

Updates to the Instant Online PV LCOE Calculator Tool

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National Renewable Energy Laboratory

DuraMAT Webinar
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Levelized Cost of Energy

$$\text{LCOE (\$/kWh)} = \frac{\text{Total Costs over Service Life (\$)}}{\text{Total Energy Produced over Service Life (kWh)}}$$



Simplified PV-LCOE Calculator

- PV technology-specific
- Editable preset fields targeted towards research applications
- Instant comparison of proposed changes to a baseline system

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology mono-Si **Package Type** glass-polymer backsheet **System Type** fixed tilt, utility scale **Location** USA MO Kansas City

Inverter Loading Ratio 1.3

Baseline

Cost

Front layer cost (USD/m²)

Cell cost (USD/m²)

Back layer cost (USD/m²)

Non-cell module cost (USD/m²)

Extra component cost (USD/m²)

O&M cost (USD/kWoc/year)

BOS cost, power-scaling (USD/W)

BOS cost, area-scaling (USD/m²)

Performance

Efficiency (%)

Energy yield (kWh/kW_{DC})

Reliability

System degradation rate (%/year)

Service life (years)

Financial

Discount rate

Proposed

Cost

Front layer cost (USD/m²)

Cell cost (USD/m²)

Back layer cost (USD/m²)

Non-cell module cost (USD/m²)

Extra component cost (USD/m²)

O&M cost (USD/kWoc/year)

BOS cost, power-scaling (USD/W)

BOS cost, area-scaling (USD/m²)

Performance

Efficiency (%)

Energy yield (kWh/kW_{DC})

Reliability

System degradation rate (%/year)

Service life (years)

Financial

Discount rate

Results

LCOE result

Baseline LCOE (USD/kWh) **0.0517**

Proposed LCOE (USD/kWh) **0.0517**

Additional results

Baseline

Module price (USD/W) **0.25**

Total installed system cost (USD/W) **0.72**

Proposed

Module price (USD/W) **0.25**

Total installed system cost (USD/W) **0.72**

Simplified PV-LCOE Calculator

- PV technology-specific
- Editable preset fields targeted towards research applications
- Instant comparison of proposed changes to a baseline system

System Advisor Model (SAM): <https://sam.nrel.gov/>

- + Different financial models
- + Detailed options for module and system designs
- + Can model solar + storage

- Learning curve
- Difficult to quickly evaluate research directions without introducing confounding factors

Presets for Inputs

Use the presets (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology: mono-Si | Package Type: glass-polymer backsheet | System Type: fixed tilt, utility scale | Location: USA MO Kansas City | Inverter Loading Ratio: 1.3

Apply to baseline | Apply to proposed

Baseline

Cost

Front layer cost (USD/m²): 3.50

Cell cost (USD/m²): 22.20

Back layer cost (USD/m²): 2.40

Non-cell module cost (USD/m²): 13.60

Extra component cost (USD/m²): 0

O&M cost (USD/kWh/year): 16.32

BOS cost, power-scaling (USD/W): 0.2

BOS cost, area-scaling (USD/m²): 53.38

Performance

Efficiency (%): 19.5

Energy yield (kWh/kWh_{DC}): 1538

Reliability

System degradation rate (%/year): 0.70

Service life (years): 25

Financial

Discount rate: 6.3

Proposed Copy from Baseline

Cost

Front layer cost (USD/m²): 3.50

Cell cost (USD/m²): 22.20

Back layer cost (USD/m²): 2.40

Non-cell module cost (USD/m²): 13.60

Extra component cost (USD/m²): 0

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Service life (years): 25

Financial

Discount rate: 6.3

Results

LCOE result

Baseline LCOE (USD/kWh) 0.0517

Proposed LCOE (USD/kWh) 0.0517

Additional results

Baseline

Module price (USD/W) 0.25

Total installed system cost (USD/W) 0.72

Proposed

Module price (USD/W) 0.25

Total installed system cost (USD/W) 0.72

Simplified PV-LCOE Calculator

Calculator access:

- pvcoe.nrel.gov
- nrel.github.io/PVLCOE/
- github.com/NREL/PVLCOE
- datahub.duramat.org/dataset/lcoe-calculator-tool

Previous Calculator Tutorials:

- duramat.org/assets/pdfs/duramat-webinar-sept2020.pdf
- nrel.gov/solar/solar-levelized-cost.html

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology Package Type System Type Location

Inverter Loading Ratio

Baseline

Cost

Front layer cost (USD/m²)

Cell cost (USD/m²)

Back layer cost (USD/m²)

Non-cell module cost (USD/m²)

Extra component cost (USD/m²)

O&M cost (USD/kWh/year)

BOS cost, power-scaling (USD/W)

BOS cost, area-scaling (USD/m²)

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Efficiency (%)

Energy yield (kWh/kWh_{DC})

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System degradation rate (%/year)

Service life (years)

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BOS cost, power-scaling (USD/W)

BOS cost, area-scaling (USD/m²)

Performance

Efficiency (%)

Energy yield (kWh/kWh_{DC})

Reliability

System degradation rate (%/year)

Service life (years)

Financial

Discount rate

Results

LCOE result

Baseline LCOE (USD/kWh) **0.0617**

Proposed LCOE (USD/kWh) **0.0617**

Additional results

Baseline

Module price (USD/W) **0.26**

Total installed system cost (USD/W) **0.72**

Proposed

Module price (USD/W) **0.26**

Total installed system cost (USD/W) **0.72**

Simplified PV-LCOE Calculator

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- nrel.github.io/PVLCOE/
- github.com/NREL/PVLCOE
- datahub.duramat.org/dataset/lcoe-calculator-tool

Calculator architects:

Tim Silverman
Mike Deceglie
Sophie Andrews
Kelsey Horowitz

Previous Calculator Tutorials:

- duramat.org/assets/pdfs/duramat-webinar-sept2020.pdf
- nrel.gov/solar/solar-levelized-cost.html

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Cell Technology: mono-Si | Package Type: glass-polymer backsheet | System Type: fixed tilt, utility scale | Location: USA MO Kansas City

Inverter Loading Ratio: 1.3

Apply to baseline | Apply to proposed

Baseline

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Discount rate: 6.3

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Baseline

Module price (USD/W): 0.25

Total installed system cost (USD/W): 0.72

Proposed

Module price (USD/W): 0.25

Total installed system cost (USD/W): 0.72

Example Use

Presets Menu

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology ?
 multi-Si
 CdTe

Package Type ?

