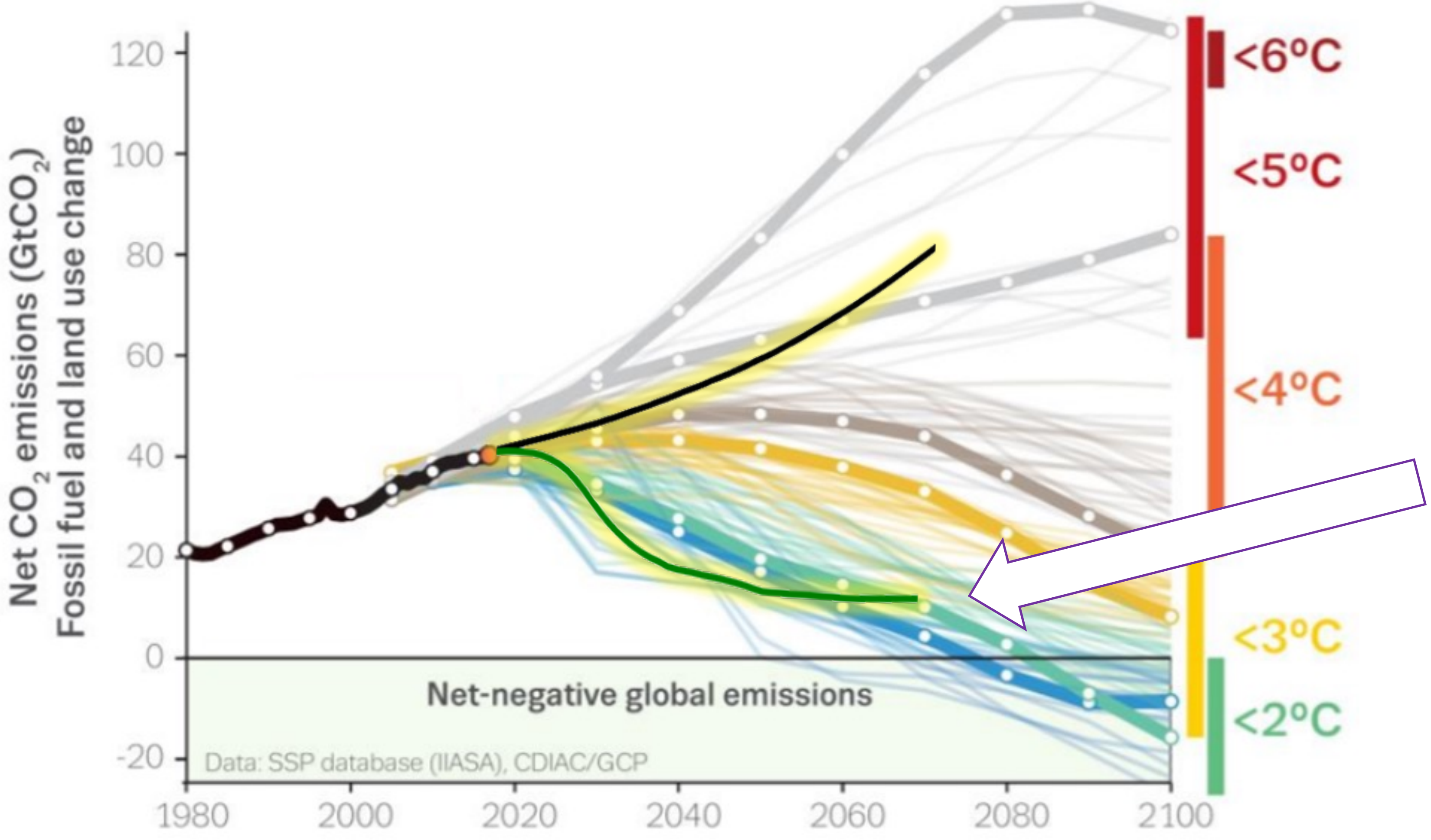


Source: Global Carbon Project (2017) and Bank of England (2018)

To achieve < 2 degrees:

- Economic growth will suffer
- We may need to reduce our energy usage
- We need to build a Carbon Capture and Storage plant every 3 days to 2100
- Electricity prices are likely to be higher

Aligns the energy system with the Paris goals for much less cost



Source: Global Carbon Project (2017) and Bank of England (2018)

The Decisive Transition is:

- No reduction in economic growth required
- No reduction in energy use applied
- Carbon Capture and Storage not used
- Electricity prices ~ *one third* of "business-as-usual"

