Cities & renewable energy, part 2 (solar)
MIT 11.165/477, 11.286J

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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:

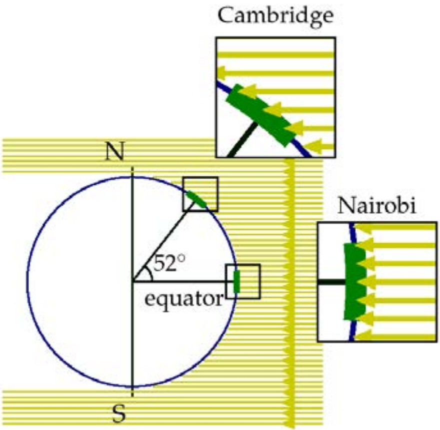
- financing
- generation
- transmission
- distribution
- balancing
- reliability
- resilience
- siting

Agenda for the next few classes

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

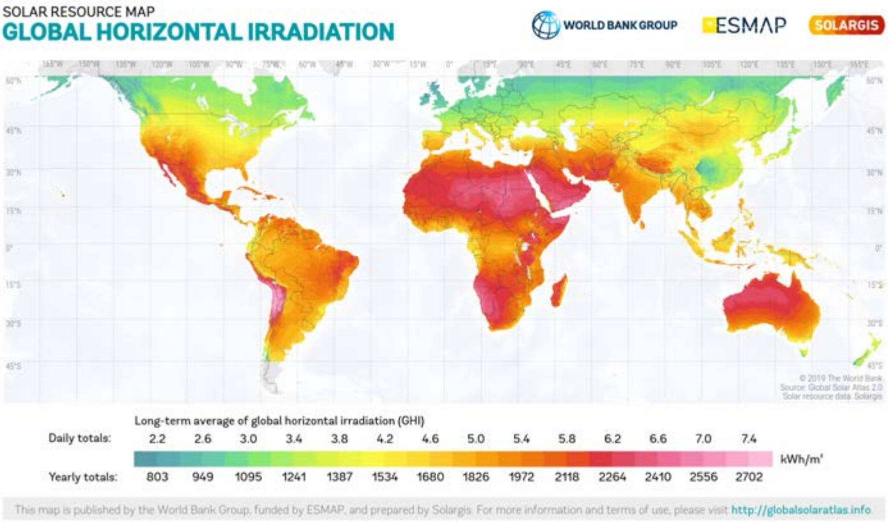
Solar: incident light

Figure courtesy of David MacKay.