System Type ?

Location ?

Inverter Loading Ratio ?

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology ?

Package Type ?

System Type ?
 single-axis tracked, utility scale
 roof-mounted, residential scale
 roof-mounted, commercial scale
 fixed tilt, commercial scale

Location ?

Inverter Loading Ratio ?

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology ?

Package Type ?

System Type ?

Location ?
 USA CA Daggett
 USA CO Denver
 USA CT Hartford
 USA DE Dover
 USA FL East Lake

Inverter Loading Ratio ?

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology ?

Package Type ?

System Type ?

Location ?

Inverter Loading Ratio ?

Baseline

Cost

Front layer cost (USD/m²)

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Non-cell module cost (USD/m²)

Extra component cost (USD/m²)

O&M cost (USD/kW_{DC}/year)

BOS cost, power-scaling (USD/W)

BOS cost, area-scaling (USD/m²)

Performance

Efficiency (%)

Energy yield (kWh/kW_{DC})

Proposed

Cost

Front layer cost (USD/m²)

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Back layer cost (USD/m²)

Non-cell module cost (USD/m²)

Extra component cost (USD/m²)

O&M cost (USD/kW_{DC}/year)

BOS cost, power-scaling (USD/W)

BOS cost, area-scaling (USD/m²)

Performance

Efficiency (%)

Energy yield (kWh/kW_{DC})

How much could this hypothetical backsheet cost?

Baseline	Proposed Copy from Baseline
Cost	Cost
Front layer cost (USD/m ²) \$ 3.50	Front layer cost (USD/m ²) \$ 3.50
Cell cost (USD/m ²) \$ 22.20	Cell cost (USD/m ²) \$ 22.20
Back layer cost (USD/m ²) \$ 2.40	Back layer cost (USD/m ²) \$ 2.40
Non-cell module cost (USD/m ²) \$ 13.60	Non-cell module cost (USD/m ²) \$ 13.60
Extra component cost (USD/m ²) \$ 0	Extra component cost (USD/m ²) \$ 0
O&M cost (USD/kW _{DC} /year) \$ 16.32	O&M cost (USD/kW _{DC} /year) \$ 16.32
BOS cost, power-scaling (USD/W) \$ 0.2	BOS cost, power-scaling (USD/W) \$ 0.2
BOS cost, area-scaling (USD/m ²) \$ 53.38	BOS cost, area-scaling (USD/m ²) \$ 53.38
Performance	Performance
Efficiency (%) \$ 19.5	Efficiency (%) \$ 19.5
Energy yield (kWh/kW _{DC}) \$ 1538	Energy yield (kWh/kW _{DC}) \$ 1538
Reliability	Reliability
System degradation rate (%/year) \$ 0.70	System degradation rate (%/year) \$ 0.70
Baseline LCOE (USD/kWh) 0.0517	Proposed LCOE (USD/kWh) 0.0517



How much could this hypothetical backsheet cost?

Baseline	Proposed Copy from Baseline
Cost	Cost
Front layer cost (USD/m ²) \$ 3.50	Front layer cost (USD/m ²) \$ 3.50
Cell cost (USD/m ²) \$ 22.20	Cell cost (USD/m ²) \$ 22.20
Back layer cost (USD/m ²) \$ 2.40	Back layer cost (USD/m ²) \$ 2.40
Non-cell module cost (USD/m ²) \$ 13.60	Non-cell module cost (USD/m ²) \$ 13.60
Extra component cost (USD/m ²) \$ 0	Extra component cost (USD/m ²) \$ 0
O&M cost (USD/kW _{DC} /year) \$ 16.32	O&M cost (USD/kW _{DC} /year) \$ 15.32
BOS cost, power-scaling (USD/W) \$ 0.2	BOS cost, power-scaling (USD/W) \$ 0.2
BOS cost, area-scaling (USD/m ²) \$ 53.38	BOS cost, area-scaling (USD/m ²) \$ 53.38
Performance	Performance
Efficiency (%) \$ 19.5	Efficiency (%) \$ 19.5
Energy yield (kWh/kW _{DC}) \$ 1538	Energy yield (kWh/kW _{DC}) \$ 1538
Reliability	Reliability
System degradation rate (%/year) \$ 0.70	System degradation rate (%/year) \$ 0.50
Baseline LCOE (USD/kWh) 0.0517	Proposed LCOE (USD/kWh) 0.0500



How much could this hypothetical backsheet cost?

The image displays a solar cost calculator interface with four panels: two 'Baseline' panels (left and right) and two 'Proposed' panels (left and right). The 'Proposed' panels are highlighted in green and feature a 'Copy from Baseline' button at the top right. The 'Baseline' panels are highlighted in blue.

Baseline (Left Panel):

- Cost
 - Front layer cost (USD/m²): 3.50
 - Cell cost (USD/m²): 22.20
 - Back layer cost (USD/m²): 2.40
 - Non-cell module cost (USD/m²): 13.60
 - Extra component cost (USD/m²): 0
 - O&M cost (USD/kW_{DC}/year): 16.32
 - BOS cost, power-scaling (USD/W): 0.2
 - BOS cost, area-scaling (USD/m²): 53.38
- Performance
 - Efficiency (%): 19.5
 - Energy yield (kWh/kW_{DC}): 1538
- Reliability
 - System degradation rate (%/year): 0.70
- Baseline LCOE (USD/kWh): 0.0517

Proposed (Left Panel):

- Cost
 - Front layer cost (USD/m²): 3.50
 - Cell cost (USD/m²): 22.20
 - Back layer cost (USD/m²): 2.40
 - Non-cell module cost (USD/m²): 13.60
 - Extra component cost (USD/m²): 0
 - O&M cost (USD/kW_{DC}/year): 15.32
 - BOS cost, power-scaling (USD/W): 0.2
 - BOS cost, area-scaling (USD/m²): 53.38
- Performance
 - Efficiency (%): 19.5
 - Energy yield (kWh/kW_{DC}): 1538
- Reliability
 - System degradation rate (%/year): 0.50
- Proposed LCOE (USD/kWh): 0.0500

Baseline (Right Panel):

