

Cities & renewable energy, part 2 (solar)

MIT 11.165/477, 11.286J

David Hsu
Associate Professor
Urban Studies & Planning
MIT

October 27, 2022

Materials for today

- David J. C. MacKay. Could energy-intensive industries be powered by carbon-free electricity? *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 371(1986):20110560, March 2013. ISSN 1364-503X, 1471-2962. [doi](#). [URL](#).
- David J. C. MacKay. Solar energy in the context of energy use, energy transportation and energy storage. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 371(1996):20110431, August 2013. ISSN 1364-503X, 1471-2962. [doi](#). [URL](#).
- Sanya Carley, David M. Konisky, Zoya Atiq, and Nick Land. Energy infrastructure, NIMBY-ism, and public opinion: a systematic literature review of three decades of empirical survey literature. *Environmental Research Letters*, 15(9):093007, August 2020. ISSN 1748-9326. [doi](#). [URL](#).
- Lawrence Susskind, Jungwoo Chun, Alexander Gant, Chelsea Hodgkins, Jessica Cohen, and Sarah Lohmar. Sources of opposition to renewable energy projects in the United States. *Energy Policy*, 165:112922, June 2022. ISSN 0301-4215. [doi](#). [URL](#).

Your renewable toolbox

Deploying these at scale requires building a new energy system:

Building blocks:

- solar (47X)
- wind (28X)
- storage
- geothermal
- electrolysis, hydrogen



To do list:

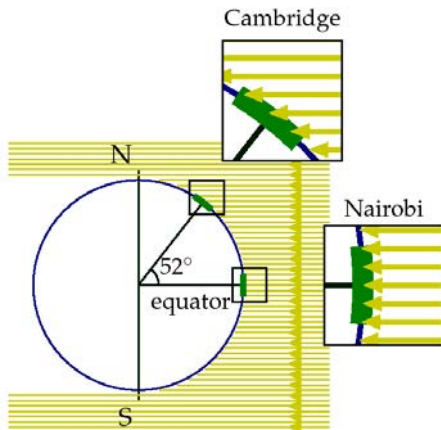
- financing
- generation
- transmission
- distribution
- balancing
- reliability
- resilience
- siting

Agenda for the next few classes

- wind basics: capacity factors
- solar basics: adoption costs, learning curves, siting issues
- storage and geothermal: developing new niches

Solar: incident light

Figure courtesy of David MacKay.



Mackay, figure 3.3

Cambridge, UK = 52.2° lat: $\cos \theta = \cos (52^\circ) = 0.60$ if flat
Cambridge, MA = 42.3° lat: \approx roof angle pitch

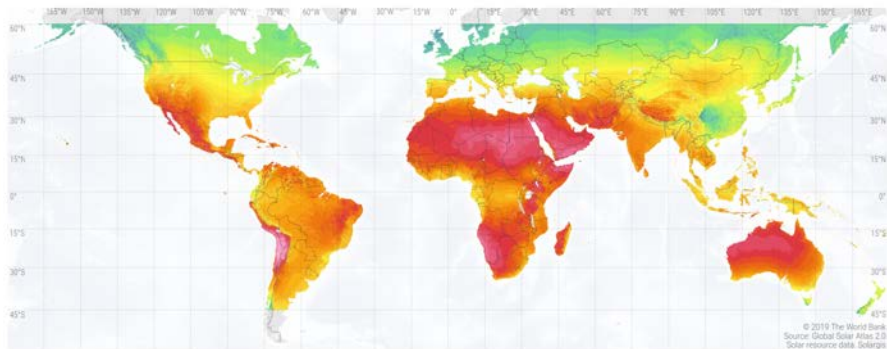
SOLAR RESOURCE MAP GLOBAL HORIZONTAL IRRADIATION



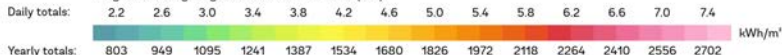
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Long-term average of global horizontal irradiation (GHI)



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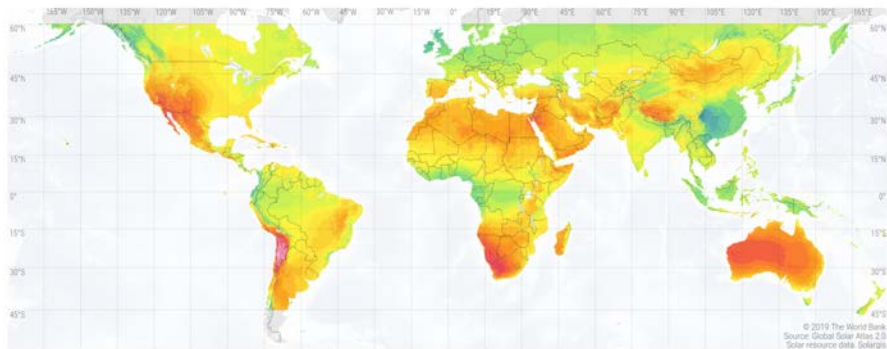
SOLAR RESOURCE MAP
DIRECT NORMAL IRRADIATION



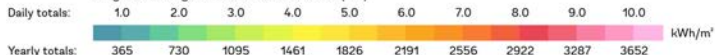
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Long-term average of direct normal irradiation (DNI)