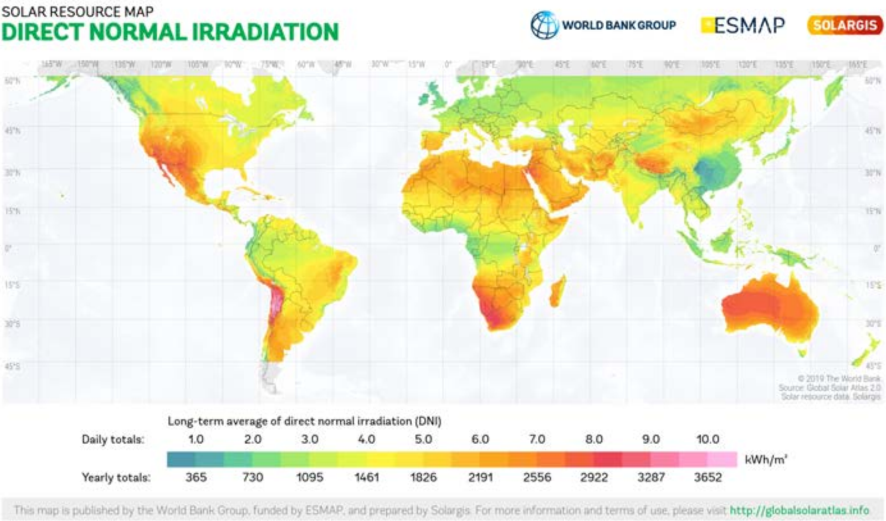


Mackay, figure 3.3

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



World Bank, 2019



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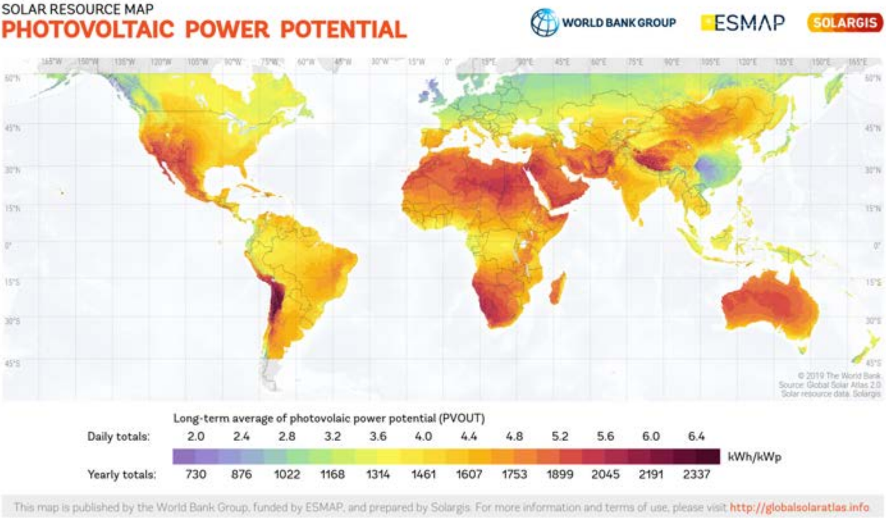
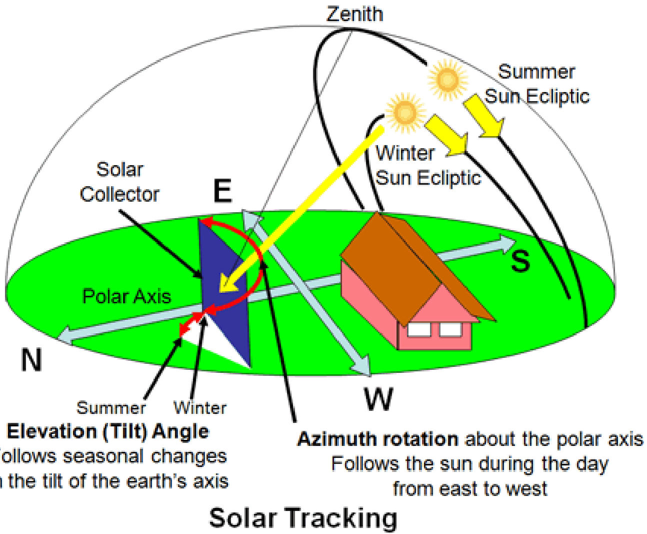


World Bank, 2019

Solar tracking (mpoweruk.com)