- Cost
 - Front layer cost (USD/m²): 3.50
 - Cell cost (USD/m²): 22.20
 - Back layer cost (USD/m²): 2.40
 - Non-cell module cost (USD/m²): 13.60
 - Extra component cost (USD/m²): 0
 - O&M cost (USD/kW_{DC}/year): 16.32
 - BOS cost, power-scaling (USD/W): 0.2
 - BOS cost, area-scaling (USD/m²): 53.38
- Performance
 - Efficiency (%): 19.5
 - Energy yield (kWh/kW_{DC}): 1538
- Reliability
 - System degradation rate (%/year): 0.70
- Baseline LCOE (USD/kWh): 0.0517

Proposed (Right Panel):

- Cost
 - Front layer cost (USD/m²): 3.50
 - Cell cost (USD/m²): 22.20
 - Back layer cost (USD/m²): 2.40
 - Non-cell module cost (USD/m²): 13.60
 - Extra component cost (USD/m²): 0
 - O&M cost (USD/kW_{DC}/year): 15.32
 - BOS cost, power-scaling (USD/W): 0.2
 - BOS cost, area-scaling (USD/m²): 7.6694
- Performance
 - Efficiency (%): 19.5
 - Energy yield (kWh/kW_{DC}): 1538
- Reliability
 - System degradation rate (%/year): 0.50
- Proposed LCOE (USD/kWh): 0.0517

A callout box points to the BOS cost, area-scaling (USD/m²) input in the Proposed (Right Panel) with the text: "Automatically adjust this input to make LCOE match the baseline LCOE."



Updates to the Calculator in 2021

Updated Calculator Features

- Breakeven buttons

The image shows a calculator interface with two columns. The left column has a blue background and contains two input fields: 'Cell cost (USD/m²)' with a value of 22.20 and 'Back layer cost (USD/m²)' with a value of 2.40. The right column has a green background and contains two input fields: 'Cell cost (USD/m²)' and 'Back layer cost (USD/m²)'. The 'Cell cost' field in the right column has a value of 7.6694, which is highlighted with a red box. A tooltip points to this field with the text: 'Automatically adjust this input to make LCOE match the baseline LCOE.' Each input field includes a small icon of a calculator and a slider control.

Updated Calculator Features

- Breakeven buttons
- Reconfigured preset menu

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology Package Type System Type Location

Inverter Loading Ratio

Baseline

Cost

Front layer cost (USD/m²)

Cell cost (USD/m²)

Back layer cost (USD/m²)

Proposed

Cost

Front layer cost (USD/m²)

Cell cost (USD/m²)

Back layer cost (USD/m²)

Updated Calculator Features

- Breakeven buttons
- Reconfigured preset menu
- Inverter Loading Ratio

Inverter Loading Ratio
affects both BOS costs
and energy yield

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology [?] Package Type [?] System Type [?] Location [?]

Inverter Loading Ratio [?]

Updated Calculator Features

- Breakeven buttons
- Reconfigured preset menu
- Inverter Loading Ratio
- Commercial system types

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology [?] Package Type [?] System Type [?] Location [?]

Inverter Loading Ratio [?]

Apply to proposed

fixed tilt, utility scale
single-axis tracked, utility scale
roof-mounted, residential scale
roof-mounted, commercial scale
fixed tilt, commercial scale

Degradation Rate Relationship

Exponential Relationship:

$$e_n = e_{yield}(1 - r)^{(n-1)}$$

Linear Relationship:

$$e_n = e_{yield}[1 - r(n - 1)]$$

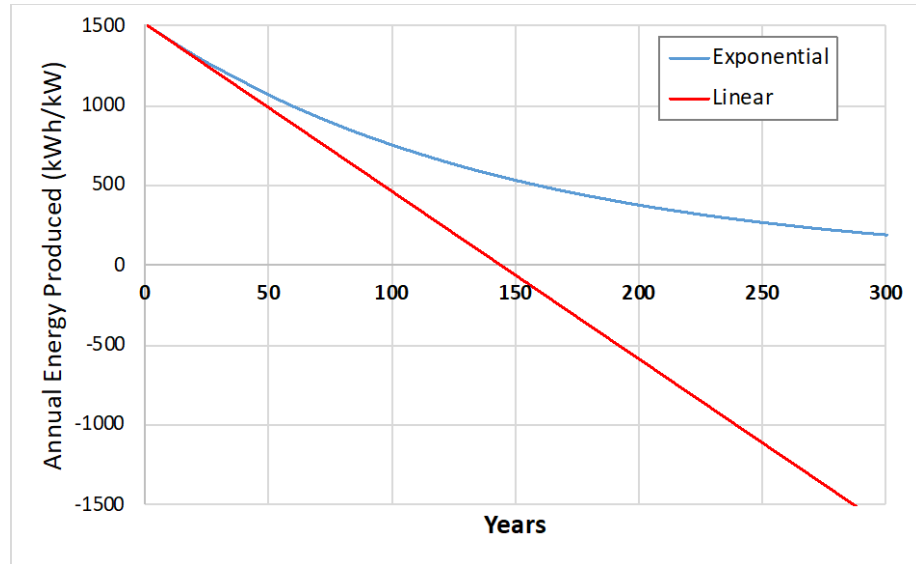
r is the degradation rate

n is the year of operation

e is the energy produced

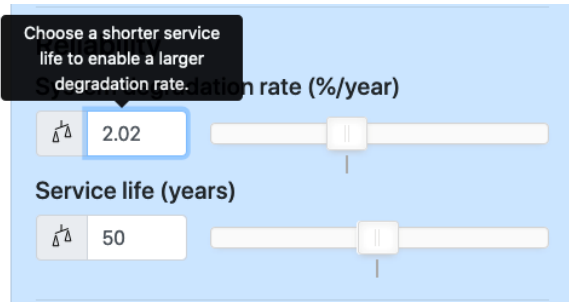
For a system with:

- 0.7% degradation rate
- 1500 kWh/kW first year energy yield



Limits on Numerical Ranges

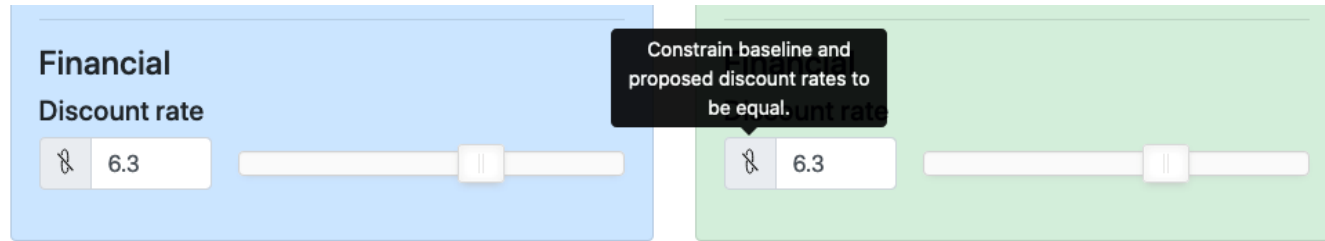
Restricted service life range & added dead zone to slider to keep energy non-negative and prevent continuous costs on a PV system that does not generate energy.



