EEE-102 Homework 4: Solar Energy
Spring 2024-2025, EE, IIT Roorkee

This document is taken from the Understand Energy Learning Hub of the School of Sustainability, Stanford University.

Fast Facts About Solar Energy

Principal Energy Uses: Daylight, Electricity, Heat
Forms of Energy: Thermal, Radiant

Solar energy is radiant energy from the sun—a fully renewable energy resource. We use the solar resource to provide daylight, electricity, and heat in four ways (in order of prevalence):

1. Indirect: Our primary use of the sun's energy is for **free light and warmth** (not counted in the data below but important for energy efficiency)
2. Solar PV: Converting photons (light) directly into **electricity** through photovoltaics (PV), also known as solar panels
3. Direct (solar thermal heat): Using the sun to **heat water and buildings** (hot water, warm pools, space heating/cooling)
4. Solar Thermal Power (CSP): Concentrating sunlight to produce high-temperature heat to **generate electricity**, sometimes called concentrating solar power (CSP)

Solar PV is the fastest-growing electricity resource in the world. It is fully renewable with few environmental impacts, and the cheapest source of electricity in many countries.

Significance

??% India

Energy Mix
3% of world 🌎
(#7 resource)
1% of U.S. 🇺🇸
(#7 resource)

Electricity Generation
5% of world 🌎
(#6 resource)
4% of U.S. 🇺🇸
(#6 resource)

??% India

Global Solar Use
Solar PV: 79%
Solar thermal heat: 20%
CSP: 1%

Global Solar PV

Most Installed Capacity
China 43% 🇨🇳
of global installed capacity

??% India

Most Generation
China 36% 🇨🇳
of global solar electricity

??% India

Highest Penetration
Chile 20% 🇨🇱
of country's electricity comes from solar

??% India

Global Solar PV Electricity Generation Change
Increase:
⇧ 186%
(2018-2023)

U.S. Solar PV

Most Installed Capacity
California 24%
of U.S. installed capacity

Most Generation
California 27%
of U.S. solar electricity

Highest Penetration
California 28%
of state's electricity comes from solar

Global Solar Thermal Heat

Most Installed Capacity
China 73% 🇨🇳
of global installed capacity

(U.S. has 3.3%)

China's main use is for heating buildings and water, while the main use in the U.S. is for heating swimming pools

Global Solar Thermal Heat Capacity Change
Increase:
⇧ 16%
(2018-2023)

Global Solar Thermal Power (CSP)

Most Installed Capacity
Spain 34% 🇪🇸
of global installed capacity

(U.S. has 19%, 64% of which is in California)

Global CSP Capacity Change
Increase:
⇧ 22%
(2018-2023)

Costs of U.S. Solar PV

Costs increase as size of installation falls:

1. **Utility scale**: largest scale, unsubsidized LCOE* = $29 - $92
2. **Community, commercial, industrial**: medium scale, unsubsidized LCOE = $54 - $191
3. **Rooftop solar / residential**: smallest scale, unsubsidized LCOE = $122 - $284

**LCOE (levelized cost of energy) - allows for the comparison of different electricity generating technologies*

Compare costs with subsidies and for other resources on the Introduction to Renewable Energy Fast Facts

Costs of solar PV have fallen over time:

Unsubsidized Utility-Scale Solar PV LCOE 2009-2024

Year	LCOE Midpoint ($/MWh)
2009	358.50
2010	248
2011	157
2012	125
2013	97.50
2014	79
2015	64
2016	55
2017	49.50

Year	LCOE Midpoint ($/MWh)
2018	43
2019	40
2020	36.50
2021	35.50
2022	39
2023	60
2024	60.50

Table showing how the cost of utility scale solar PV has decreased dramatically since 2009 (from over $350/MWh in 2009 to $60/MWh in 2024). The LCOE increase from 2022 to 2023 and 2024 is due to higher interest rates and other cost pressures, according to Lazard's June 2024 report.

This graph shows the prices for utility scale, but the same trends hold for different sizes of solar installations

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Drivers

- Abundant, nondepletable source of energy
- Low climate and environmental impact
- Utility-scale solar PV: very low LCOE relative to fossil fuels, competitive with onshore wind
- Continued PV productivity gains
- Declining energy storage costs enable grid integration
- No fuel price volatility/risk
- Relatively short implementation timeframe from project start to electricity generation
- Financial incentives (investment tax credit)
- Renewable energy/climate targets
- Rooftop solar PV: no transmission needed; no additional land use
- Solar thermal heat: low-cost option for heating buildings, certain industrial processes

Barriers

- Grid integration challenges due to intermittency and duck curve*
- Inconsistent/decreasing incentives
- NIMBY/BANANA** concerns
- U.S. economic sanctions against panels manufactured in China, which is the largest solar PV manufacturer in the world
- Lack of solar PV recycling capacity at end of life
- Rooftop solar PV: very high LCOE; net metering reforms and utility rate redesign threaten economic viability
- Solar thermal heat: hard to reach high enough temperatures for certain industrial processes

**Non-solar power plants are forced to ramp up quickly when the sun goes down because solar electricity drops and net demand peaks*

***NIMBY - not in my backyard; BANANA - build absolutely nothing anywhere near anything*