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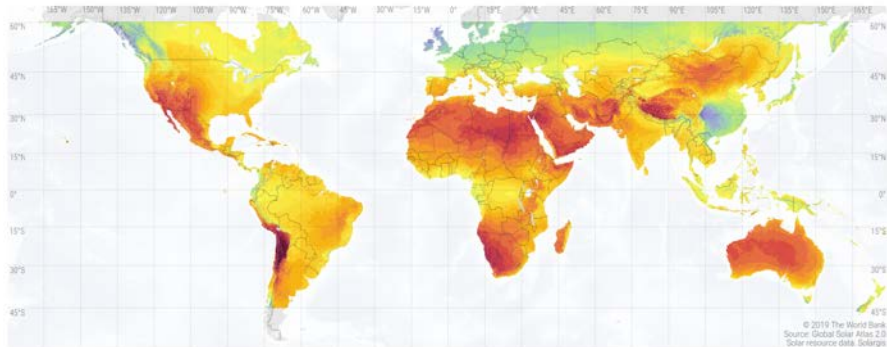
SOLAR RESOURCE MAP PHOTOVOLTAIC POWER POTENTIAL



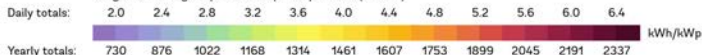
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Long-term average of photovoltaic power potential (PVOUT)

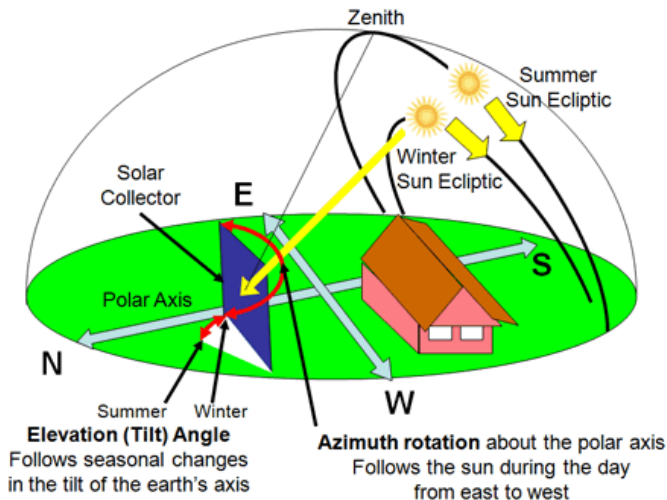


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Solar tracking (mpoweruk.com)



Solar Tracking

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Concentrated solar power (CSP) or solar thermal towers



By Amble - Own work, CC BY-SA 4.0

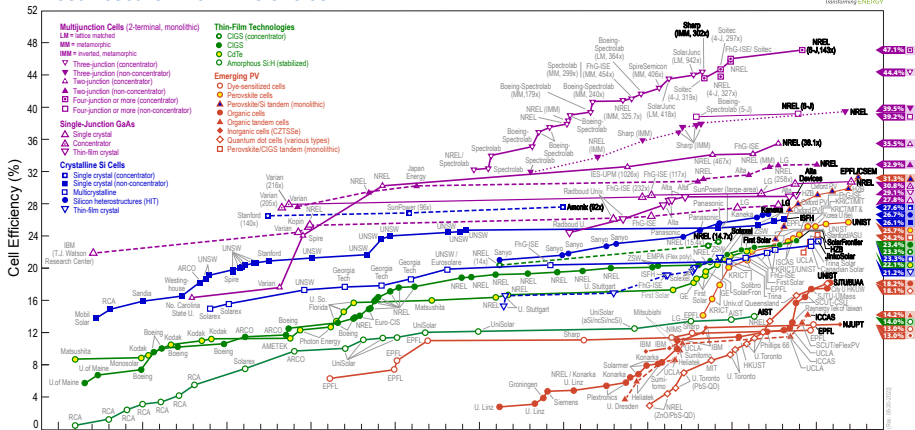
Solar photovoltaic panels

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Best Research-Cell Efficiencies

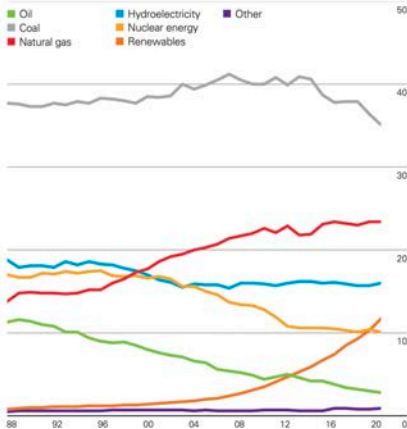


Solar PV, NREL graph, 6/30/2022

Public domain figure courtesy of NREL / US Department of Energy.

Share of global electricity generation by fuel

Percentage



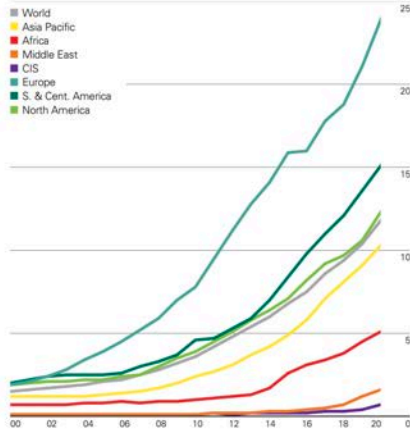
At a global level, coal is the dominant fuel for power generation, however its share fell 1.3 percentage points to 35.1% in 2020, the lowest level in our data series. The share of renewables rose to record levels last year (11.7%), with the combined share of renewables and gas-fired power (35.1%) equalling coal for the first time. Europe's share of renewables in power generation reached 23.8%, surpassing nuclear energy and making Europe the first region where renewables are the dominant source of power generation.