SUSTAINABLE DEVELOPMENT GOALS

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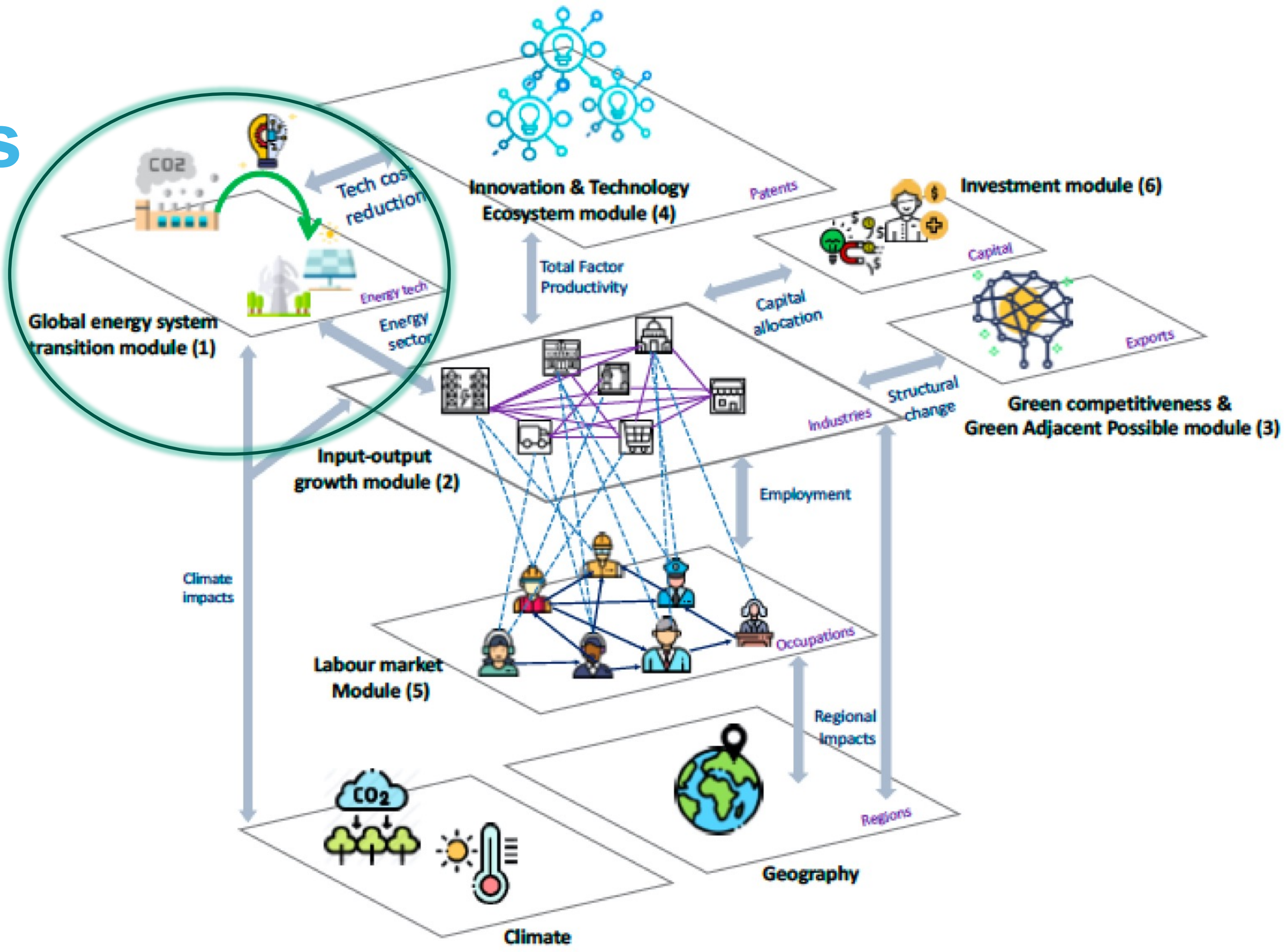
- There is an opportunity to change the “mood music” being played to decision makers
- Continued strong growth in investment in key renewable and storage technologies over the next decade will:
  - Put us on track to meet the Paris emission reduction goals
  - Cost trillions less than business as usual
  - Need not reduce economic prosperity
  - And could make electricity much cheaper for everyone
- COP26 offers an opportunity for a *Glasgow Accord* on action - decisive support for renewables + storage now will pay huge dividends

Oxford Integrated Climate Economics Model

- ➢ Modular by design
- ➢ Empirically grounded, verified & tested
- ➢ Driven by micro level data
- ➢ Enables simulations based on model predictions for policy exploration



Thank you