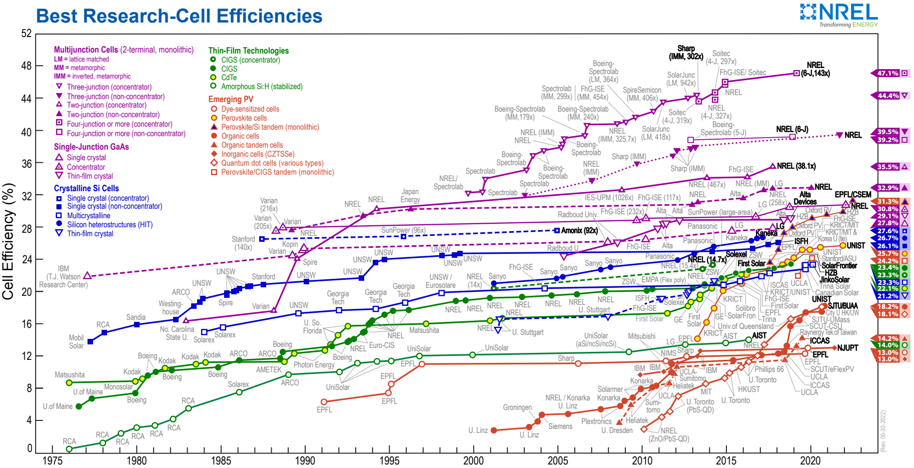


Concentrated solar power (CSP) or solar thermal towers

By Amble - Own work, CC BY-SA 4.0

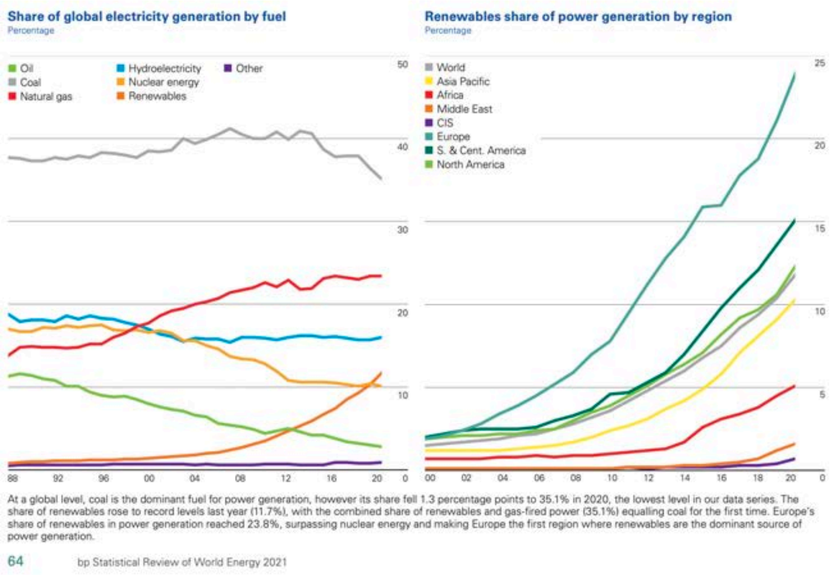
Solar photovoltaic panels

By AleSpa - Own work, CC BY-SA 3.0



Solar PV, NREL graph, 6/30/2022

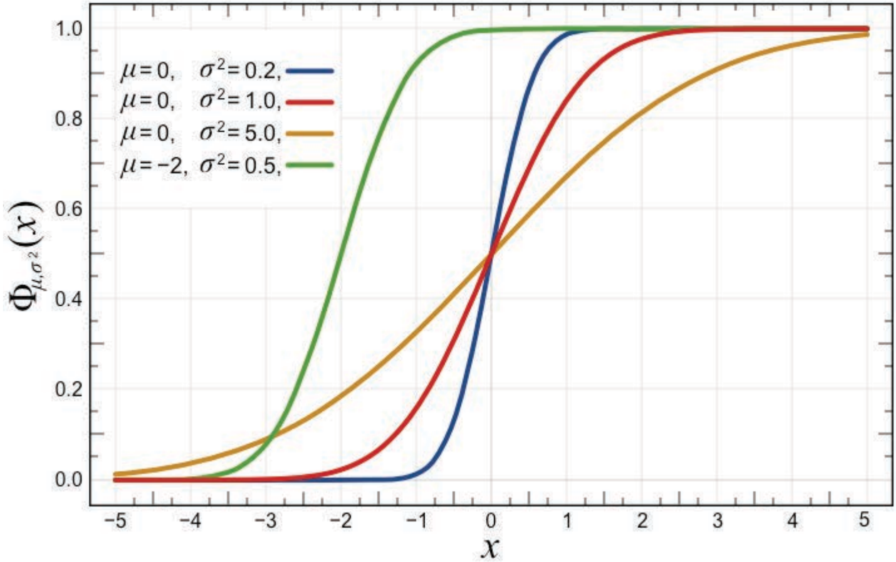
Public domain figure courtesy of NREL / US Department of Energy.



BP Statistical Review of World Energy, June 2021

Figures courtesy of BP Statistical Review of World Energy 2021.

Cumulative distribution function



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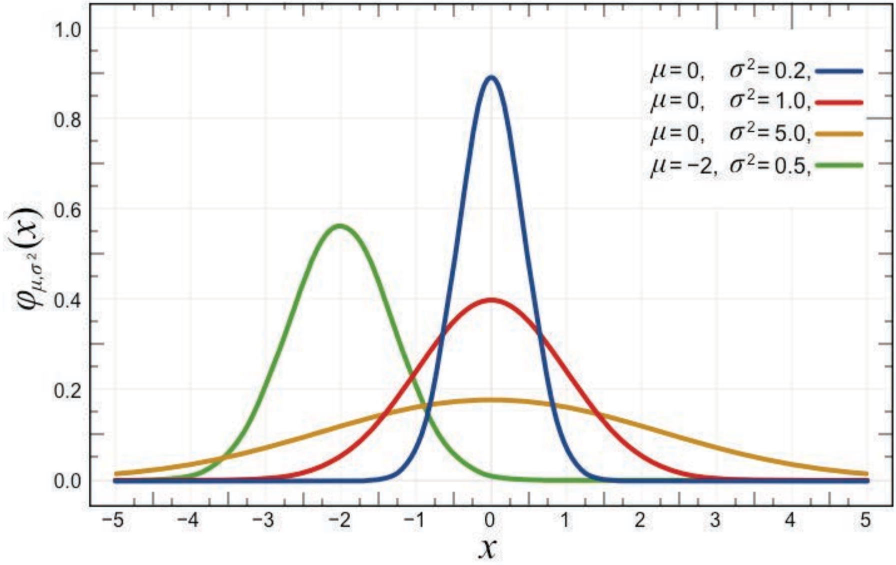
Probability distribution function



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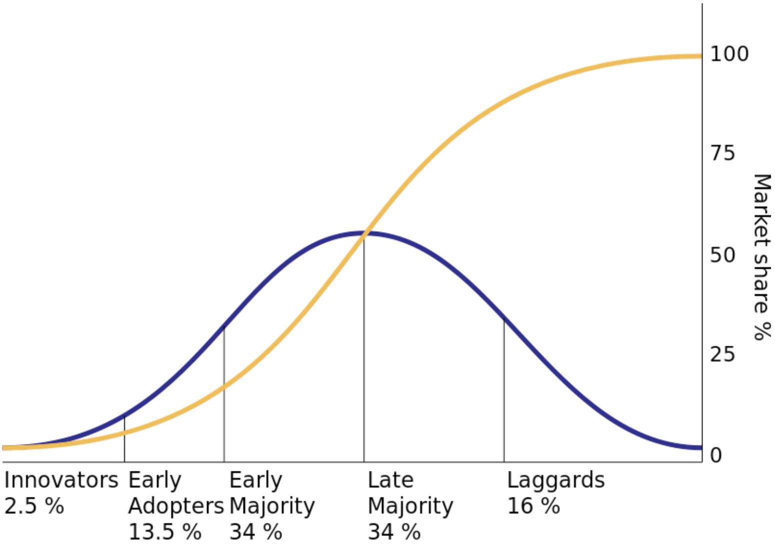
Everett Rogers: diffusion of innovations curve