64

bp Statistical Review of World Energy 2021

Renewables share of power generation by region

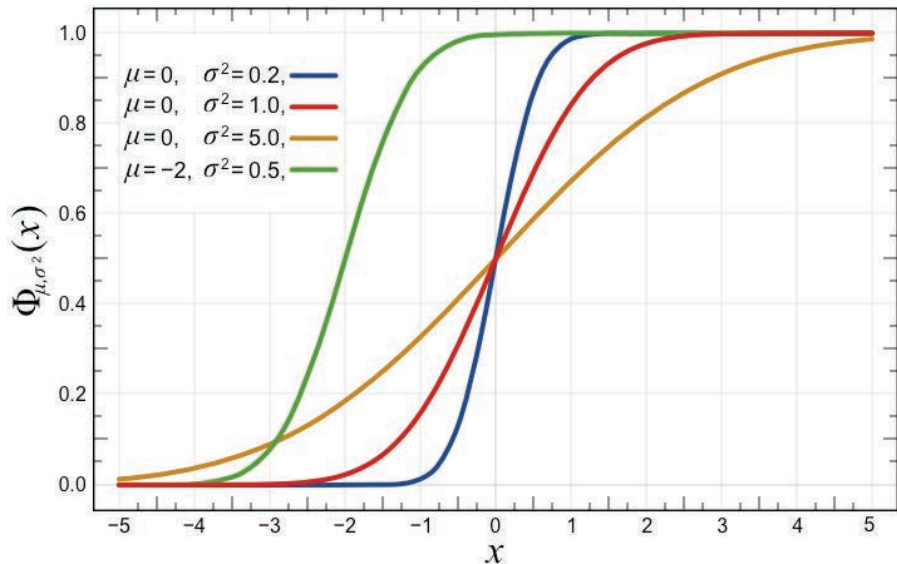
Percentage



BP Statistical Review of World Energy, June 2021

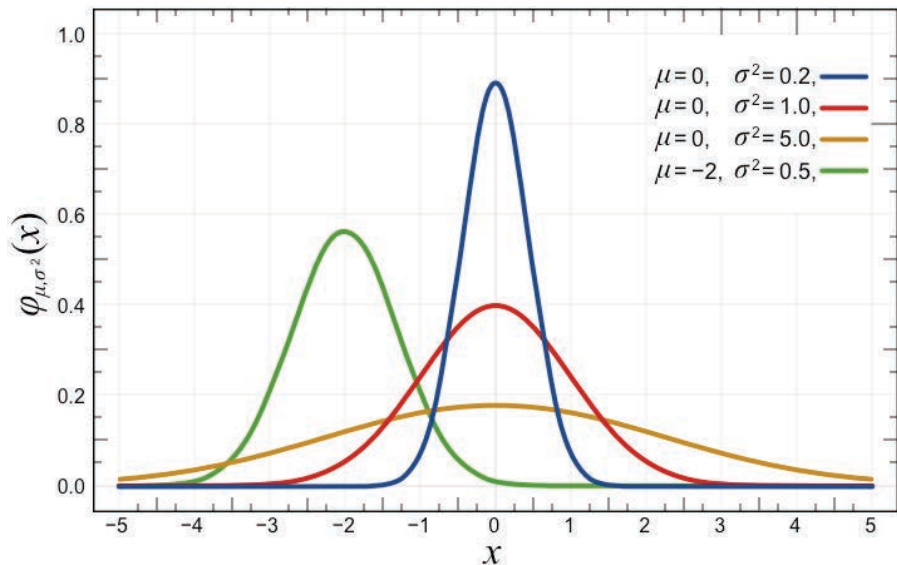
Figures courtesy of BP Statistical Review of World Energy 2021.