Physically-motivated limits on:

- efficiency (0-100%)
- energy yield > 0
- degradation rate > 0%

Discount Rate Comparison



- Sync / unsync discount rates (instead of breakeven button)

Updated Default Preset Values

Updated from 2017 data:

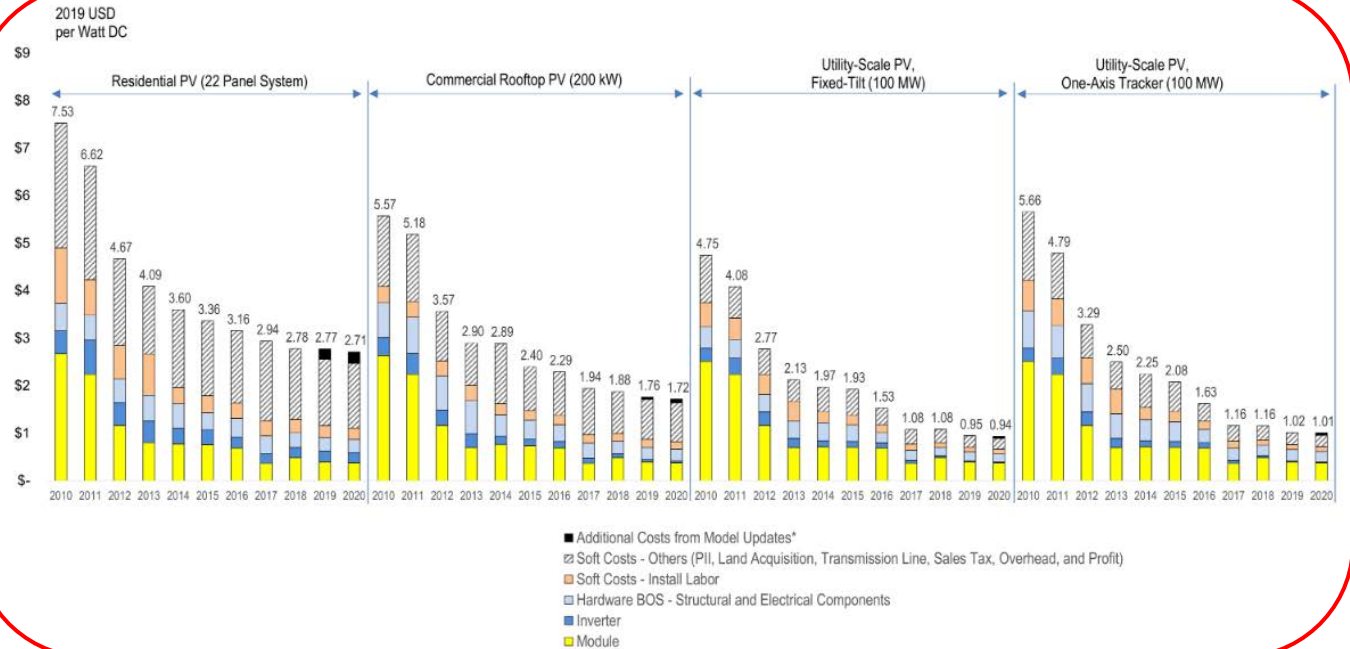
- System costs
- O&M costs
- Module-level costs
- Module efficiency values

Updated Default Preset Values

Updated from 2017 data:

Q1 2020 US PV System Cost Benchmark - [nrel.gov/docs/fy21osti/77324.pdf](https://www.nrel.gov/docs/fy21osti/77324.pdf)

- System costs
- O&M costs
- Module-level
- Module efficiency



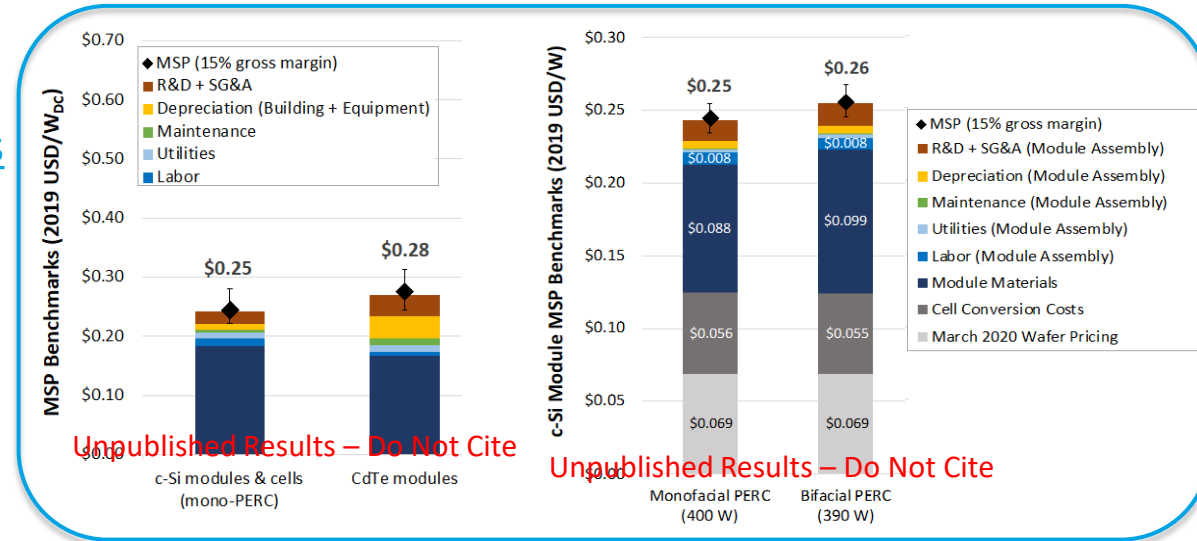
Also removed BOS cost dependence on location

Updated Default Preset Values

Updated from 2017 data:

- System costs
- O&M costs
- [Module-level costs](#)
- [Module efficiency values](#)

2020 Module Cost Benchmark Report, Forthcoming



Unpublished Results – Do Not Cite

Unpublished Results – Do Not Cite

Energy Yield Values called directly from SAM

Previously, the calculator relied on a table of energy yield values built manually from SAM using the “Detailed PV Model”










Now, PySAM package is used by calculator to call SAM directly.