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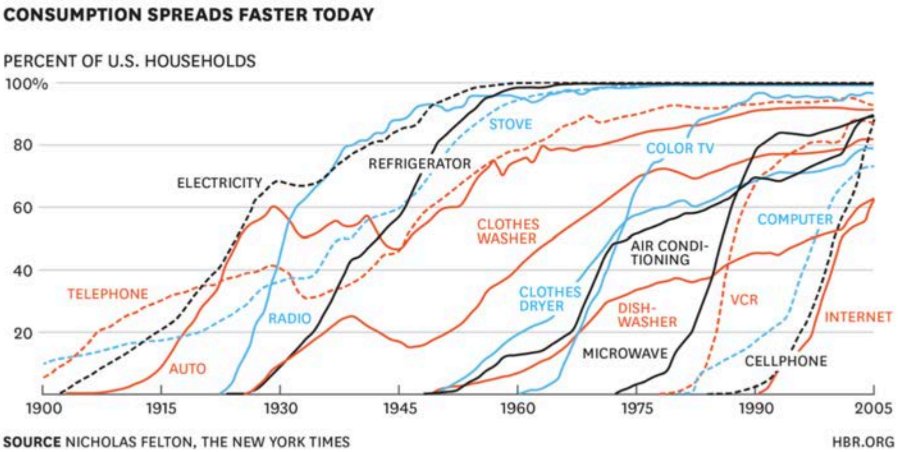
Nicholas Felton, NYT



Harvard Business Review, 2013

Our World in Data, updated 2021

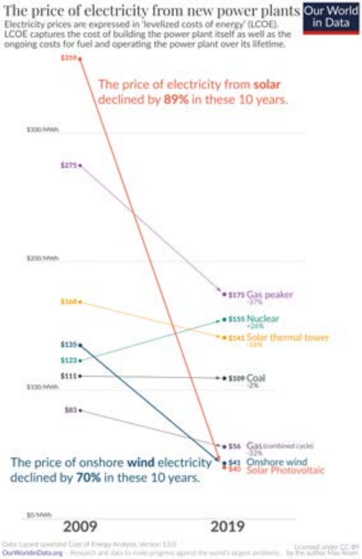
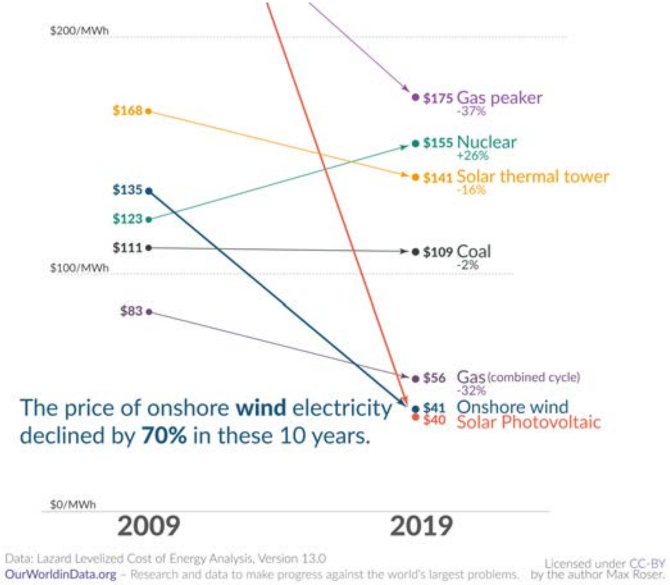
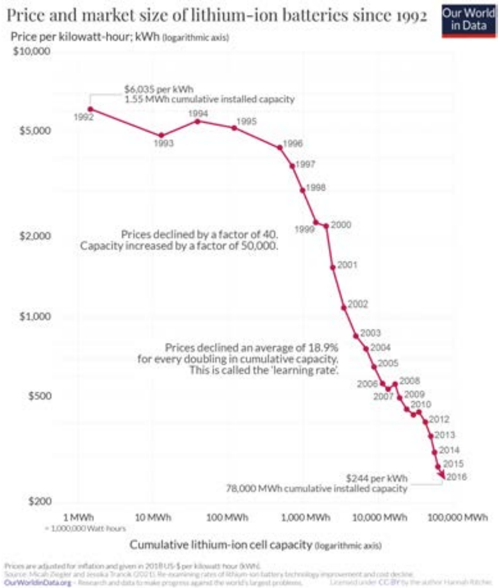


Figure courtesy of Max Roser on Our World in Data. License: CC BY.



From Our World in Data



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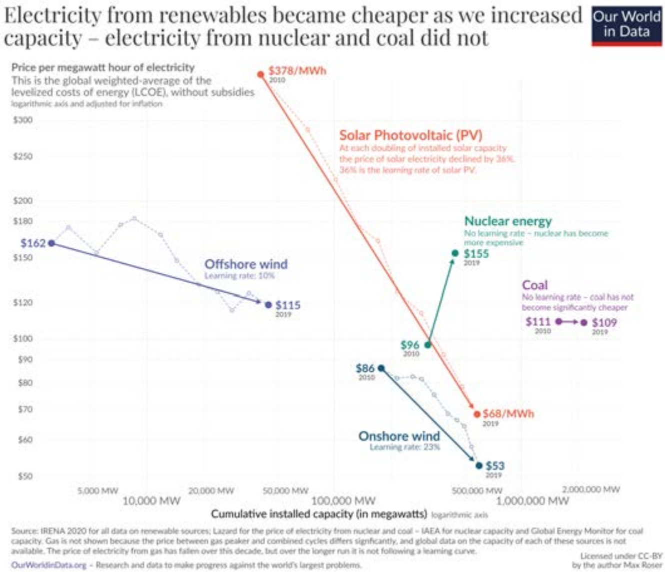