Cumulative distribution function



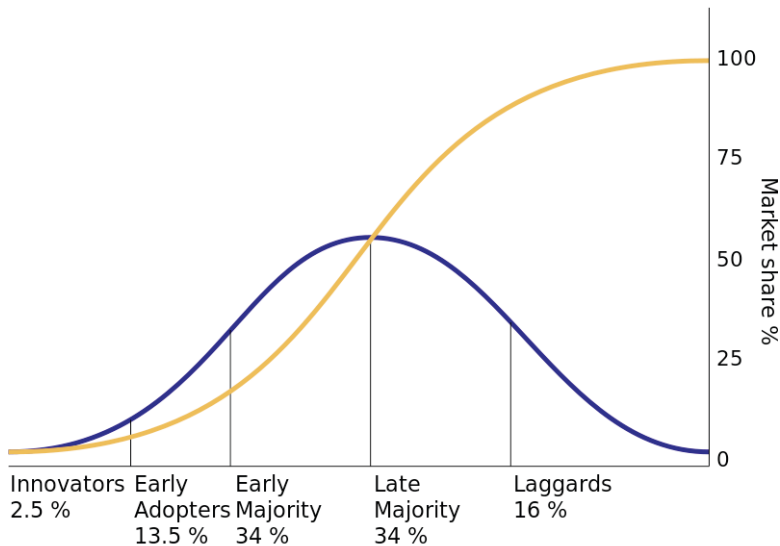
Wikimedia

Probability distribution function



Wikimedia

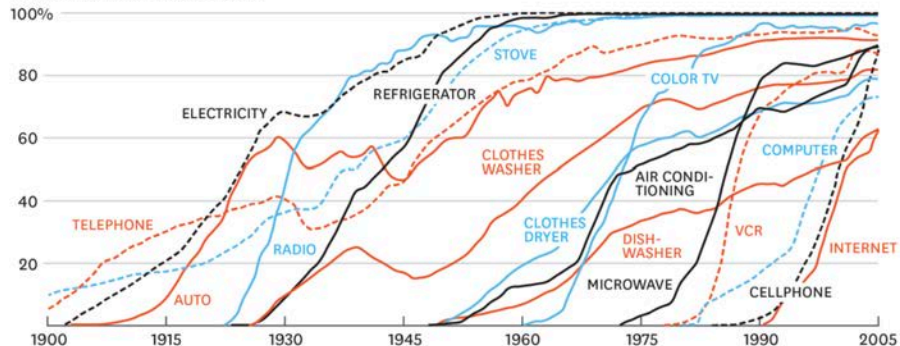
Everett Rogers: diffusion of innovations curve



Wikimedia

CONSUMPTION SPREADS FASTER TODAY

PERCENT OF U.S. HOUSEHOLDS



SOURCE NICHOLAS FELTON, THE NEW YORK TIMES

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Harvard Business Review, 2013

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Our World in Data, updated 2021

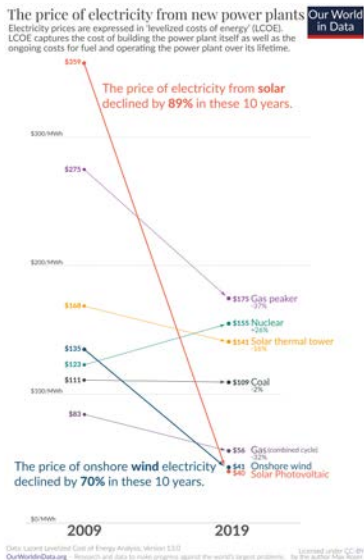
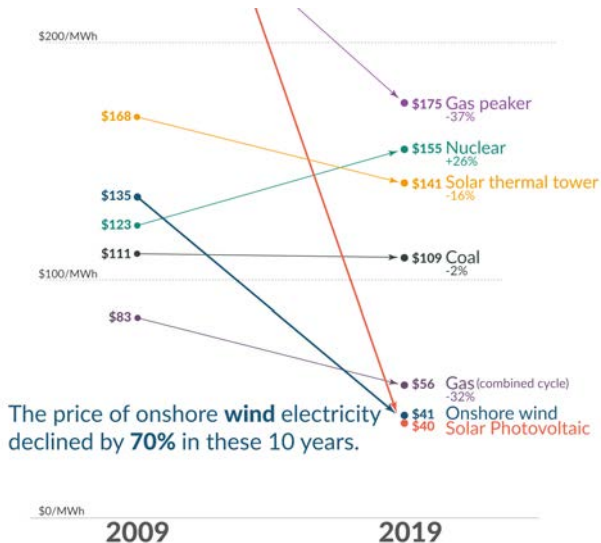


Figure courtesy of Max Roser on Our World in Data. License: CC BY.

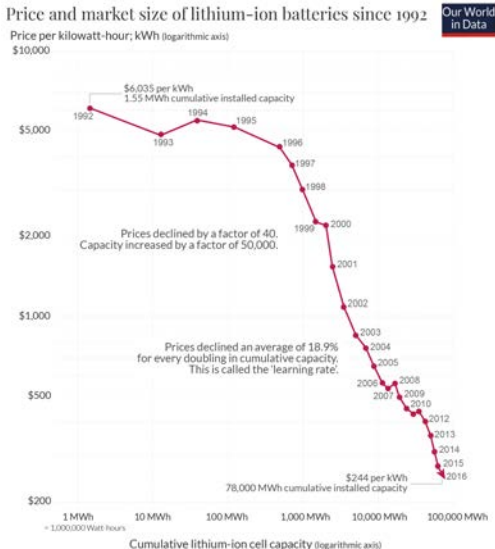


Data: Lazard Levelized Cost of Energy Analysis, Version 13.0

OurWorldinData.org - Research and data to make progress against the world's largest problems.

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From Our World in Data

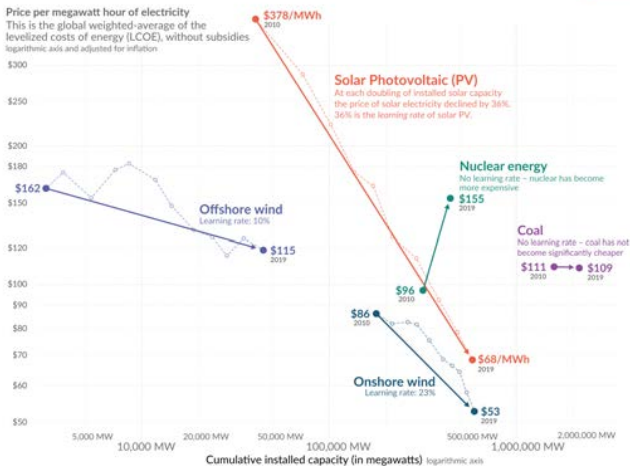


Prices are adjusted for inflation and given in 2018 US-\$ per kilowatt-hour (kWh).
 Source: Michael Zenger and Jessica Trankle (2017) The learning rates of lithium-ion battery technology improvement and cost decline.
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From Our World in Data

Renewable energy, part 2 (solar)

Electricity from renewables became cheaper as we increased capacity – electricity from nuclear and coal did not



Source: IRENA 2020 for all data on renewable sources; Lazard for the price of electricity from nuclear and coal - IAEA for nuclear capacity and Global Energy Monitor for coal capacity. Gas is not shown because the price between gas peaker and combined cycles differs significantly, and global data on the capacity of each of these sources is not available. The price of electricity from gas has fallen over this decade, but over the longer run it is not following a learning curve.