Relies on:

- PVWatts model
- NSRDB weather data

Customize a Local Version of the Calculator

GitHub Repository Structure

 build-presets
 css
 img
 js
 .gitignore
 LICENSE
 README.md
 lcoe_calculator.html
 lcoe_calculator_documentation.html

github.com/NREL/PVLCOE

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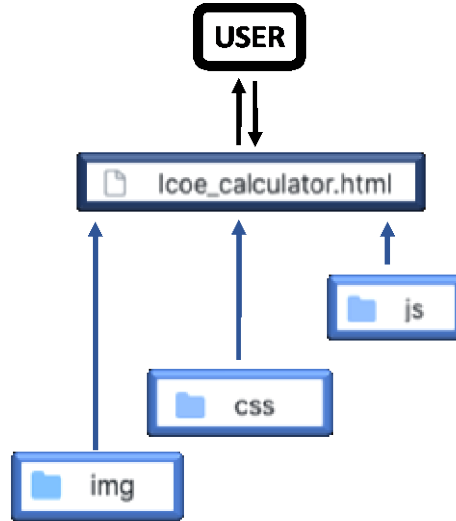
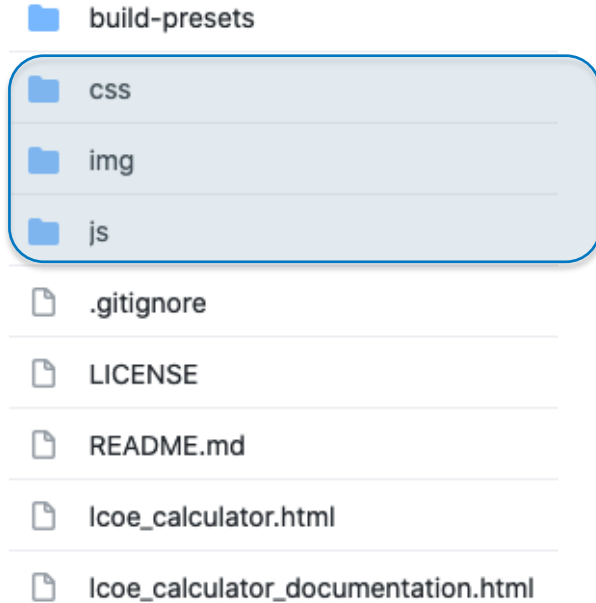
USER