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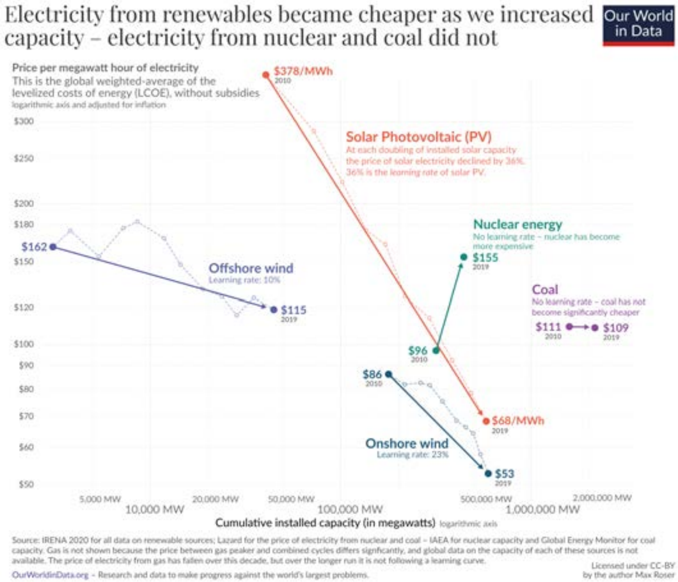
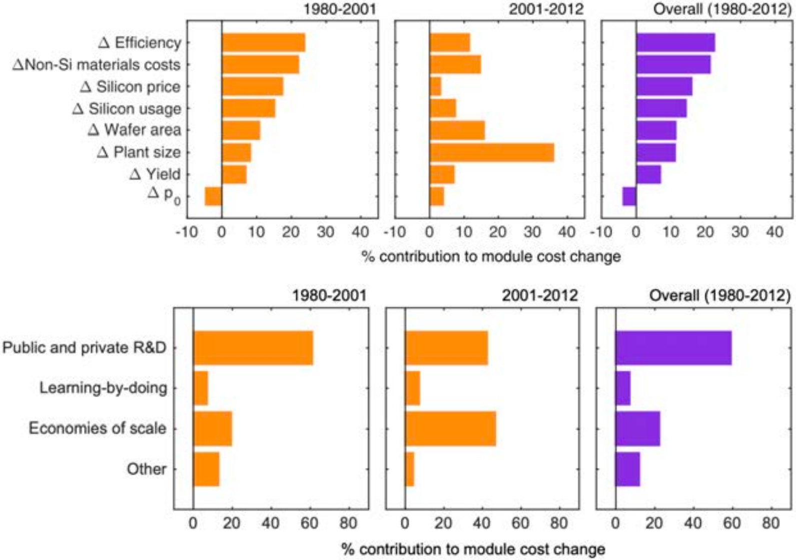


From Our World in Data

Why have solar prices declined?



Kavlak, McNerney, Trancik, 2018 Energy Policy

Will solar prices continue to decline?

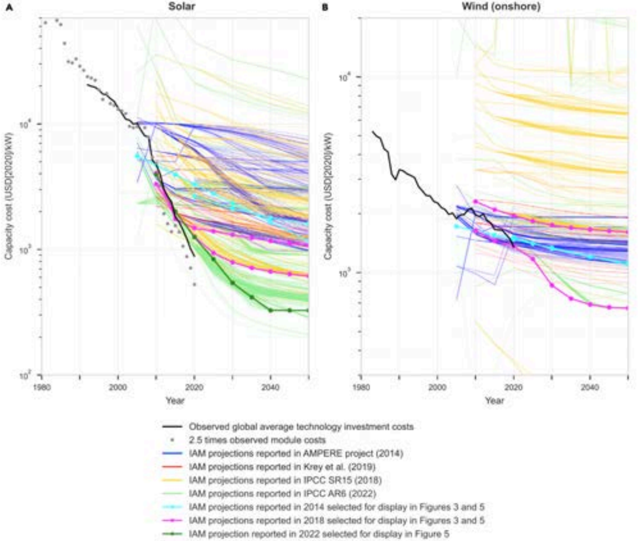
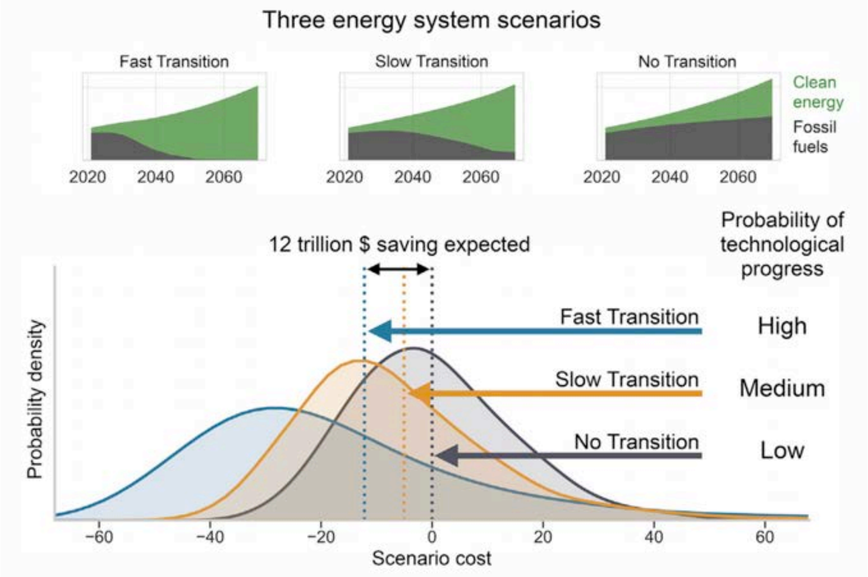