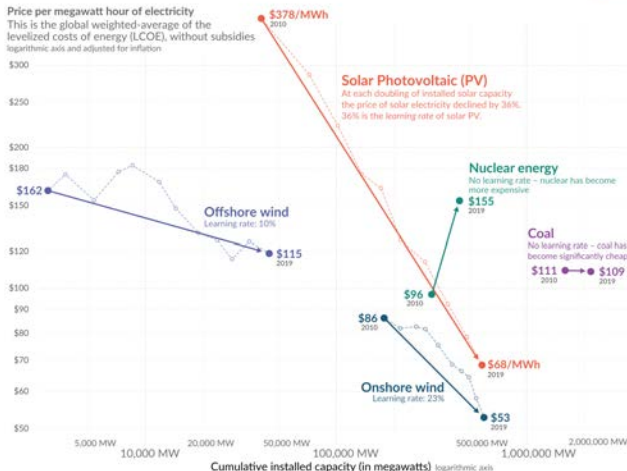
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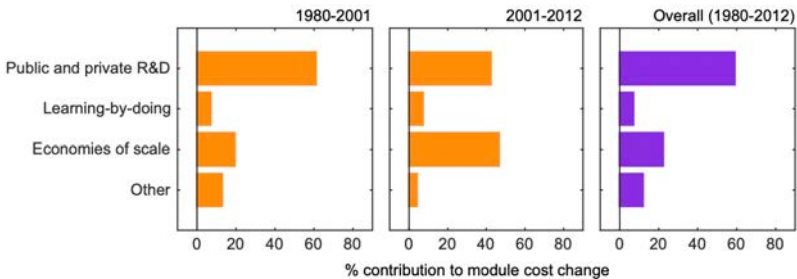
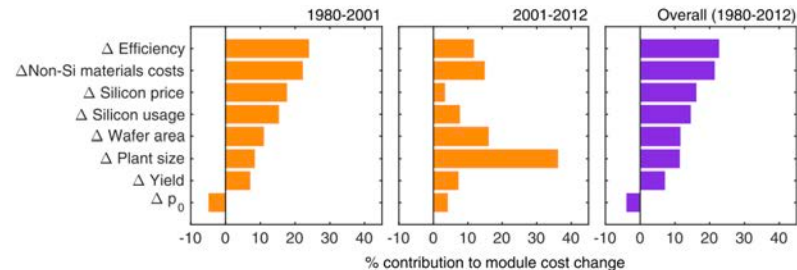
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From Our World in Data

Renewable energy, part 2 (solar)

Why have solar prices declined?



Kavлак, McNerney, Trancik, 2018 Energy Policy

Will solar prices continue to decline?

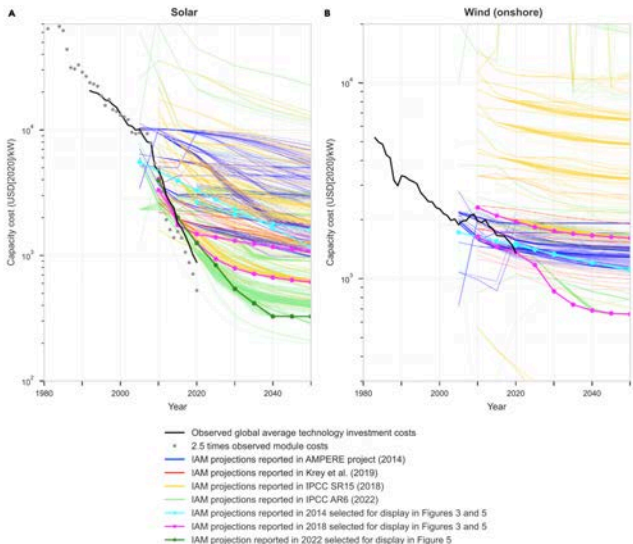
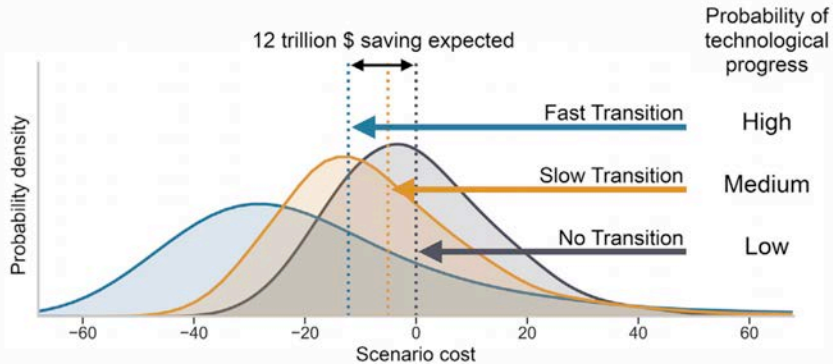
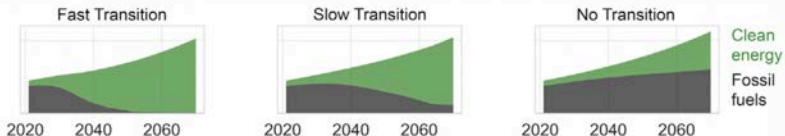


Figure 9. PV and wind capital cost projections reported by IAMs

Joule 2022 paper by Way, Ives, Mealy & Farmer

What would the economic impact be?