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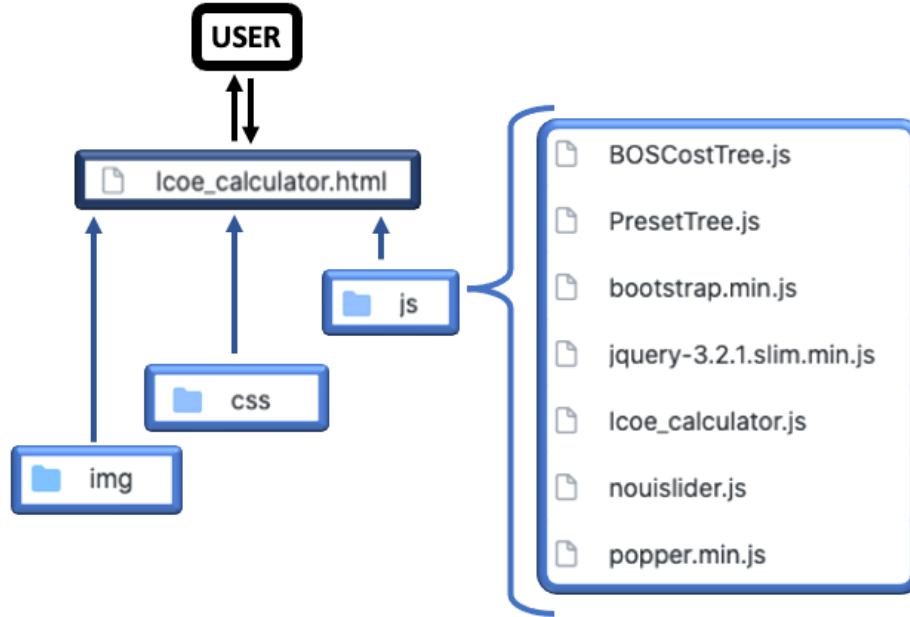
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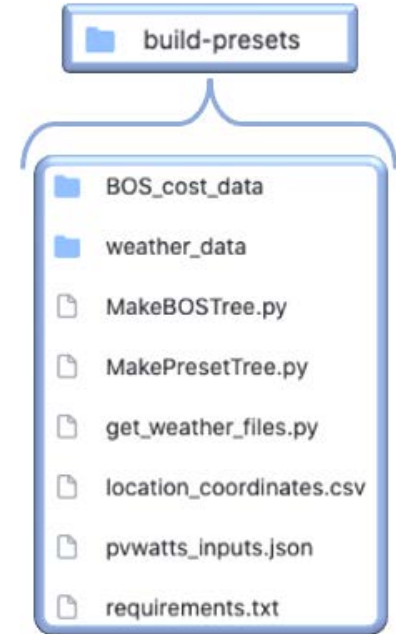
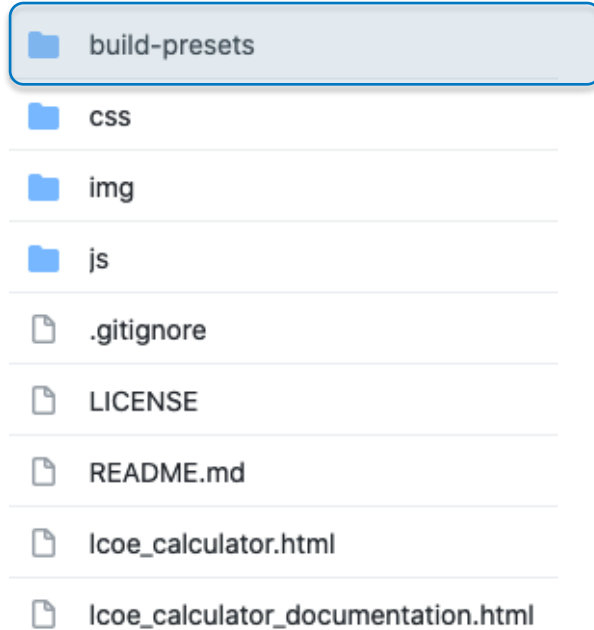
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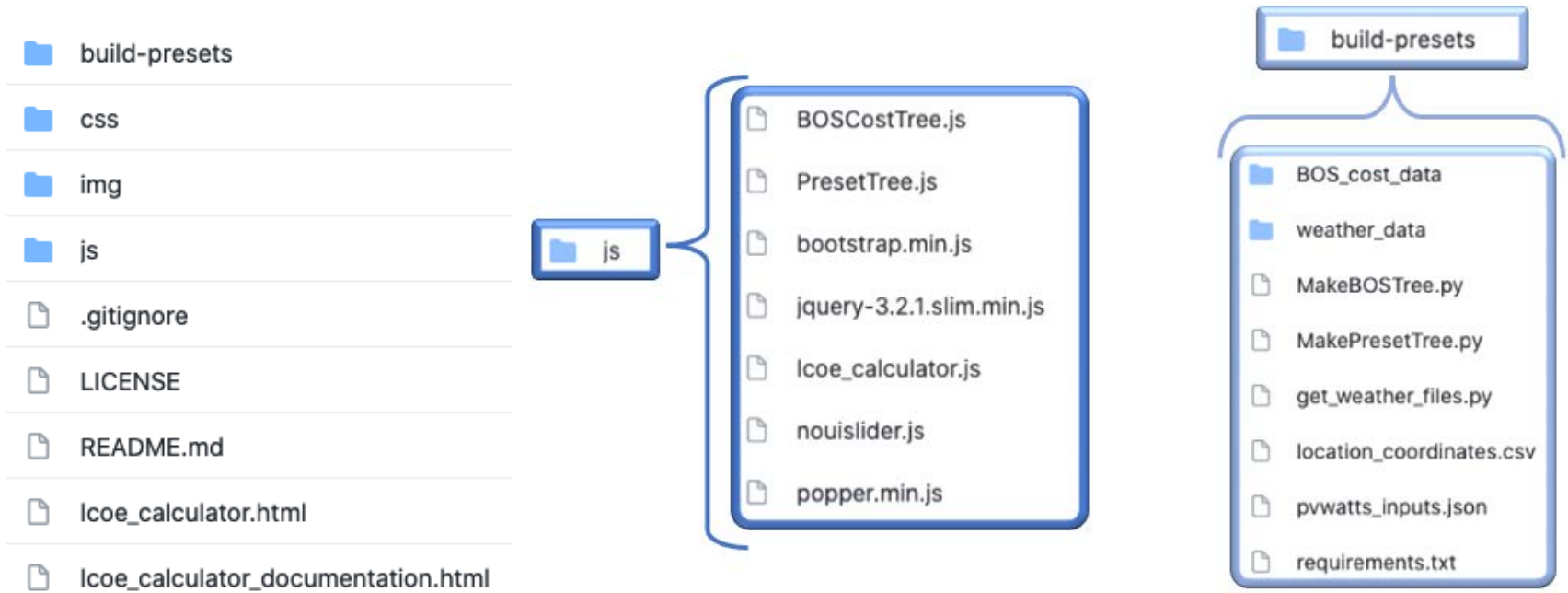
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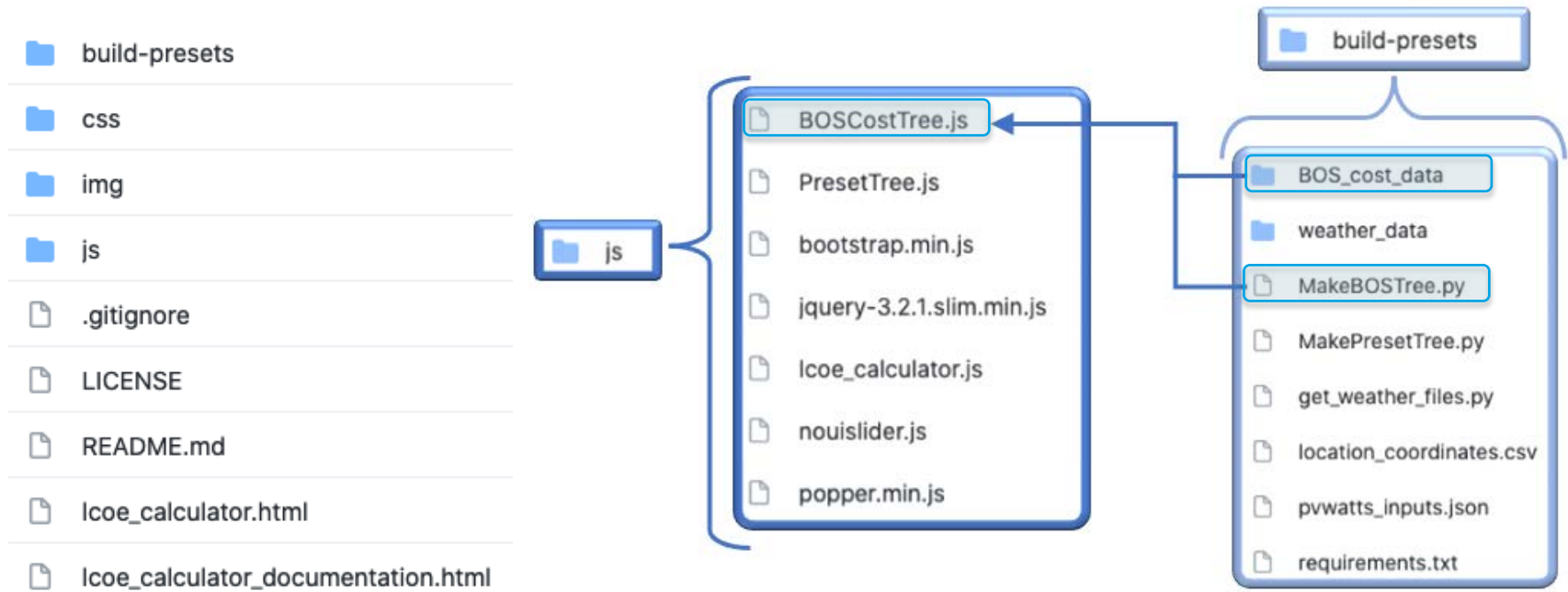
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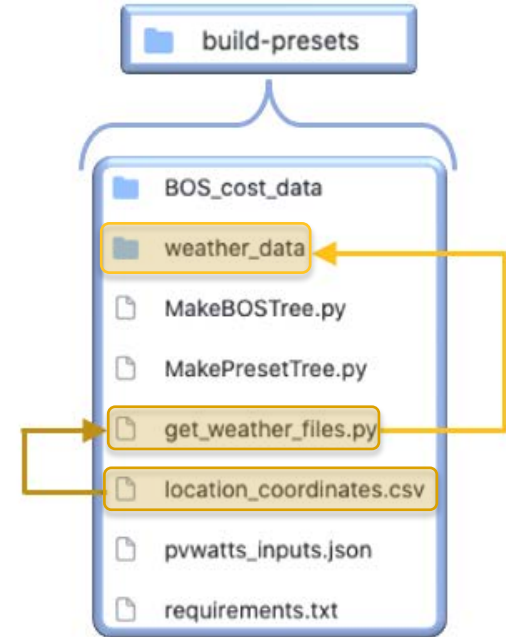
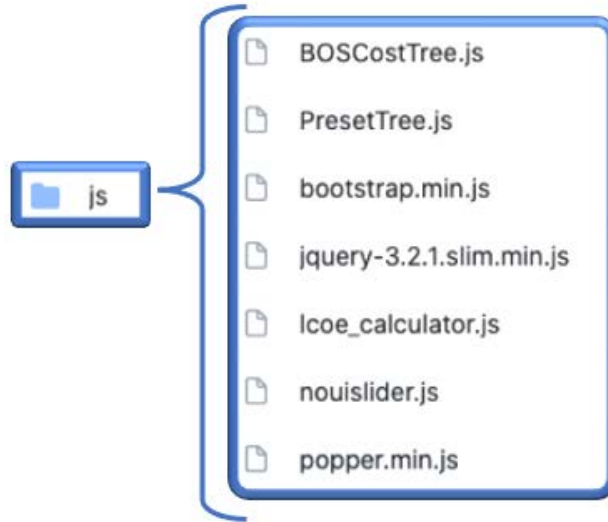
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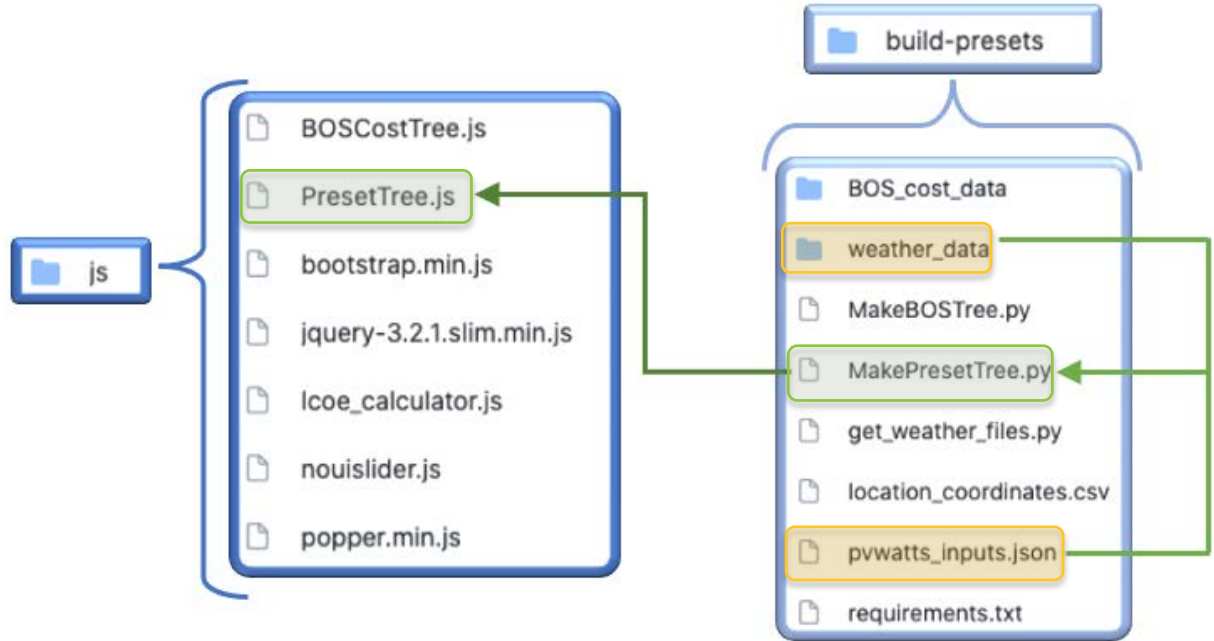
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github.com/NREL/PVLCOE