Figure 9. PV and wind capital cost projections reported by IAMs

Joule 2022 paper by Way, Ives, Mealy & Farmer

What would the economic impact be?



Joule 2022 paper by Way, Ives, Mealy & Farmer

Solar installation costs (NREL, 2015)

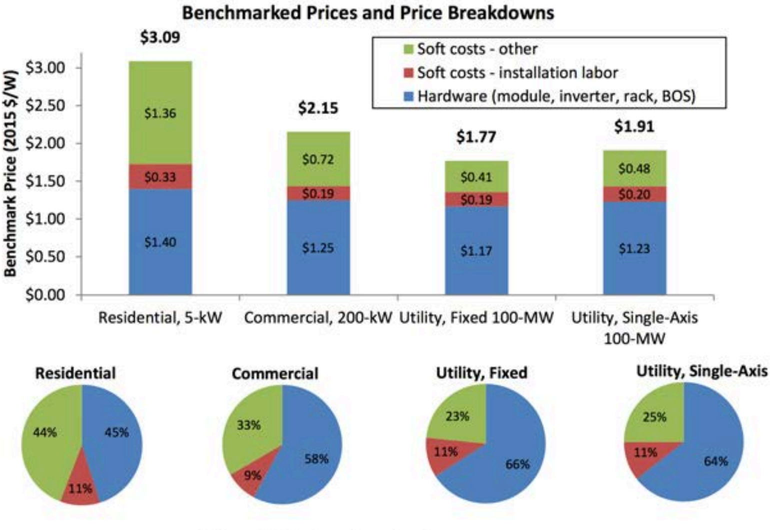


Figure ES-1. Benchmark price summary

Roadmap to cheaper solar (NREL, 2018)

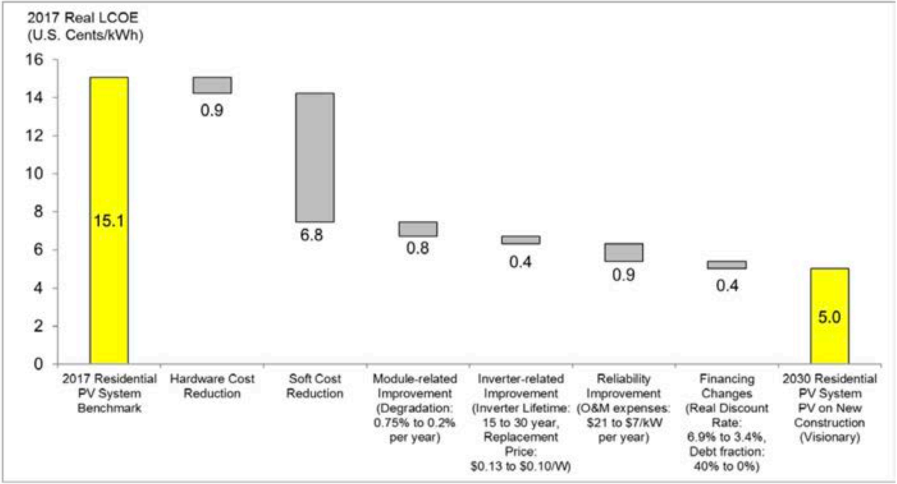


Figure ES-4. Modeled residential PV LCOE reductions for the new home construction market visionary pathway in 2030, compared with the Q1 2017 benchmark

Energy density per area (David Mackay, 2013)