Three energy system scenarios



Joule 2022 paper by Way, Ives, Mealy & Farmer

Solar installation costs (NREL, 2015)

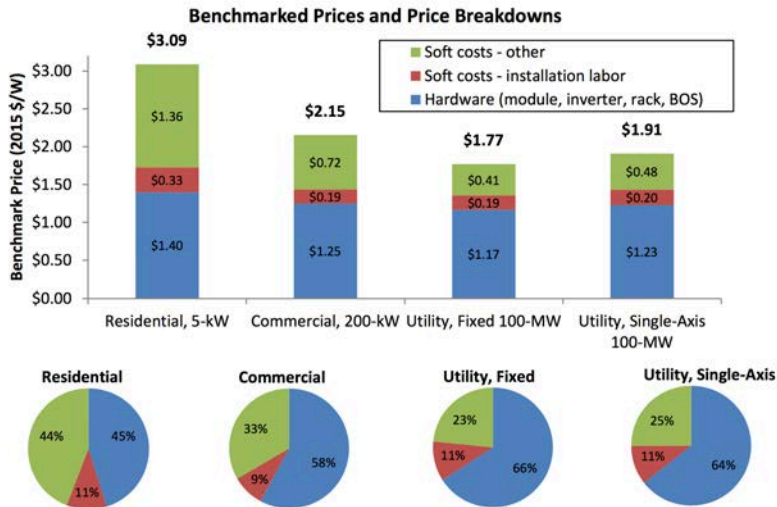


Figure ES-1. Benchmark price summary

Public domain content courtesy of NREL / US Department of Energy.

Roadmap to cheaper solar (NREL, 2018)

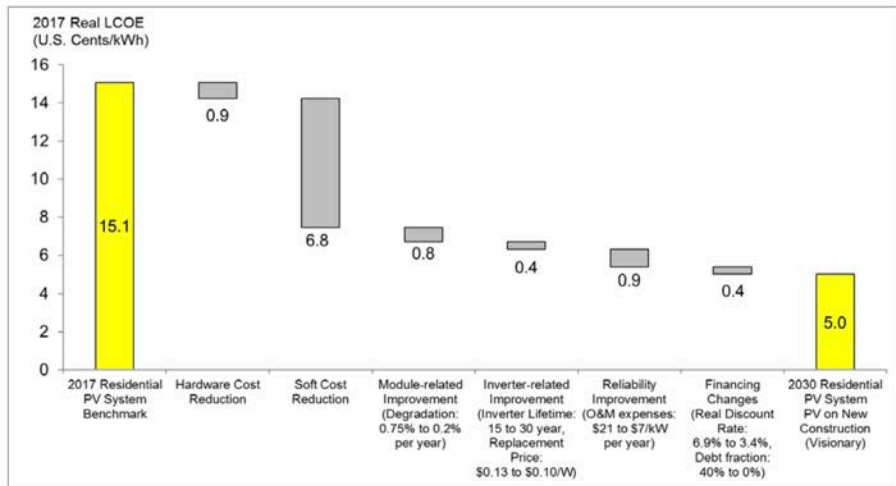


Figure ES-4. Modeled residential PV LCOE reductions for the new home construction market visionary pathway in 2030, compared with the Q1 2017 benchmark

Public domain content courtesy of NREL / US Department of Energy.

Energy density per area (David Mackay, 2013)

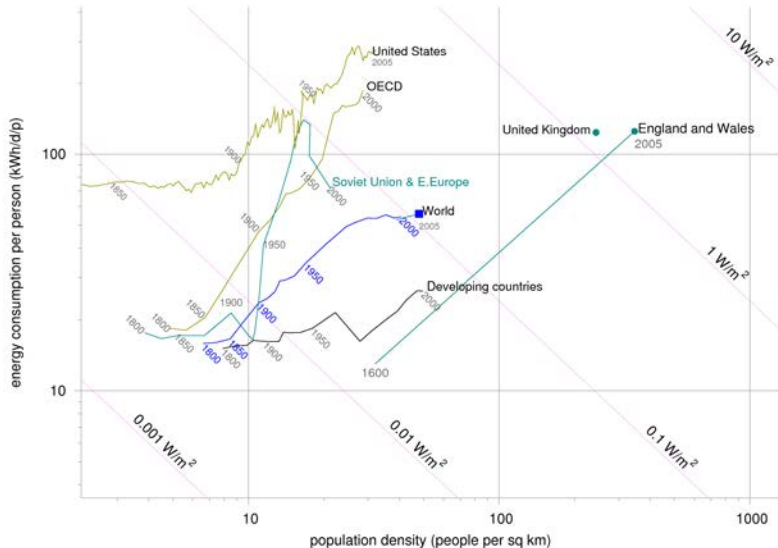


Figure courtesy of David Mackay.