Editing Your Local Version

If you want...

More locations to choose from:

- add coordinates to “location_coordinates.csv”

Changes to energy yield or SAM settings:

- Edit PVWatts inputs in “pvwatts_inputs.json”
- Edit SAM settings within “MakePresetTree.py”

Changes to cell technologies, package types, system types, non-BOS costs, efficiencies, or degradation rates:

- Add menu items or edit values in “MakePresetTree.py”

Changes to BOS costs:

- Edit contents of the /BOS_cost_data/ folder within the /build-presets/ folder

All this is documented
in more detail in the
repository README file

Citation

If you use results from this calculator in a publication or proposal, please cite:

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Note: We recommend including the URL for a specific commit if citing results from an unreleased version.

Thank You

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Backup Slides

Preset Constraints

Cell Technology

Cell technology affects **cell cost**, **efficiency**, and the available values for **package type** and **system type**.

Choose a different cell technology, package type, system type, location, or inverter loading ratio

Cell Technology [?] mono-Si

Package Type [?] glass-polymer backshe

System Type [?] fixed tilt, utility scale

Location [?] USA MO Kansas City

Inverter Loading Ratio [?] 1.3

Apply to baseline Apply to proposed

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology [?] mono-Si

Package Type [?] glass-polymer backshe

System Type [?]

- ✓ fixed tilt, utility scale
- single-axis tracked, utility scale
- roof-mounted, residential scale
- roof-mounted, commercial scale
- fixed tilt, commercial scale

Location [?] MO Kansas City

Inverter Loading Ratio [?] 1.3

Apply to proposed

Presets for Inputs

Use the **presets** (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology [?] CdTe

Package Type [?] glass-glass

System Type [?]