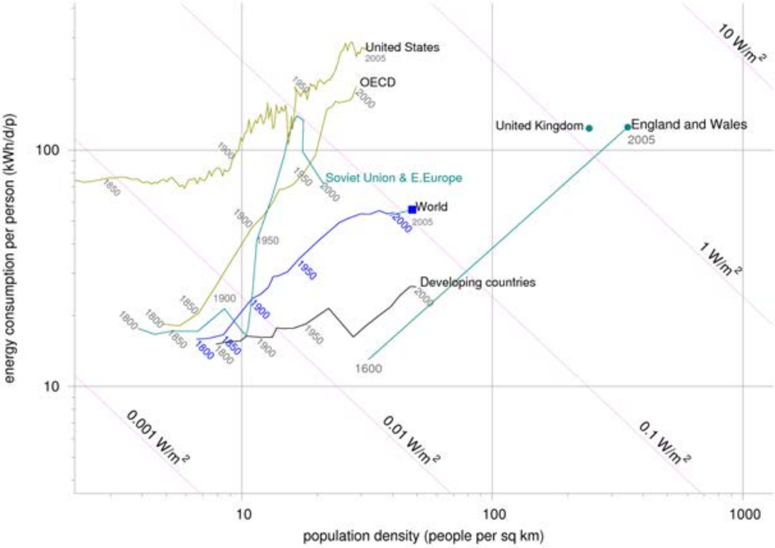
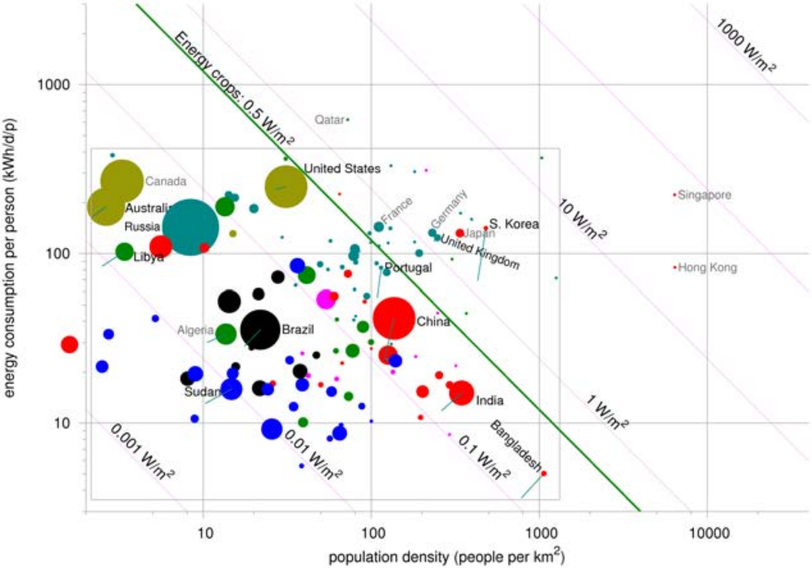


Figure courtesy of David MacKay.

Energy density per area (David Mackay, 2013)



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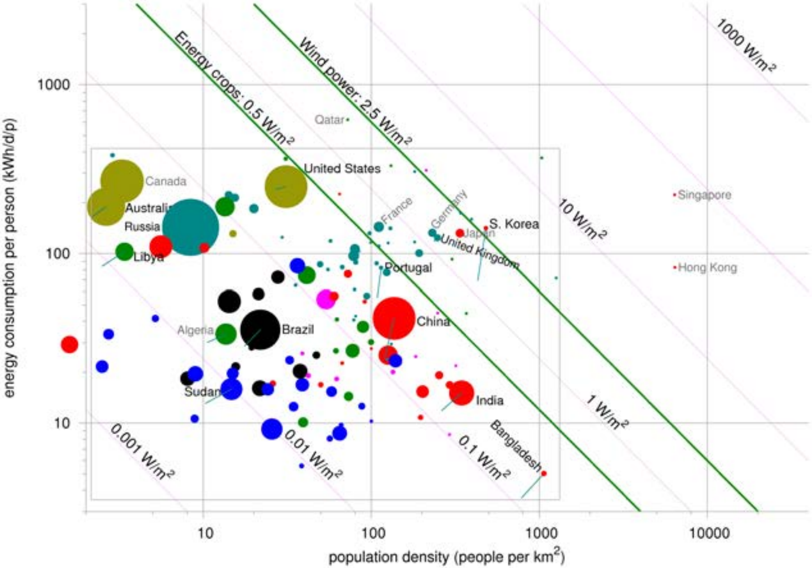

Figure courtesy of David MacKay.

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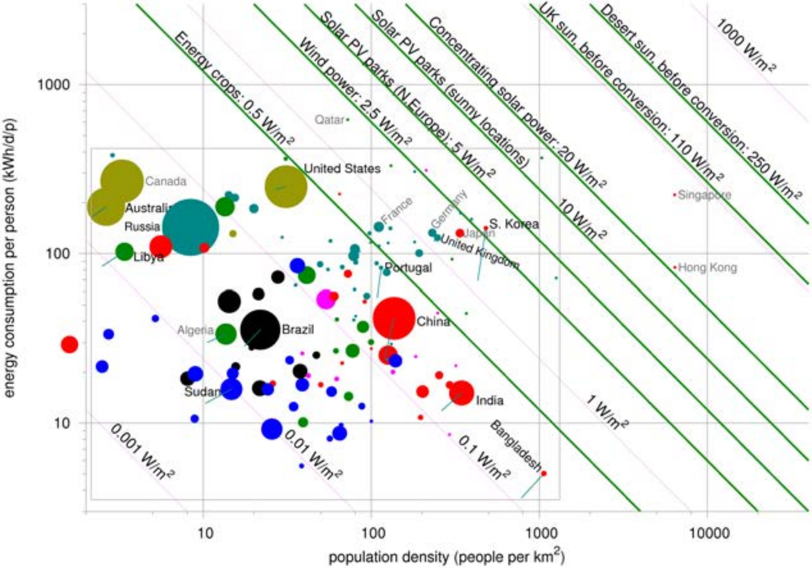


Figure courtesy of David MacKay.