Energy density per area (David Mackay, 2013)

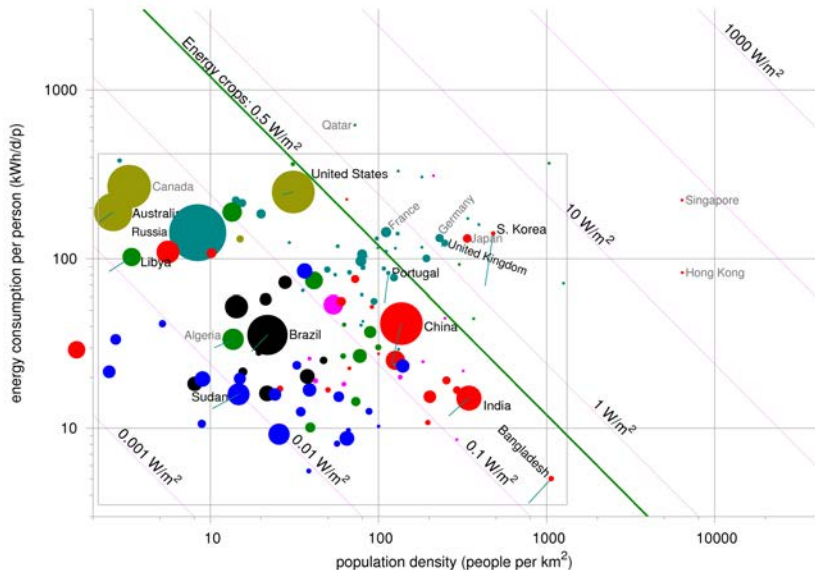


Figure courtesy of David Mackay.

Energy density per area (David Mackay, 2013)

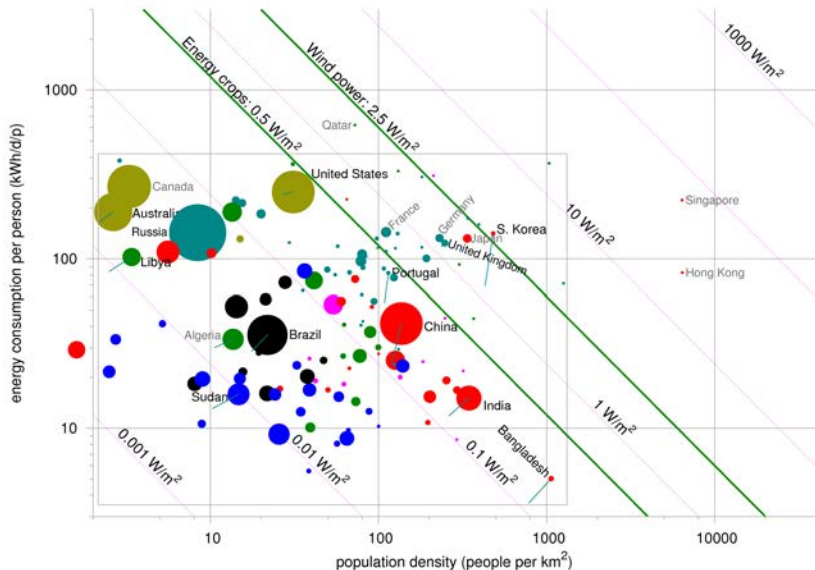


Figure courtesy of David MacKay.

Energy density per area (David Mackay, 2013)

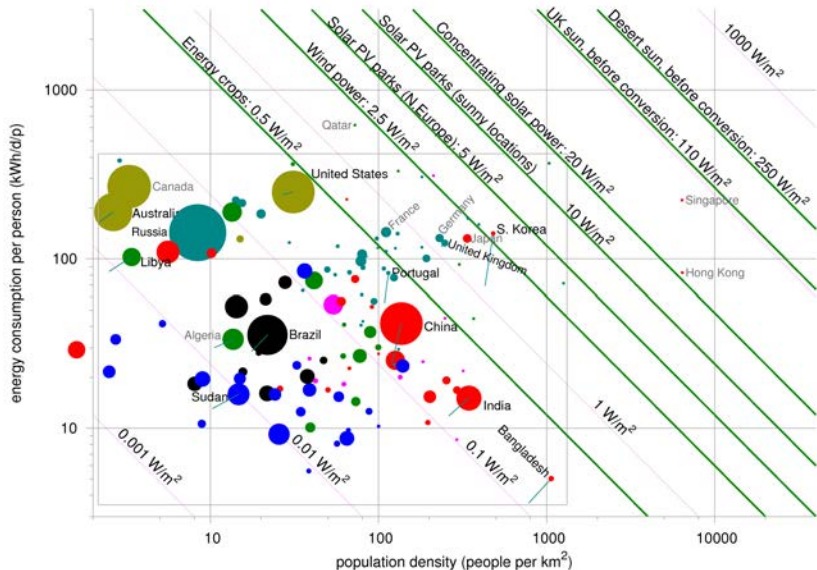


Figure courtesy of David Mackay.

Carley et al 2020: energy infrastructure and NIMBY-ism

What is a systematic literature review?

- set particular search terms and parameters
- extract relevant academic literature
- code, analyze, summarize by data, methods, findings

Findings:

- 1 p. 1: “knowledge, trust, and positive perceptions about the benefits of projects [are] positively correlated with support for projects . . . with variation across energy types”
- 2 p. 11: “in our assessment, it is not clear that NIMBY, as traditionally defined, is often being evaluated. At best, we have a set of inconsistent findings regarding the weight that people give to proximity”
- 3 p. 13: “The high rates of support found in the literature may seem to contradict what is often portrayed as significant opposition.”