- ✓ fixed tilt, utility scale
- single-axis tracked, utility scale
- roof-mounted, commercial scale
- fixed tilt, commercial scale

Location [?] MO Kansas City

Inverter Loading Ratio [?] 1.3

Apply to proposed

Make-Preset-Tree.py

```
2 This code uses the PySAM wrapper for the SAM GUI to generate energy yield and create a new preset tree.
3 It loops through every combination of cell technology, package type, system type, inverter loading ratio
4 and location to determine the energy yield with those settings.
5
6 Note: this script runs PySAM 3300 times (for each preset combination) and takes ~30 mins to finish running.
7 """
8 import pandas as pd
9 import json
10 import PySAM.Pvwatts7 as pvwatts
11 import glob
12 import PySAM.ResourceTools as tools
13 import PySAM.PySSC as pssc
14 from pathlib import Path # for platform independent paths
15
16 # to avoid rounding issues, the lat and lon returned by pysam are in this file
17 # locations maps a lat/lon pair to the string name of the location
18 locations = {}
19 df = pd.read_csv('location_coordinates.csv')
20 for index, row in df.iterrows():
21     locations[row['ID']] = 'USA ' + \
22         row['State'] + ' ' + row['Place']
23
24 # Define feasible system configurations
25 cell_technologies = ['mono-Si', 'multi-Si', 'CdTe']
26
27 package_types = {
28     'mono-Si': ['glass-polymer backsheet', 'glass-glass'],
29     'multi-Si': ['glass-polymer backsheet', 'glass-glass'],
30     'CdTe': ['glass-glass']
31 }
32
33 system_types = {
34     'mono-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale', 'roof-mounted, commercial scale', 'fixed tilt, utility scale'),
35     'multi-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, commercial scale', 'fixed tilt, commercial scale', 'fixed tilt, utility scale'),
36     'CdTe': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, commercial scale', 'fixed tilt, commercial scale')
37 }
38
39
40 # Preset values for module parameters: costs are in USD per square meter, efficiency reported as a percentage
41 module_details = {
42     'cost_front_layer': 3.5,
43     'cost_cell': {'mono-Si': 22.2, 'multi-Si': 19.4, 'CdTe': 21.3},
44     'cost_back_layer': {'glass-polymer backsheet': 2.4, 'glass-glass': 3},
45     'cost_noncell': 13.6,
46     'efficiency': {'mono-Si': 19.5, 'multi-Si': 17.5, 'CdTe': 18.0},
47 }
48
49
50 # Preset values for operation & maintenance costs, reported in USD/kW(DC) per year
51 cost_om = {
52     'fixed tilt, utility scale': 16.32,
53     'single-axis tracked, utility scale': 17.46,
54     'roof-mounted, residential scale': 28.94
```

To keep energy non-negative, degradation rate and service life must satisfy the inequality:

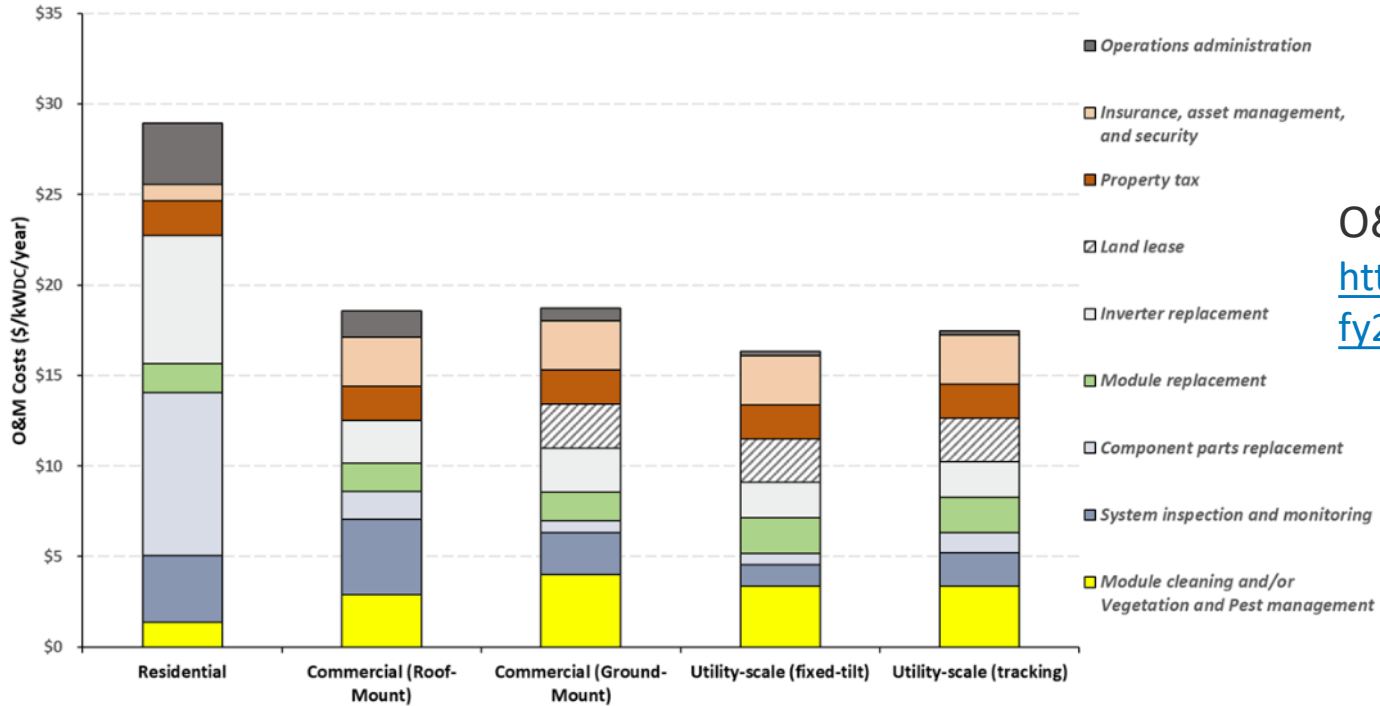
$$(n - 0.5) / R_d < 1$$

Where:

n is service life

R_d is degradation rate

O&M Costs



O&M cost tool

<https://www.nrel.gov/docs/fy20osti/74840.pdf>

Curve-fitting: BOS Cost as a Function of Efficiency

Area-dependent costs

Cost fixed per watt

$$C_{system} \left[\frac{\$}{W} \right] = \frac{C_A}{\eta * 1,000 [W/m^2]} + C_P \left[\frac{\$}{W} \right]$$