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."

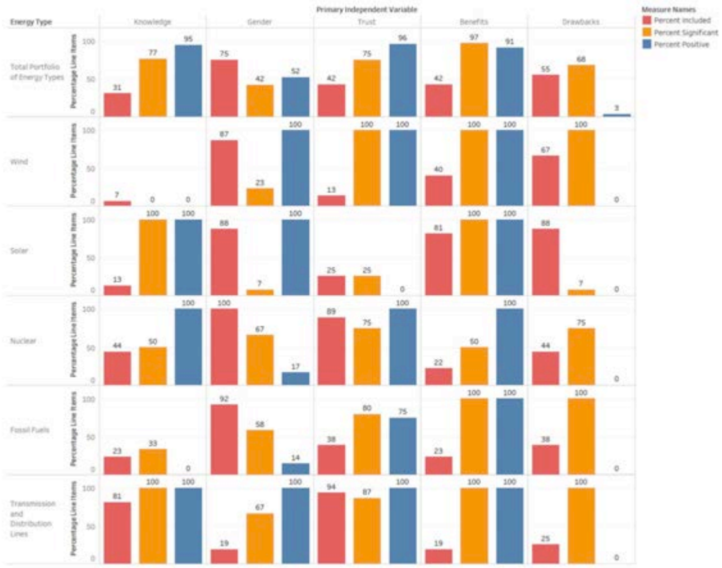


Figure 6. Graph of the percentage of line items (included in the formal modeling category) that included any of the following five variables of interest: knowledge, gender, trust, perceptions about benefits and drawbacks of the energy infrastructure project.

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

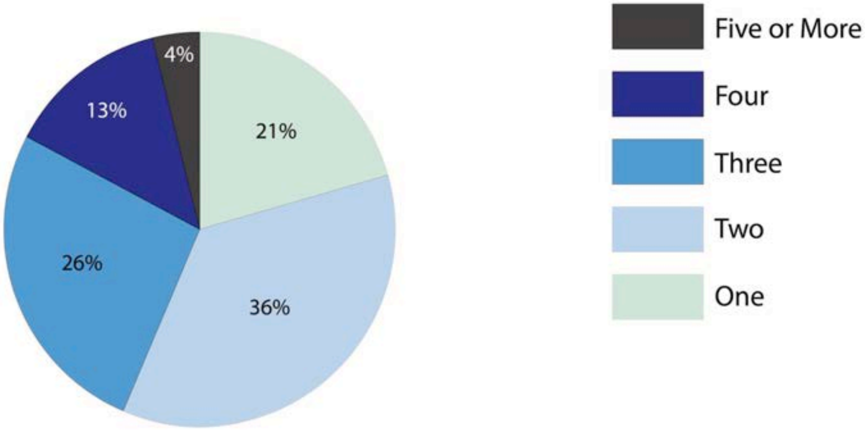
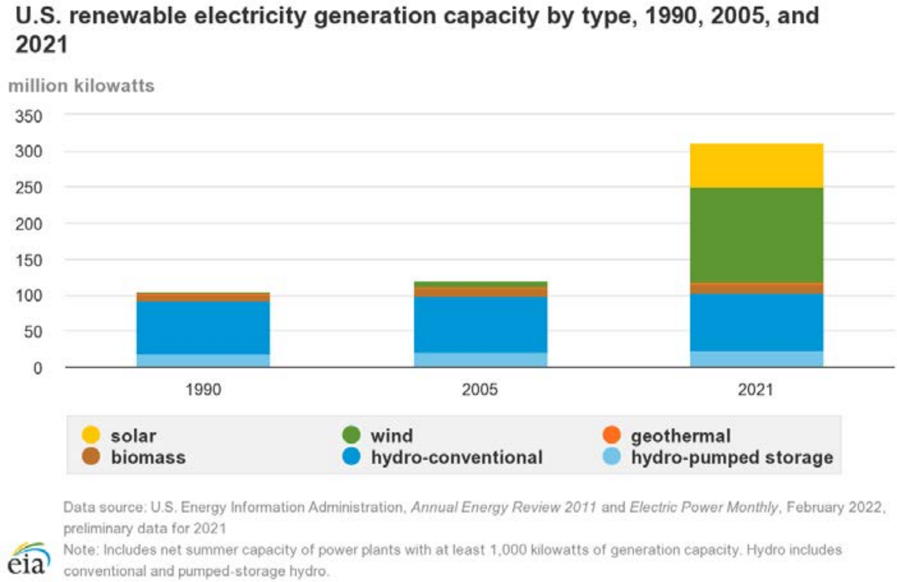


Fig. 4. Number of conflict types per case study as a percentage of the total sample set.

Susskind et al 2022: sources of opposition



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!