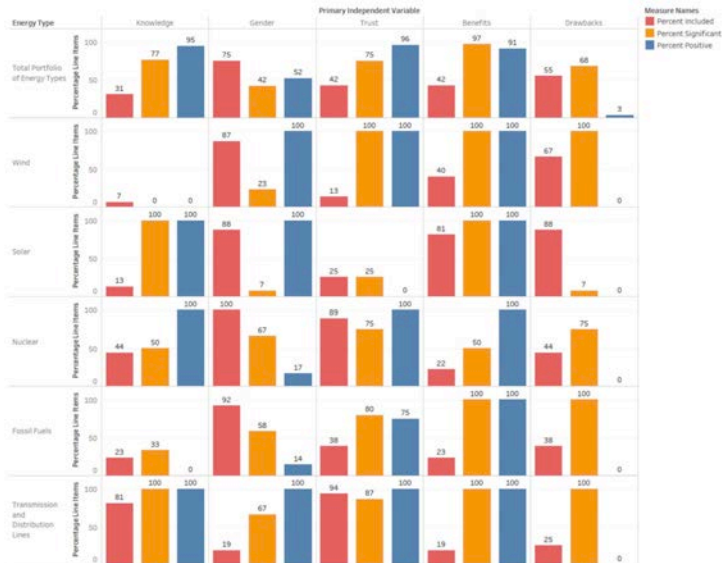


Figure 6. Graph of the percentage of line items (included in the formal modeling category) that included any of the following five variables of interest: knowledge, gender, trust, perceptions about benefits and drawbacks of the energy infrastructure project.

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Susskind et al 2022: sources of opposition

MIT team builds a database of opposition to renewable energy projects.

p. 3: “Reviewed open access media reports and published scholarship to identify instances in which conflict or opposition paused, delayed, or canceled a utility-scale renewable energy project . . . There were media reports on projects that had been completed, including some concerns about these projects that did not lead to stoppage or delay. We did not include these in our study.”

Find 53 projects equivalent to 9586 MW affected:

- 34% delayed
- 49% cancelled permanently
- 26% resumed after being stopped for several months or years.

Susskind et al 2022: sources of opposition

“Seven distinct hypotheses regarding sources of opposition and barriers to renewable energy development:”

- 1 Concerns over possible environmental impacts, including impacts on wildlife
- 2 Challenges to project financing and revenue generation
- 3 Public perceptions of unfair participation processes or inadequate inclusion in light of regulatory requirements
- 4 Failure to respect Tribal rights, including the right to consultation
- 5 Health and safety concerns
- 6 Intergovernmental disputes
- 7 Potential impacts on land and property value

Susskind et al 2022: sources of opposition

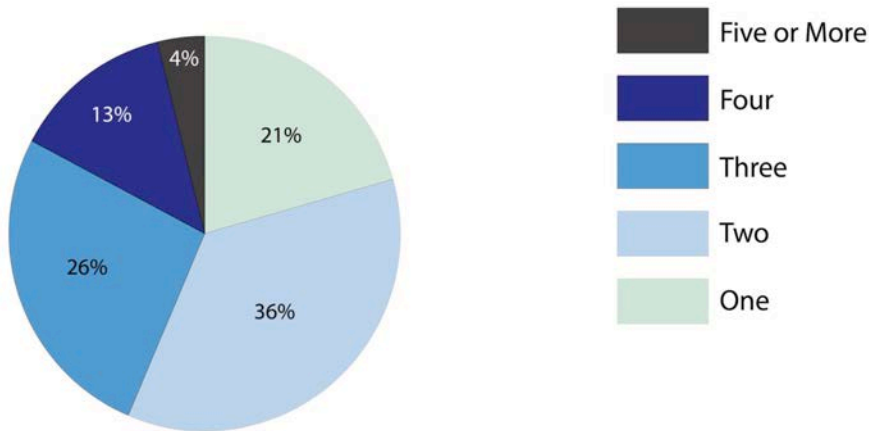


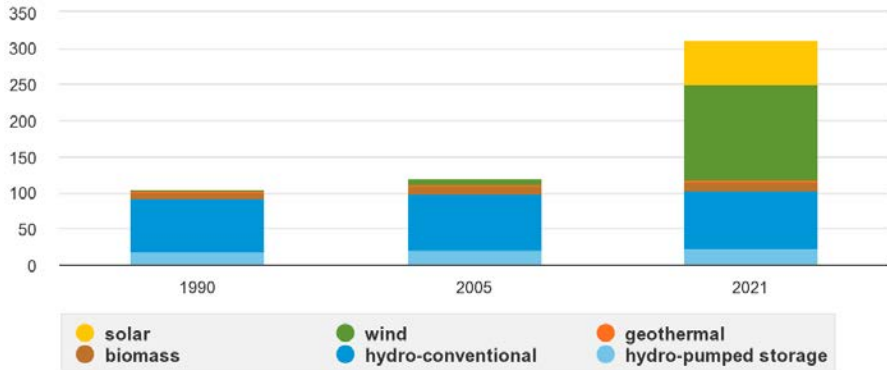
Fig. 4. Number of conflict types per case study as a percentage of the total sample set.

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Susskind et al 2022: sources of opposition

U.S. renewable electricity generation capacity by type, 1990, 2005, and 2021

million kilowatts



Data source: U.S. Energy Information Administration, *Annual Energy Review 2011* and *Electric Power Monthly*, February 2022, preliminary data for 2021



Note: Includes net summer capacity of power plants with at least 1,000 kilowatts of generation capacity. Hydro includes conventional and pumped-storage hydro.

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Susskind et al 2022: sources of opposition

Are these findings general?

Source	Years	Total renewable capacity
Susskind et al, 53 projects	2008-2021	9.6 GW
EIA	2005-2021	184.6 GW

Three perhaps-stupid questions:

- How big is the problem of permitting?
- How pervasive is the problem of permitting?
- Will future problems be similar to past problems?

Thank you!

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